Additive manufacturing of microscale metal-ceramic architectures with tunable mechanical properties

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Abstract

Over the past years, significant progress has been made towards improving our understanding and manufacturing capability of 3D architectured materials at the nano- and microscale. This holds the potential for preparing novel materials that combine usually mutually exclusive properties such as high strength, toughness, and low density through intelligent design making use of size effects and material architecture.
In the last years, we have developed a process combining template assisted electrodeposition and atomic layer deposition (ALD) that allows synthesizing complex shaped metal-ceramic architectures at the microscale. Polymeric molds are created by two photon lithography and filled with metals including Cu, Co, Au, Zn, Ni, and NiP using electrodeposition from aqueous electrolytes. After removing the polymer using oxygen plasma etching, the metal architectures are coated by ALD to create metal-ceramic core-shell structures with improved properties. Micromechanical testing inside a scanning electron microscope at various boundary conditions combined with transmission electron microscopic analysis allows investigating the microstructure and dominating deformation mechanisms.

As a case study, the preparation and in-depth analysis of complex Al2O3-coated Ni structures will be presented combining synchrotron nanoCT imaging, electron microscopy, micromechanical testing, and finite element modeling. The combination of methods allowed us to investigate the distribution of defects and geometric imperfections and their role in the apparent deformation behaviour of the complex architectures as well the deformation mechanisms of the metal lattice at the atomic scale including stress-induced densification of dislocation networks, creation of nano-twins, and localized grain refinement. Finite element analysis was employed to study stress distribution in the complex structures and the effects of stress sharing between the different phases. Thus, our multiscale analysis spanning from the atomic to the component level allowed us to identify the deformation mechanisms and their respective contributions to the apparent structural behavior.

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This work opens up pathways towards the future design and synthesis of metal-ceramic nanocomposites and metamaterials for various applications from impact mitigation for MEMS devices to functional biomaterials.