Designing immiscible metallic composites using additive manufacturing

Nabila Ali [1], Yuheng Nie [1], Davin Yoo [1], Yen-Ting-Chang [1], Marie A. Charpagne[1]
[1]*Materials Science and Engineering Department, University of Illinois, Urbana-Champaign USA*

Keywords: Immiscible alloys, Direct Energy Deposition, Gradient Materials, EBSD, Mechanical properties.

Abstract

A subset of hetero-structured materials, metallic composites made of immiscible elements such as Fe/Ag, Cu/Cr, Cu/Ta, or Cu/Fe exhibit attractive combinations of strength, ductility, thermal conductivity, and resistance to irradiation among others. Characterized by a positive enthalpy of mixing, they all exhibit liquid phase separation and cannot be synthesized via traditional methods like casting, due to sedimentation and macro-segregation after phase separation. Instead, deposition techniques or solid-state fabrication methods have been employed, but those prevent the fabrication of complex shapes and offer limited microstructure control.

Using additive manufacturing, we intend to leverage rapid solidification as an asset to synthesize Fe-Cu-based immiscible composites in a fully scalable manner. Considering Fe-Cu, 316L-Cu and 304L-CuCrZr alloys, we employ gradient deposition strategies using on-the-fly alloying and combinatorial deposition in direct energy deposition, to quickly probe the composition-process space. We achieve fully dense materials with hierarchical microstructures that exhibit features down to the nanoscale.

This presentation will first explore the printability of these immiscible alloys, focusing on their unique printing defects, hot-cracking phenomena and their cause, and associated mitigation strategies, supported by computational thermodynamics. We will then explore the metallurgical mechanisms governing microstructure development in fully dense alloys, considering liquid phase separation, grain nucleation, dendrite growth, and solid-state phase transformations, informed by multi-scale electron microscopy measurements (EBSD, TEM, STEM-EDX, 4D-STEM). Finally, we will delve into the mechanical behavior of the most promising Fe-Cu-based alloys using micro-tensile specimen testing and nanoindentation, with emphasis on the interaction between slip bands, phase boundaries, grain boundaries, and back-stress development using AFM.