The Effect of Post-Processing on the Mechanical Properties of Additively Manufactured Polymeric Materials

A.O. Oladoye, O.E. Coker, L.O. Oladosu, R.M. Mohammed and L.O. Osoba

Department of Metallurgical and Materials Engineering, University of Lagos, Akoka, Lagos, Nigeria

Corresponding author: L.O. Osoba (losoba@unilag.edu.ng) · FEIC 2026, University of Lagos, 18–20 November 2026

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BACKGROUND AND AIM

FDM builds parts layer by layer, which causes anisotropy: strength depends on the loading direction. Z-oriented parts keep only part of the X-oriented strength, because successive layers bond weakly [1].

Annealing in open air leaves the softened part unsupported, so it shrinks and warps. Salt-bed annealing supports the part during heating and has been reported to raise tensile properties [2].

Evidence remains sparse and partly non-peer-reviewed: one independent test reported Z-axis gains of 157% (ABS) and 71% (PLA) [3]. How annealing interacts with layer height and orientation is little studied.

Aim. To evaluate soda-ash salt annealing at 165 °C on the tensile strength, ductility, hardness, dimensional stability and fracture behaviour of FDM PLA and ABS at three layer heights and two orientations.

MATERIALS AND METHODS

SUNLU PLA (Tg 61 °C) and ABS (Tg 105 °C), 1.75 mm, printed on a Creality Ender 3 V3 SE (0.4 mm hardened-steel nozzle). Only X and Z orientations were printed [4].

Fixed parameter	PLA	ABS
Nozzle temperature (°C)	200	240
Bed temperature (°C)	60	100
Print speed (mm/s)	50	50
Infill density (%)	100	100
Wall thickness (mm)	1.2	1.2

Varied: layer height (0.12, 0.20, 0.28 mm) and orientation (X, Z).

Specimens: 72 tensile specimens tested (3 per condition).

Tensile: ASTM D638, Servo UTM JD-101, 5 mm/min.

Hardness: ASTM E384 Vickers, 50 gf, 10 s, on 50 × 50 × 5 mm specimens; ten retained readings per direction.

Fractography: Olympus BHM microscope, ×50 and ×100.

Analysis: mean ± SD; no inferential tests.

ANNEALING TREATMENT

Medium. Fine soda ash, compacted around the specimens, supports the part and carries heat evenly.

Temperature selection. Trial specimens were held 30 min at several salt-core temperatures (ABS: 135 to 210 °C; PLA: 135 to 180 °C), then sectioned and checked for densification, dimensions, warping and finish.

Trial outcome. 165 °C fully fused ABS, which overheated at 185 °C and above. PLA never fully fused and burned at 180 °C. 165 °C was used for both, above the Tg of PLA (61 °C) and ABS (105 °C).

Heating and cooling. A thermocouple in the salt confirmed the core temperature. Specimens were held at 165 °C for 30 min, then cooled to room temperature in the salt to avoid new thermal stress.

Dimensional check. ABS width changed by up to 0.33% and thickness by up to 0.63%. PLA width was unchanged and thickness changed by up to 0.31%. No specimen warped or cracked.

RESULTS

<1%
Width and thickness change after annealing

+80%
ABS across-layer (Z) tensile strength

+20%
PLA across-layer (Z) tensile strength

49% → 91%
ABS Z/X strength ratio after annealing

+52%
PLA hardness (ABS: +14%)

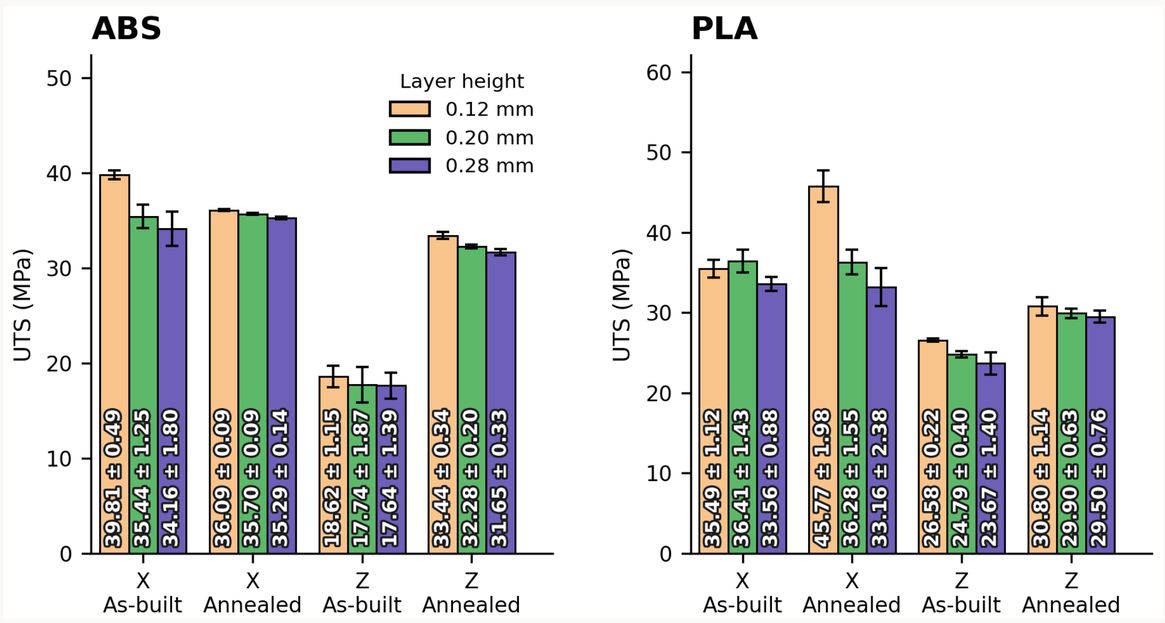


Fig. 1. Ultimate tensile strength (mean ± SD, n = 3). Across-layer (Z) strength rose at every layer height in both materials.

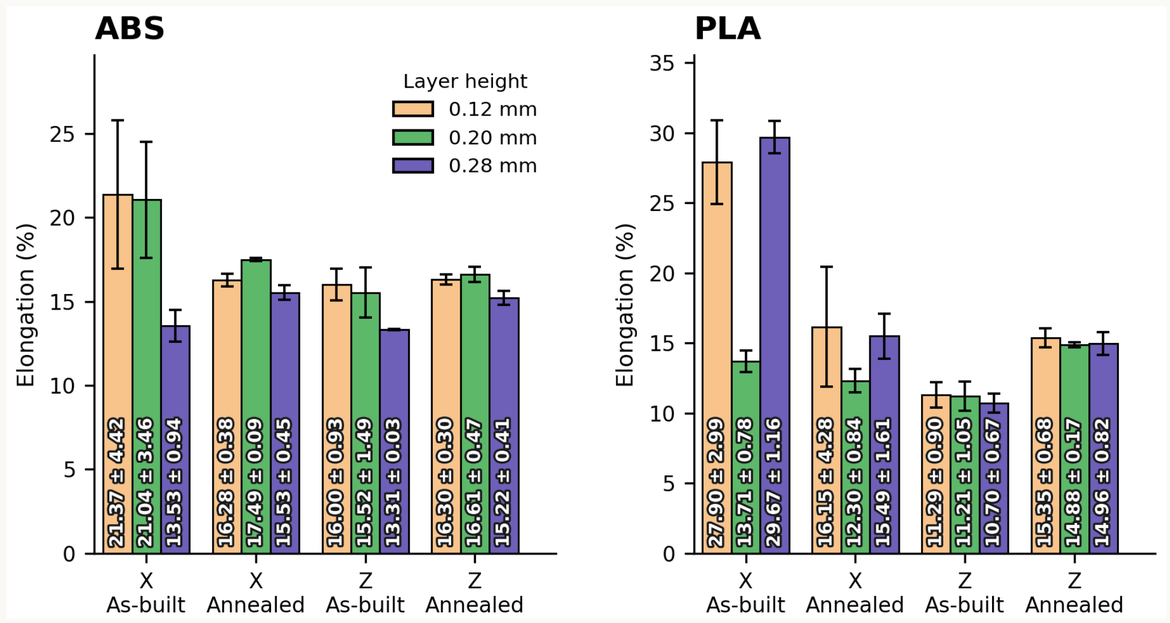


Fig. 2. Elongation at break. Annealed values converged: ABS 15.2–17.5%, PLA 12.3–16.2%.

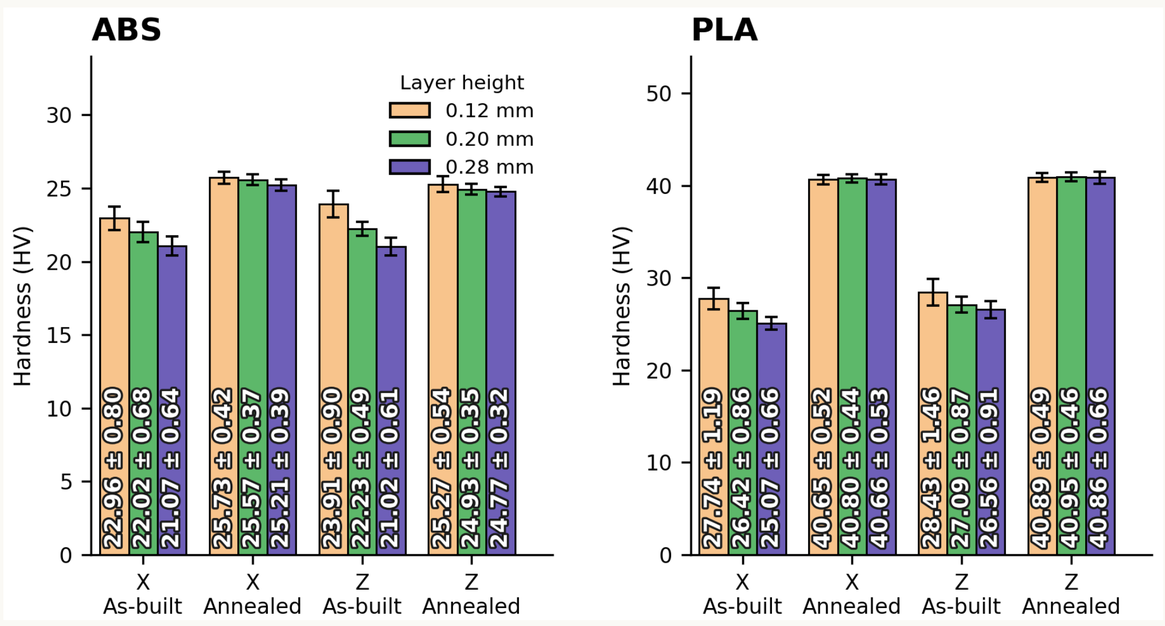
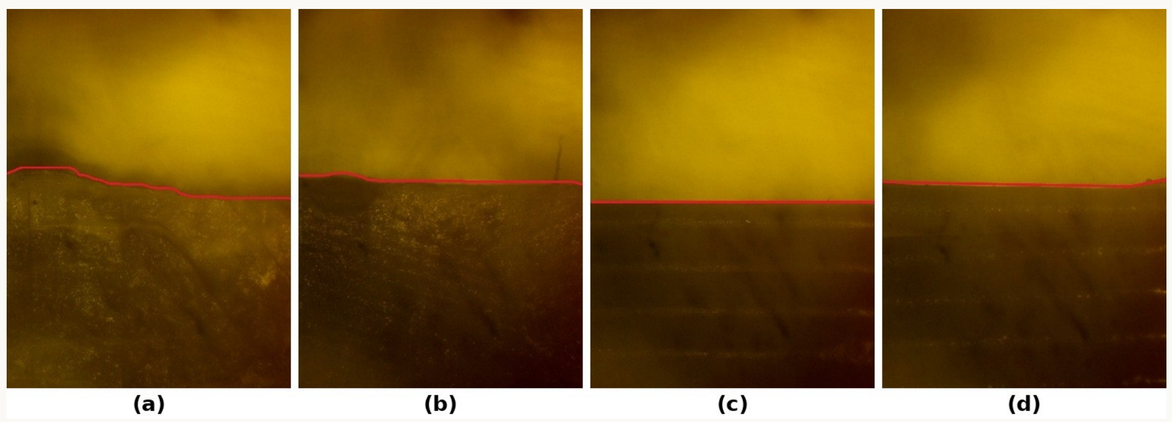
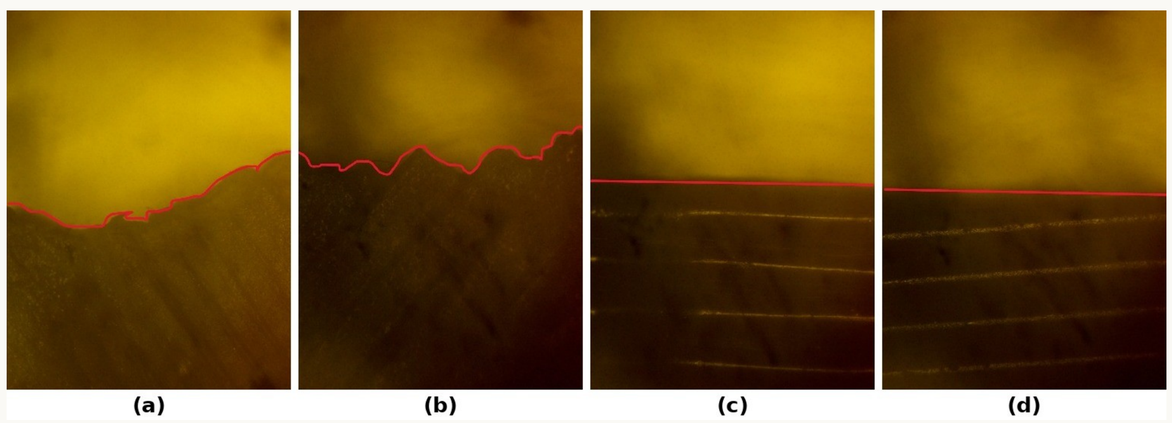


Fig. 3. Vickers hardness, both indentation directions pooled. PLA +51.8%, ABS +13.7%.

FRACTURE SURFACES (×50)



ABS: (a) as-built 0.12X; (b) annealed 0.12X; (c) as-built 0.28Z; (d) annealed 0.28Z. Flat break across layers, less sharp after annealing.



PLA: (a) as-built 0.20X; (b) annealed 0.12X; (c) as-built 0.28Z; (d) annealed 0.28Z. Sharp, granular facets after annealing at 0.12X.

DISCUSSION

- ABS: 165 °C is above its glass transition (105 °C), so layers fuse and printing stress relaxes. This explains the large Z-axis gain.
- PLA: it is largely amorphous as printed [5], so the large hardness gain and faceted fracture fit cold crystallisation. This is a hypothesis; crystallinity was not measured.
- Limits: n = 3, one temperature and hold time, no inferential statistics. Stiffness, crystallinity, density and polymer–salt interaction were not measured. Next: DSC or XRD, SEM, more temperatures.

CONCLUSIONS

1. Salt annealing at 165 °C reduced anisotropy in both polymers. The Z/X strength ratio rose from 49.3% to 90.9% (ABS) and from 71.2% to 78.3% (PLA).
2. Mean Z-axis strength rose by 80.4% (ABS) and 20.2% (PLA). Elongation became more consistent, and hardness rose by 51.8% (PLA) and 13.7% (ABS).
3. The method is simple, dimensionally stable (below 1%) and needs only a furnace, fine salt and a thermocouple, so it suits locally produced FDM parts for resilient infrastructure. Creep, fatigue and ageing tests are needed before load-bearing use.

REFERENCES

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