
Where the Nano-Worlds Collide: Nanoporosity-Driven Deformation of Nano-Architected Metals

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Abstract

The emergence of 3D printing methods for small-scale metals has enabled attaining a unique dimensional niche, on the order of 10-100 nm, at the nexus of the functional feature sizes, the critical microstructural detail, and atomic-level defects. This convergence fundamentally challenges the conventional relationships across structural hierarchies and has significant nanomechanical implications. We demonstrate the fabrication of nano-architected metals with superior resolution and structural integrity enabled by a novel nanoscale additive manufacturing approach based on two-photon lithography and hydrogel infusion (nano-HIAM). The produced nickel nanoarchitectures – beam-based and shell-based, periodic and non-periodic – exhibit remarkable specific mechanical strengths, achieving ~ 10 -100 MPa.g⁻¹cm³ at feature dimensions of ~ 100 -500 nm. The *In situ* nano-compression experiments unveiled unique nanomechanical behaviors in the regime where structural, functional, and microstructural dimensions converge, ~ 10 -100nm. A predominant global "material failure" mechanism allows for a direct correlation between the structural response and the experimentally measured strength of nano-building blocks that comprise the nano-architected materials. Through integrated experimental characterizations and physics-informed, multi-hierarchy finite element analysis, nodal nanoporosity is identified as the key factor controlling deformation modes and size-dependent strength, which ultimately links the nano-building block properties to the structural response of representative octahedral nanolattices. This study highlights nano-architected Ni as a model system to demonstrate the capability of nano-HIAM for fabricating complex 3D geometries with high resolution. Future work could explore the application of the nano-HIAM method to more complex material systems and microstructures, including multi-principal elements alloys, ceramics, doped carbon composites, hetero-structured nanostructures, and multi-stable nanoarchitecture. The versatile infusion and thermal treatment processes of nano-HIAM, combined with its superior 3D-freeform capability, could enable wide multifunctional applications in nanotechnology. The nano-defect-mediated size-dependent structure properties identified here likely extend to other nanoarchitectures with converging characteristic dimensions, posing new challenges for developing high fidelity multi-hierarchy modelling frameworks for evaluating and designing nanoarchitectures with superior target properties.

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