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Characterizing Process-Induced Defects in Metal and Ceramic Fused Filament Fabrication for Accessible Aerospace Components

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Metal and ceramic material extrusion (MEX) offers a cost-effective, powder-free pathway to aerospace-grade components using desktop printers and accessible kilns. The layer-by-layer toolpath introduces inter-layer lack-of-fusion (LOF) defects whose severity is governed by slicing geometry, yet NASA-STD-6030 provides no standardized defect acceptance criteria for MEX. This study investigates whether wall count of 3, 4, and 5—a measurable process-independent structural descriptor independent of printer platform—predicts LOF defect distribution and its mechanical and thermal consequences across five sintered materials: copper, SS 316L, inconel 718, borosilicate glass-ceramic, and zirconium silicate (Virtual Foundry Filamet™). Prior shrinkage work on copper MEX demonstrated that geometric parameters predict dimensional change ($R^2=0.672$, gradient boosting), with non-prismatic geometries producing higher prediction error, consistent with irregular toolpath geometry creating preferential LOF sites. All sintered specimens will receive shrinkage measurements, optical cross-section analysis, and Vickers microhardness spatial mapping. ASTM E8 tensile testing for metals, ASTM C1161 four-point flexural strength testing for ceramics, and SEM/EDS elemental mapping will be done for in full for inconel 718 and borosilicate and for representative cases for the remaining materials. Sample thermal expansion anisotropy will be characterized by using a custom rough-vacuum dilatometry setup incorporating pushrod displacement measurement and IR thermometry through a ZnSe viewport. A bead-scale thermo-mechanical finite element model driven by G-code toolpaths are being developed to validate measured thermal profiles and assess inter-layer defect severity. Results will produce practical design guidelines enabling engineers with limited budgets to use MEX structural and thermal components without part-by-part destructive qualification. Potential applications include motor retention rings, rail button mounts and fin attachment hardware, forward and rear closures, liquid cooling channels on low pressure systems, sled standoffs, and grounded electronic housing. Ceramics could be especially useful for nozzle inserts.

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