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Extrusion 3D-Printing: from Oxide Inks to Metallic Micro-lattices

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Abstract
To create metallic scaffolds or microlattices with sub-millimeter strut architectures, we develop a new method, *Extrusion 3D-Printing*, consisting of two simple steps. First, metal oxide particle suspensions (inks) are extruded, in air and at ambient temperature, into linear struts creating self-supporting lattices. Second, the oxides are hydrogen-reduced to metal and sintered into dense metallic microlattices.

We describe here micro-lattices made of pure metals – copper, iron, nickel or tungsten - created from inks consisting of the respective metal oxides. In all cases, thermochemical reduction and sintering of the 3D-printed oxide scaffolds results in large shrinkages (up to 80% by volume) but without cracking or distortion, as investigated via *in-situ* x-ray tomography.

We also demonstrate metallic alloys, using blends of oxides: Fe-20Ni-5Mo (a steel) and Co-Cr-Fe-Ni (a high-entropy alloy) and study, via *in-situ* x-ray diffraction, the interdiffusion resulting in homogenous alloys. Finally, we present more complex tungsten geometries, *i.e.*, gyroids with triply periodic minimal surfaces.

Bio
David Dunand received a BS/MS degree at the Swiss Federal Institute of Technology (ETH, Zurich) in materials engineering in 1986 and a Ph.D. in materials science and engineering from the Massachusetts Institute of Technology (MIT) in 1991. After serving on the MIT faculty until 1997, he joined Northwestern University (NU). His research focuses on processing, structure and mechanical properties of metallic alloys, composites and foams. Examples range from freeze-cast iron foams for batteries to selective-laser- melted aluminum scaffolds for light-weight structures, to creep- and oxidation-resistant Al-, Ni-, Co- and Fe-based alloys for engines and gas turbines.

Dunand is a fellow of ASM International (the Materials Information Society) and a fellow of TMS (the Minerals, Metals and Materials Society). His awards include the 2012 Materials Science & Engineering A Journal Prize, the Distinguished Scientist/Engineering Award Structural Materials Division of TMS and three departmental "Teacher of the Year" Awards at NU. Dunand is co-Founder of NanoAl, LLC, a start-up company developing high-strength, high-temperature aluminum alloys, recently acquired by Braidy Industries.

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