Comparative analysis of selected properties of FFF 3D printed polymers

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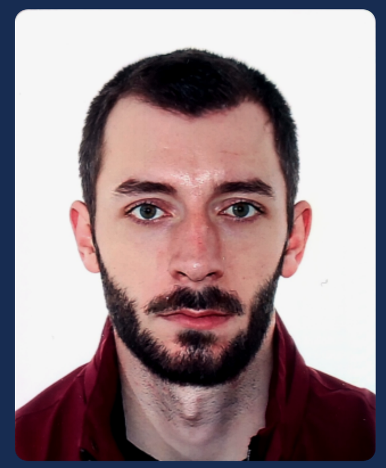

INTRODUCTION

This study evaluates mechanical and physical properties of selected thermoplastic and fibre-reinforced filaments processed via FFF, aiming to compare material performance and limitations for functional applications.

MATERIALS AND METHODS

Ten filaments (PLA, PETG, PCTG, ASA, PVC, PP, PC, PA12, PA+GF, PA+CF) were printed using a modified Prusa MK3S under controlled conditions (chamber, 0.4 mm hardened nozzle, 0.2 mm layers, printed fully from perimeters).

Specimens included:

- Standard test bars (Types A and B, ISO 20753; see Figure 1)
- Square-shaped plates (25 × 25 × 2 mm) for water absorption.

Tests conducted according to ISO standards:

- Water absorption (ISO 62)
- Heat deflection temperature – HDT (ISO 75-2)
- Charpy impact properties (ISO 179-1)
- Flexural properties (ISO 178)
- Tensile properties (ISO 527-2)

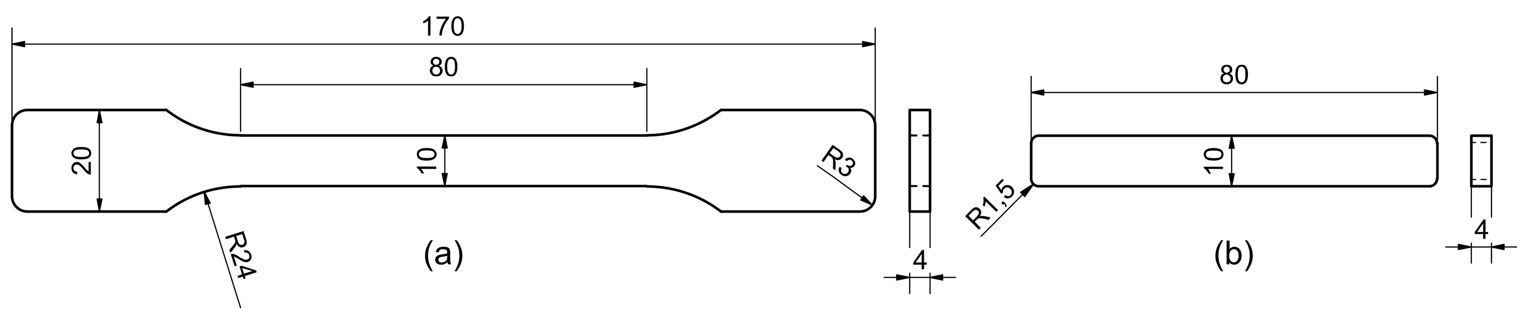

Figure 1. *Test specimens used (a) Type A and (b) Type B.*

RESULTS AND DISCUSSION

Water Absorption (see Figure 2)

- Most materials gained on average ~50% of total moisture in the first 24 h.
- PP absorbed the least (0.13% after 15 days) → suitable for humid environments.
- PETG and PLA: rapid initial uptake likely due to internal cavities; fast drying.
- Fibre-reinforced composites: steep and continuous absorption; retain the most water after immersion.
- Polyamides: highest overall absorption.
- ASA mimics composites but dries quickly.

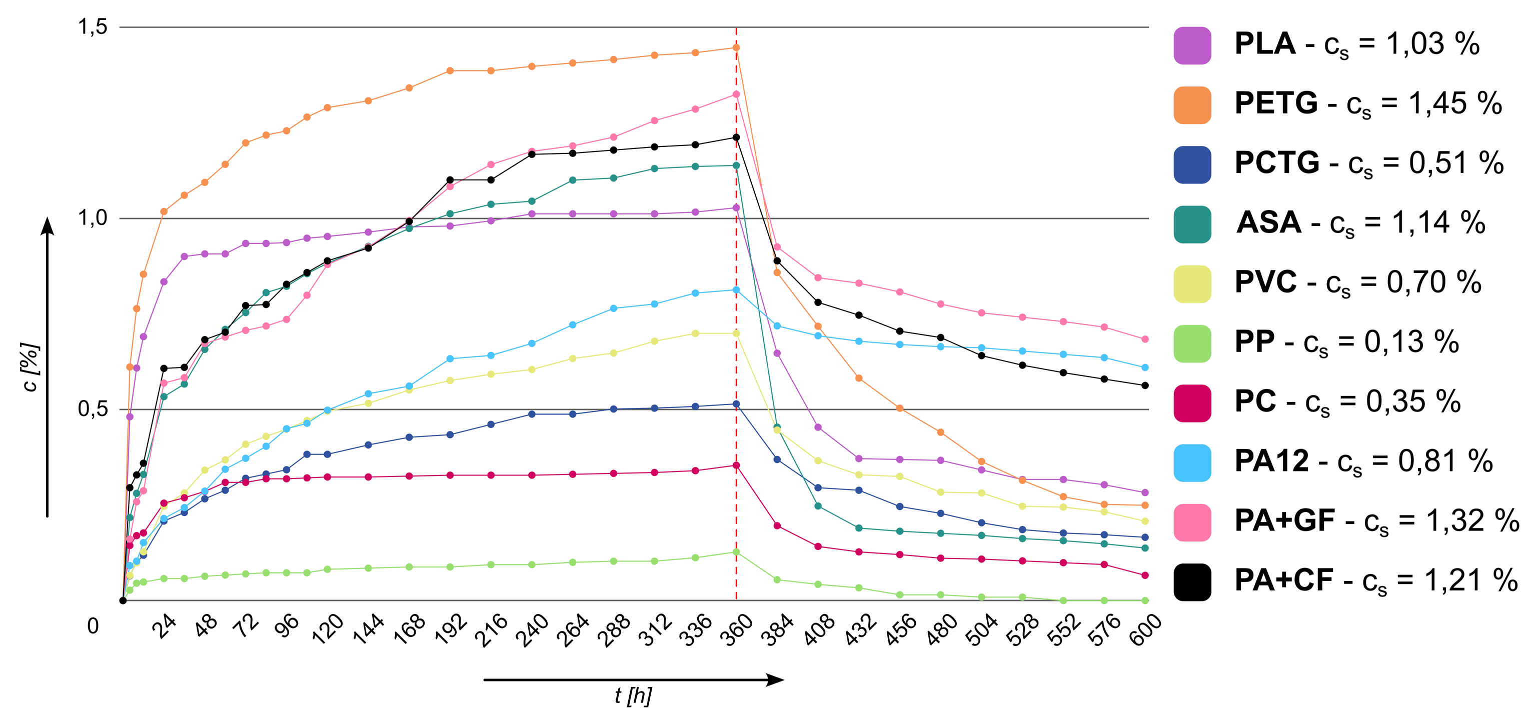

Figure 2. *Mass change during and after immersion.*

Thermal Resistance

- PA12 had the lowest HDT (46 °C), significantly improved by fibre reinforcement: +106% for PA+GF, +220% for PA+CF.
- PC showed highest HDT among unfilled materials (106 °C).
- PLA, PETG, PCTG, PVC, PP and PA12 all below 80 °C (see Table 1) → not suitable for elevated-temperature use.

Impact Strength

- PLA and PA+GF: lowest impact strength (C fracture)
- PVC: highest unnotched (315 kJ/m² - P fracture).
- Toughest materials (PCTG, PA12, PP): further tested with a type A notch
- PP remained unbroken even with notch → toughest material of all tested.

Flexural & Tensile Strength

- PA+CF and PC: highest values in both tests (>110 MPa flexural).
- PLA exceeded expectations in flexural strength (~97 MPa).
- Toughest materials: >100% elongation at break.
- PP: highest ductility (A_t >400%) but lowest strength (13 MPa flexural, 12 MPa tensile).

Table 1. *Summary of properties of tested materials.*

Material	T_f [°C]	a_{cU} [kJ/m²]	a_{cA} [kJ/m²]	σ_{fM} [MPa]	σ_m [MPa]	A_t [%]
PLA	59.00 ±0.71	27.04 ±6.05 (C)		96.72 ±1.08	60.08 ±3.03	4.40
PETG	72.00 ±0.00	98.98 ±7.61 (C)		67.60 ±0.52	48.96 ±0.66	202.06
		209 ±46.33 (P)				
PCTG	76.00 ±1.41		11.14 ±1.85 (C)	67.88 ±0.37	44.11 ±0.43	165.79
ASA	95.00 ±0.71	142.91 ±22.47 (P)		56.40 ±0.30	38.22 ±0.27	5.98
PVC	75.00 ±0.71	233.88 ±36.66 (C)		71.28 ±1.65	46.72 ±0.28	10.90
		315.29 ±11.30 (P)				
PP	50.00 ±0.00		53.63 ±5.21 (P)	12.84 ±0.29	12.42 ±0.50	430.92
PC	106.00 ±0.00	79.83 ±4.73 (C)		111.06 ±0.83	79.88 ±1.59	7.34
PA12	46.00 ±1.41		15.60 ±7.34 (C)	43.14 ±1.14	40.18 ±0.14	111.98
PA+GF	95.00 ±0.71	37.46 ±4.28 (C)		63.98 ±0.76	47.65 ±0.30	14.14
PA+CF	147.00 ±1.41	45.73 ±2.83 (P)		112.26 ±1.18	82.84 ±0.80	7.07

CONCLUSIONS

Carbon fibre reinforcement significantly improves polyamide strength and thermal stability.
PC combines strength, toughness, and low moisture uptake, making it one of the most versatile FFF materials tested.
Material selection should balance mechanical performance and environmental resistance for real-world applications.
Results support the use of standardized methods for comparing FFF materials.