Evaluation of Mechanical and Physicochemical Properties of Materials for 3D Printing

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The study evaluated mercury adsorption and the mechanical properties of polymer filaments (ABS, PLA, and Tritan) after exposure to contaminated environments. Using methodologies such as atomic absorption spectrometry and tensile testing, it was found that Tritan showed high adsorption (69.3%), while ABS and PLA showed lower affinity for mercury (<2%), making them more suitable for applications in critical environments. Significant structural changes were observed in all materials, indicating the need for further research on chemical stability under different environmental conditions.

Keywords: 3DP. Water Quality. Mechanical and Physical-Chemical Parameters. Mercury. DMA-80.

Additive manufacturing is characterized by a variety of printing techniques, including stereolithography (SLA—stereolithography), in which liquid resin is used; model fabrication through the process of fused deposition modeling (FDM—fused deposition modeling); and selective laser sintering (SLS—selective laser sintering), in which materials are selectively fused by a laser.

These processes are collectively referred to as three-dimensional (3DP) printing. Notwithstanding the absence of indicators that would facilitate the evaluation of the repercussions of the proliferation of 3DP utilization, as well as the replacement of production methodologies for materials that are presently obtainable through homemade means, it is nevertheless possible to discern the considerable potential in domains such as dentistry, particularly in the fabrication of aligners, the production of molds, and suction devices for pediatric dentistry, among others [1].

In the field of construction, the practice of printing models of architectural designs, pre-fabricated structures, and prototypes in miniature, along with the use of FreeFAB Wax in concrete molds, has become increasingly prevalent [2,3]. The development and implementation of 3DP have had significant ramifications, particularly in the context of environmental protection and the pursuit of a more sustainable manufacturing process (CP).

This approach aligns with the principles of Green Chemistry and addresses the imperative to mitigate the impact of climate change, as outlined in ODS 9, 11, 12, 13, and 17.

According to Santana (2018) [4], the numerous FDM filaments available on the market, PLA (polylactic acid) [5]; ABS (acrylonitrile butadiene styrene) [6]; PETG (polyethylene terephthalate glycol); Tritan (Copolyester) [7], in addition to various types of liquid resins, have well-established mechanical properties that are made available by manufacturers. However, there is a lack of qualitative and quantitative information about the chemical composition and behavior of printed materials in the environment. As a result, they can be sources of contamination that pose an imminent risk to the environment, compromising the use of these materials and the advancement of 3DP technologies for commercial purposes. Therefore, it is necessary to apply methods to acquire information regarding material stability. The purpose of the stability test is to provide evidence of how the quality of a product varies over time under the influence of environmental factors such as temperature, humidity, solar incidence, salinity, acidity, and chemical species with high toxicological potential.

Received on 12 December 2025; revised 27 February 2026.
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J Bioeng. Tech. Health 2026;9(3):209-213

This information can also provide data to determine the shelf life of printed products, in addition to recommending appropriate conditions for use, storage, and disposal [8].

In cases of environments contaminated with ions with high toxic potential, such as in the Mundaú-Maguaba Estuarine Lagoon Complex (CELMM) in Alagoas, mercury levels above the limit established by Brazilian law have already been found [9]. As this is a high-risk element to health, and due to the significant socioeconomic and environmental importance of the CELMM, products intended for use in this region must meet physical and chemical stability criteria in the natural environment in order to be viable for use.

Based on the high adsorption capacity of a functionalized resin for retaining mercury species, both in their inorganic and organic forms, the Portable Floating Device for Removing Hg Species in Aqueous Media was developed and registered with the National Institute of Industrial Property (INPI) under registration number BR 10 2024 024566 0 [10,11].

This technology is an innovative solution for the treatment of water bodies contaminated by mercury, with direct application in natural aquatic environments and effluent systems. The device was designed with a focus on low-cost floating structure, ease of handling in the field, and compatibility with 3D-printed materials, ensuring that there is no interference in the adsorption process by structural components. This approach prevents cross-contamination and maximizes the selectivity and efficiency of the contaminant removal system

Considering the need to advance the TRL and evaluate the characteristics and quality parameters of the 3D-printed material, the present study aimed to characterize the mechanical properties through printed samples inserted in different extreme environments containing mercury and then obtain the chemical properties. It also sought to draw an analogy between pure samples and samples after insertion in critical environments, providing a more accurate comparative study between chemical stabilities. This ensures the possibility of manufacturing products following the principles of environmentally friendly manufacturing and the development of cleaner production.

Materials and Methods

Glassware cleaning and solution preparation were performed with ultrapure water (electrical conductivity < 0.1 µS cm-1) with a resistivity equivalent to 18.2 MΩ.cm-1, using a Milli-Q Reference reverse osmosis purifier (Merck, HE, Germany).

Materials Decontamination

All glassware used in the analyses underwent a decontamination process, beginning with washing in running water and Extran neutral detergent (Merck, HE, Germany) to remove macroscopic residues, followed by rinsing with ultrapure water. The glassware was immersed in a 10% (v/v) nitric acid (HNO_3) solution for a minimum of 12 hours to ensure the removal of contaminants. Subsequently, a new rinse with ultrapure water was performed to eliminate residues. Drying was conducted in a manner that differentiated between volumetric glassware, non-volumetric glassware, and 1.5 mL quartz cuvettes. Volumetric glassware was kept at room temperature to preserve calibration, while non-volumetric glassware was dried in an oven (Soldatel, MG, Brazil) at 50°C for 1 hour to eliminate moisture without compromising the integrity of the material. The quartz cuvettes were dried and any residues were evaporated in a muffle furnace for 1 hour at a temperature of 200°C.

Reagents and Solution Preparation

All reagents used in the experiments were of analytical purity. The solutions were prepared using ultrapure water obtained through a Milli-Q Reference purification system (Merck). Among the materials used, the following polymer filaments stand out: ABS (acrylonitrile butadiene styrene) (GTMax3D, SP, Brazil), PLA (polylactic acid)

(Stratasys, MN, USA) and Tritan, as well as the mercury standard (1000 mg/L) acidified with 5% HNO_3 (Agilent Technologies, California, USA).

Separation Techniques

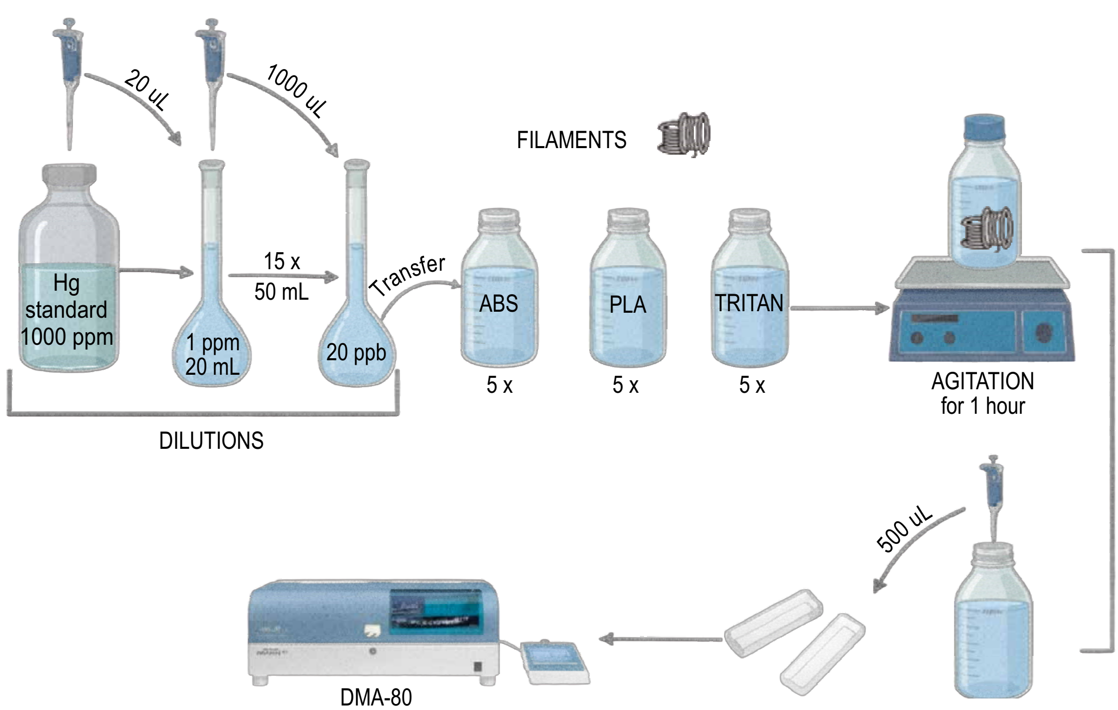
It began with the dilution of the 1000 ppm (mg/L) mercury standard to a stock solution of 1 ppm, followed by dilutions to 20 ppb (µg/L). The 20 ppb dilutions were transferred to shotts bottles containing 3D printed test specimens (ISO 527 – 5A) with ABS, PLA, and Tritan filaments. All bottles were then transferred to the TE-421 shaker (TECNAL, Piracicaba, São Paulo) and exposed to agitation at 150 RPM for 1 hour, thus beginning the adsorption kinetics test (Figure 1).

At the end of the adsorption stage, all samples were transferred for mercury determination. The total mercury in the samples was determined using a DMA-80 analyzer (Milestone, BR, Denmark), a device based on thermal decomposition coupled with atomic absorption spectrometry. Aliquots of 500 µL were taken from the samples in order to standardize the mercury mass to 10 ng and deposited in quartz cuvettes. The samples, deposited in quartz cuvettes, were inserted directly into the system and subjected to a temperature ramp reaching >600°C, promoting the release of mercury in the form of vapor. This vapor is then concentrated in gold wires, forming amalgams ($AuHg_2$, Au_2Hg, and/or AuHg). Subsequently, a second heating releases the monoatomic mercury, which is quantified by atomic absorption at 253.7 nm. The main advantage of this technique lies in the elimination of pretreatment steps, allowing direct analysis of liquid and solid matrices without the need for conversion to an aqueous medium, unlike conventional atomic absorption methods.

Finally, the test specimens were subjected to a tensile test using EMIC (São José dos Pinhais, Paraná) DL 200 equipment, with a displacement rate of 5 mm/min. The aim was to obtain data such as: modulus of elasticity (MPa), yield stress (MPa), yield strain (%), tensile strength (MPa), and elongation at break (%).

The equipment used is operationally versatile, allowing for multiple types of tensile, compression, and flexural tests to be performed, in addition to covering a wide range of materials such as metals, plastics, composites, and insulators, as a result of

Figure 1. Filament adsorption Kinetics test.



the robust structure of the machinery, variable speed in the range of 0.01 to 500 mm/min, and maximum load of 20kN.

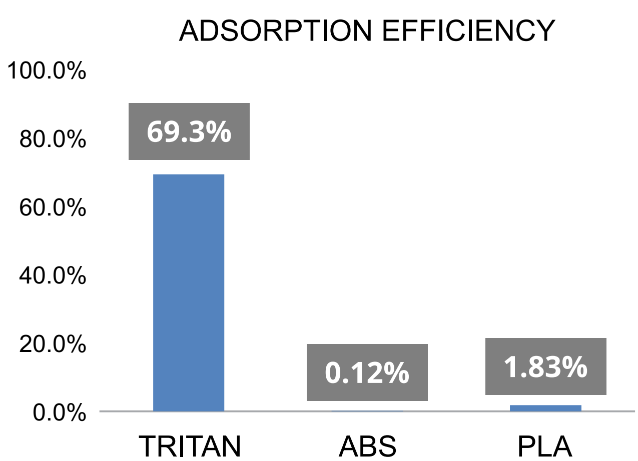
Results and Discussion

Adsorption Test

The adsorption test made it possible to obtain the adsorption efficiency of each polymer filament used. The Figure 2 represents the adsorption capacity of each filament.

The ABS, PLA, and TRITAN filaments resulted in adsorption percentages of 0.12%, 1.83%, and 69.30%, respectively. TRITAN showed high adsorption, which makes it unsuitable for use in products that may be in contaminated environments, despite being the filament with the best physical characteristics compared to the other filaments. Furthermore, ABS and PLA resulted in adsorption efficiencies of 0.12% and 1.83%, respectively, thus, they demonstrated greater feasibility for printing the device structure without material interference and, at the same time, without a memory effect in the event of reuse of the device or filament.

Figure 2. Adsorption efficiency of tritan, ABS, and PLA.



Tensile Test

The results obtained from the tensile analyses of all filaments were compiled in the Table 1 to facilitate the evaluation of these data.

Comparing the physical and mechanical properties listed in the datasheets for each filament, it is possible to determine that there were major structural changes in all filaments due to exposure to water or contact with mercury.

Conclusion

The study showed significant results in a new physical-chemical and mechanical evaluation of the filaments. ABS and PLA showed adsorbent activity of less than 2%, compared to TRITAN's adsorption of 69.3%, emphasizing that both are the most viable options for manufacturing products in contaminated environments, following environmental protection guidelines and the development of cleaner production.

However, all these filaments showed significant structural changes in a critical aquatic environment

Table 1. Results of the tensile test of filaments after adsorption with mercury.

Tensile Test							
Test piece	Stress with Max Force (MPa)	Specific Def with Max Strength (%)	Specific Breakage Def (%)	Breaking Strength (MPa)	Yield stress (MPa)	Def Specific of Flow (%)	Modulus Elasticity (MPa)
Tritan	23.87	7.770	11.88	14.03	13.28	2.669	546.8
ABS	19.77	3.183	7.942	13.81	15.80	2.195	827.2
PLA	27.14	2.877	3.493	22.80	22.28	1.937	1329

with the presence of mercury. This indicates the need for new medium- and long- term chemical stability tests, in addition to the addition of new variables such as other inorganic ions, changes in pH of the medium, and salinity. Thus, increasing the range of data related to the filaments.

References

1. Pinho AC. Análise ambiental, financeira e social da construção por impressão 3D: uma revisão da literatura [dissertação]. Universidade do Porto; 2024.
2. Carvalho JGA. Processos de fabricação aditiva: oportunidades emergentes em arquitetura [dissertação]. Universidade do Porto; 2018.
3. Aguiar LCD. Um processo para utilizar a tecnologia de impressão 3D na construção de instrumentos didáticos para o ensino de ciências [dissertação]. Universidade Estadual Paulista (UNESP); 2016.
4. Santana L, Alves JL, Sabino Netto AC, Merlini C. Estudo comparativo entre PETG e PLA para impressão 3D através de caracterização térmica, química e mecânica. Rev Matéria. 2018;23(4).
5. Stratasys Latin America. PLA filament technical datasheet. 2018
6. Creality. Hyper-ABS filament technical datasheet. 2024.
7. 3DLAB. Ficha técnica tritan. 2024.
8. Agência Nacional de Vigilância Sanitária (ANVISA). Guia de estudos de estabilidade: medicamentos. Guia nº 28, versão 1. Brasília (DF); 2019.
9. Queiroz MIC. A exposição crônica in vivo ao mercúrio inorgânico piora a hipercolesterolemia, o estresse oxidativo e a aterosclerose em camundongos knockout para o receptor de LDL. Ecotoxicol Environ Saf. 2024;275:116254.
10. Associação Brasileira de Normas Técnicas (ABNT). Dispositivo portátil flutuante para remoção de espécies de Hg em meio aquoso. BR 10 2024 024566 0; 2024.
11. Sheremetieff A, Gonçalves AAG. Uma introdução às tecnologias de manufatura aditiva em acordo com a ABNT NBR ISO/ASTM 52900:2018. REUCP. 2020;14(2):81-91.