# INFLUENCE OF SLICING ON THE MORPHOLOGY AND STRUCTURE OF DEPOSITED COPPER

ROMAN BABCHUK, DMYTRO USCHAPOVSKYI, GEORGII VASYLIEV

National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"

The paper investigates the effect of slicing parameters – toolpath type (concentric, zigzag, triangle) and infill step (1, 2, 4 mm) – on the morphology and crystalline structure of copper fabricated using electrochemical additive manufacturing (ECAM). The deposits were studied using SEM and XRD. It was shown that the slicing parameters greatly affect the uniformity, porosity, and internal stresses of the material. Crystallite size and residual stresses decreased with increase in infill steps. Triangular infill produced the most homogeneous and fine-grained coatings.

*Keywords:* additive manufacturing, ECAM, 3D printing, slicing, cooper, sulfate electrolyte, SEM, XRD, internal stress, metal structure

Alternative metal additive manufacturing technologies are of interest from both scientific and technological perspectives. One such approach is electrochemical additive manufacturing (ECAM), which offers unique advantages due to its precision and the nature of materials involved. Opposing other metal additive manufacturing methods that utilize powders, wires, or significantly larger particles, ECAM is based on utilizing the smallest possible material particles – ions. Given the scale of ions, most research focuses on electrochemical additive manufacturing of micro- and submicron-scale objects [1].

Slicing in additive manufacturing is the process of converting a digital 3D model into a sequence of printer control commands (GCODE) that determine the movement of the printing nozzle [2,3]. In localized electrodeposition, where the object is built through atom-to-atom bonding within each layer, the chosen slicing pattern and nozzle movement step play a critical role in how layers are connected. These parameters can directly influence the material's microstructure, surface morphology, and, consequently, its functional characteristics, including electrochemical performance. Variations in infill geometry or movement strategy can lead to significant differences in the final properties of the manufactured object, making slicing a key factor to consider in experimental methodology. This work was aimed at investigation of slicing parameters on the morphology and structure of 3D-printed copper.

Circular copper disks, 20 mm in diameter, were fabricated by electrochemical 3D printing via localized electrodeposition. Slicing parameters included several infill strategies (concentric, zigzag, triangular) and infill steps of 1, 2, and 4 mm, generated in. GCODE to define the anode/nozzle movement sequence. The electrolyte was prepared in distilled water (220 g/L $CuSO_4 \cdot 5H_2O$; 32 mL/L concentrated $H_2SO_4$; additives: Rubin T200-A 2 mL/L, T200-G 8 mL/L, T200-E 2 mL/L). The printing regime and main parameters are summarized in the table below Printing was performed with a layer thickness of 150 µm, current of 0.03 A, voltage of 4.5 V, and a cathode–anode distance of 1 mm. The anode capillary diameter was 2 mm, the electrolyte volume was approximately 1 L, and the total printing time was 8 h.

The samples were analyzed using SEM and XRD techniques. A scanning electron microscope (SEM-106I, Selmi, Ukraine) was used to observe surface morphology and microstructure. XRD analysis was performed using a Rigaku Ultima IV diffractometer (Cu Kα radiation) $2\theta = 20°–120°$, step 0.04°, 2 s/step, 40 kV, 40 mA) for phase analysis, crystallite size (CSR) and lattice strain calculations. Data was processed using PDXL software with the ICDD PDF-2 (2025) database, employing the RIR method for quantitative phase analysis.

To visually assess the uniformity and quality of the deposit, macro-images of copper disks fabricated using different toolpath patterns (concentric, zigzag, triangular) and infill steps (1, 2, 4 mm) were analyzed. The SEM images of the deposited metal surface are shown in Fig. 1.

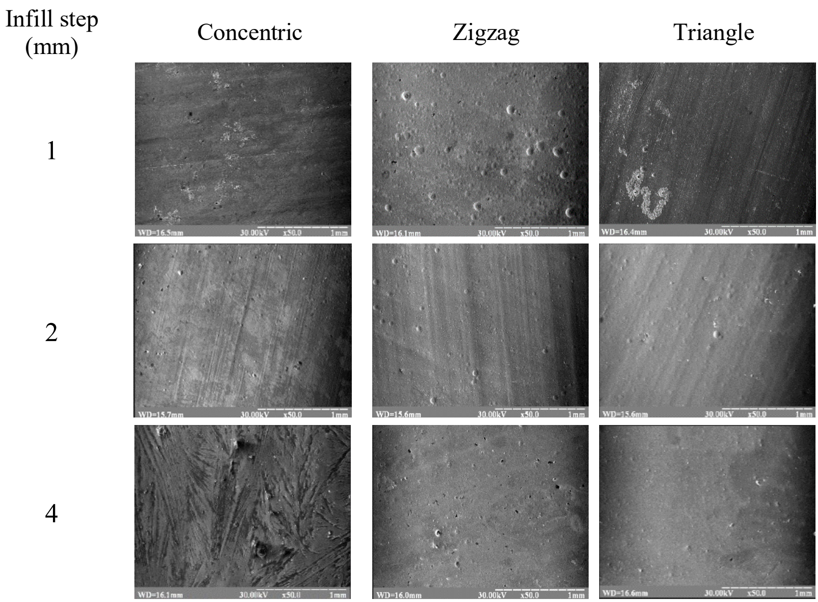


Fig. 1. Influence of slicing parameters on the appearance of printed objects

SEM analysis demonstrated that slicing parameters have a significant impact on the morphology of the deposited layer: at a small step size (1 mm), all trajectories (concentric, zigzag, triangular) exhibit microporosity and non-uniformity, most pronounced in the form of globules for the zigzag pattern; at a 2 mm step, partial stabilization occurs, although concentric still shows grooves, zigzag produces globules, while triangular provides the best quality with a smooth and uniform surface; at a 4 mm step, concentric and zigzag lead to dendritic structures, voids, and major defects, whereas triangular maintains homogeneity, forming a dense fine-grained layer. Thus, the triangular pattern at step sizes of 2–4 mm proved to be optimal, ensuring stable current distribution and controlled grain growth.

Table 1. Crystal lattice parameter, size of coherent scattering regions, degree of deformation of the crystal lattice of the electrochemically printed copper

| Infill type and step | K1 | K2 | K4 | Z1 | Z2 | Z4 | T1 | T2 | T4 |
|---|---|---|---|---|---|---|---|---|---|
| Lattice parameter, nm | 0,3616 | 0,3616 | 0,3615 | 0,3621 | 0,3615 | 0,3616 | 0,3615 | 0,3616 | 0,3614 |
| OCD, nm | 66 | 14,5 | 12 | 252 | 68 | 45 | 45 | 11,5 | 9,9 |
| $\varepsilon$, % | 0,12 | 0,07 | 0,08 | 0,05 | 0,04 | 0,02 | 0,01 | 0,02 | 0,01 |
| $I_{200}/I_{111}$ | 0,41 | 0,22 | 0,21 | 0,20 | 0,25 | 0,20 | 1,51 | 0,14 | 0,23 |
| $\sigma$, MPa | -245 | -203 | -158 | -297 | -399 | -1366 | -892 | -827 | -798 |

X-ray diffraction analysis confirmed the significant influence of slicing parameters on the morphology of the fixed material. For all trajectories, an FCC lattice with an almost constant parameter (≈0.3615–0.3621 nm) was observed; however, with increasing step size, the size of coherent scattering domains decreases (e.g., concentric: 66→14.5→12 nm; zigzag: 252→68→45 nm; triangle: 45→11.5→9.9 nm), indicating the formation of a fine-grained structure. The level of residual stresses is lowest for concentric and monotonically decreases with increasing step, whereas in zigzag the stresses sharply increase (up to −1366 MPa), and in triangular mode they remain intermediate and stable. Textural differences include a growing (111)-orientation for concentric, a consistently strong (111)-texture in zigzag (I200/I111 ≈ 0.2–0.25), and the formation of a (100)-texture for triangular mode at small step size (I200/I111 ≈ 1.51), shifting toward (111) at larger steps. Thus, the triangular trajectory provides the smallest crystallite size under stable stress conditions, zigzag results in maximum compressive stresses and the largest grains, while concentric ensures the weakest texture and minimal internal stresses.

The study showed that slicing parameters significantly affect the morphology, crystallite size, and internal stresses of electrochemically printed copper disks. Concentric infill produces dendrites at the center, zigzag and triangular infill cause coating defects along the perimeter, while the triangular pattern yields the most uniform and dense layers. Crystallite size is largest with zigzag, smaller with concentric and triangular infill, and decreases with increasing infill step. Internal stresses are lowest with concentric, highest with zigzag, and intermediate with triangular infill, with larger infill steps reducing stress except for the zigzag pattern. Overall, the triangular slicing mode provides the best balance of uniform morphology and structural quality.


1. *Ayalew A.A., Han X., Sakairi M. A critical review of additive material manufacturing through electrochemical deposition techniques // Addit. Manuf. – 2023. – 77: – № 103796. https://doi.org/10.1016/j.addma.2023.103796*
2. *Frank M., Matthews M., Madril J., Winfield I. Electrochemical additive manufacturing: A novel approach to thermal management of electronics // In: 2023 IEEE 73rd Electronic Components and Technology Conference (ECTC). – 2023. – P. 432–436. IEEE. https://doi.org/10.1109/ECTC51909.2023.00078*
3. *Brant A (2016) An Exploratory Study of Electrochemical Additive Manufacturing // Master's thesis, University of Cincinnati. – 2016. – P.112. http://rave.ohiolink.edu/etdc/view?acc_num=ucin1470672617*