Multiscale approach to super-resolve CT data of crushed fayalite slag, using generative adversarial networks

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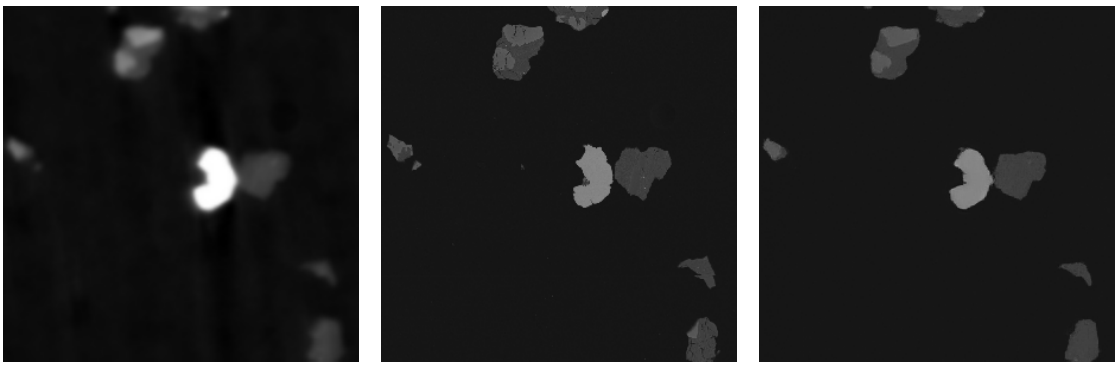
Fayalite slag, a by-product of copper smelting, contains valuable minerals such as fayalite and magnetite, forming complex intergrown structures that require precise multiscale characterization for the optimization of recycling processes. Computed tomography (CT) provides non-destructive 3D insights but is limited in resolution, whereas scanning electron microscopy-backscattered electron (SEM-BSE) imaging offers high-resolution details for 2D slices.

This study utilizes a multiscale approach to super-resolve 3D CT image data of crushed fayalite slag using an enhanced super-resolution generative adversarial network with dual perceptual loss (ESRGAN-DP), as introduced by Song et al., 2023[1]. By training on registered high-resolution SEM-BSE images, the network learns to map low- to high-resolution representations, capturing intricate mineral textures and particle boundaries. To obtain super-resolved 3D CT data, the trained network is applied to slices along different axes of the low-resolution CT data, generating multiple super-resolved volumes. However, due to the lack of 3D context during the generation of these initial volumes, discontinuities may occur along the axis orthogonal to the slicing direction. To address this, the super-resolved volumes are combined to produce consistent super-resolved CT data (Kirstein et al., 2025)[2].

This multiscale approach improves segmentation accuracy, with Dice coefficients increasing significantly compared to bicubic-interpolated CT when evaluated against the SEM-BSE ground truth. Particle-wise descriptors, such as area-equivalent diameter and perimeter, exhibit reduced mean absolute errors. As shown in Figure 1, the super-resolved CT data exhibits improved resolution and transfers the compositional contrast and fine textural details from the SEM-BSE images to the 3D CT data. The method effectively bridges scales from 2D high-resolution SEM-BSE slices to 3D micro CT data, combining the strengths of both imaging techniques for enhanced multiscale materials characterization in mineral processing.



(a) (b) (c)

Figure 1: Comparison of measured image data (a,b) and super-resolution result (c): (a) 2D slice of CT data (after bicubic upscaling), (b) High-resolution SEM-BSE slice (ground truth), (c) 2D slice of super-resolved CT data (using the ESRGAN-DP approach).

[1]Song, J., Yi, H., Xu, W., Li, X., Li, B., & Liu, Y. (2023). ESRGAN-DP: Enhanced super-resolution generative adversarial network with adaptive dual perceptual loss. *Heliyon*, 9(4), e15134.

[2]Kirstein, T., Siddique, A., Gräfensteiner, P., Schröer1, L., Leißner, T., Cnudde , V., Peuker, U.A., & Schmidt, V. (2025). Multiscale approach to super-resolve CT data of crushed fayalite slag, using generative adversarial networks. (in preparation)