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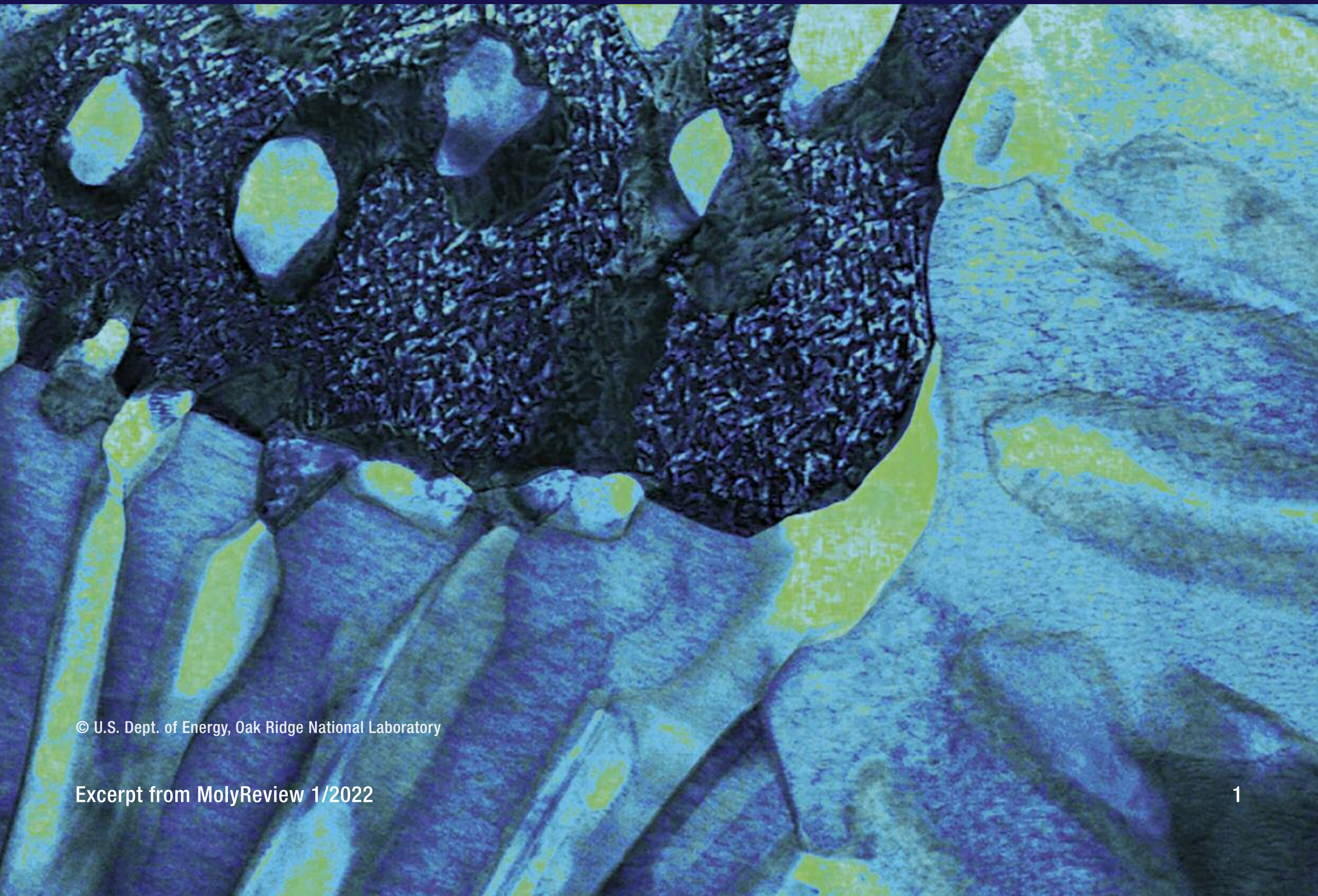
3D printing a hot commodity

Molybdenum metal is indispensable to several industries because of its strength at high temperatures. But some applications require complex and not so-easily-fabricated shapes. 3D printing is one approach to overcoming production issues with complicated parts, however, when produced in molybdenum metal, such parts often suffer from defects. A new process, alloying it with titanium carbide, may indicate a turning point.



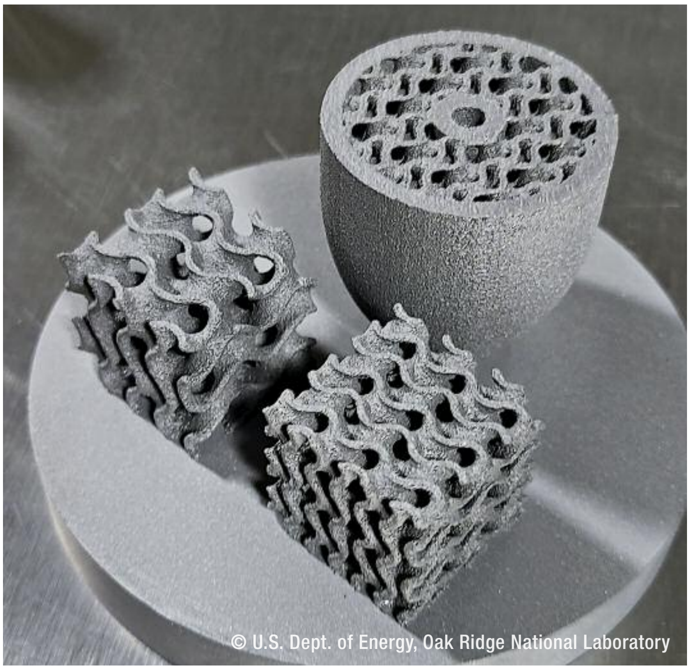
In 30 years, the world is projected to need double the electricity it currently uses. But expanded energy production must coincide with emissions decreasing below current levels to avoid the worst effects of climate change. The solution to increasing the power supply without increasing emissions will be multifaceted, but it's likely to involve raising the operating temperature inside power conversion plants to increase their efficiency. For example, upping the temperature inside nuclear reactors from 900 to 1000°C would raise productivity by 10%.

Although this offers major opportunities to reduce emissions as well as costs, turning up the heat in these sectors is a materials science conundrum. Only a few materials are potential candidates for such infernos. Mo-metal and Mo-metal alloys can tolerate temperatures that warp or liquify others. This is because molybdenum has one of the highest melting points of any element in existence (2622°C). Most importantly, it retains its shape and strength at high heats. Other metals that tolerate extreme temperatures well, like rhenium and niobium, are naturally less abundant than molybdenum and can be expensive or confer supply risks. Mo-metal is sometimes used in tandem with carbon-composites, which offer even greater stability at high heats. However, carbon-composites are wildly expensive and time consuming both to design and to manufacture. Thus, the scientific community continues to consider Mo-metal as a solution – but it also presents challenges.

Printing a paradigm-shift

Parts for highly-specialized industries are increasingly produced through additive manufacturing (AM), also known as 3D printing. AM originated in the mid-1980s to accelerate the development of product prototypes. The process is characterized by fusing layers of material together, often at the microscopic level. The "printer" references a computerized 3D model, producing an exact replica layer by layer. Unlike the "subtractive" methods of traditional milling, cutting, drilling and grinding – successful AM produces virtually no waste. It is often more cost-effective to add complexity to a part with AM because the design can be simply altered on the computer. Some designs that are difficult or even impossible to make with traditional manufacturing, such as parts with hollow portions that lack a connection to the external part surface, can be realized with 3D printing.

The ability to 3D print Mo-metal in the complex shapes required by the aerospace, defense and energy conversion sectors could result in increased thermal efficiency, which ultimately means more power generated with fewer resources. The challenge, however, is that 3D printed Mo-metal can suffer a loss of mechanical properties and stability that can render it unusable. This is because the 3D printing of Mo-metal and Mo-alloys is prone to the formation of defects such as porosity and cracks under improper print



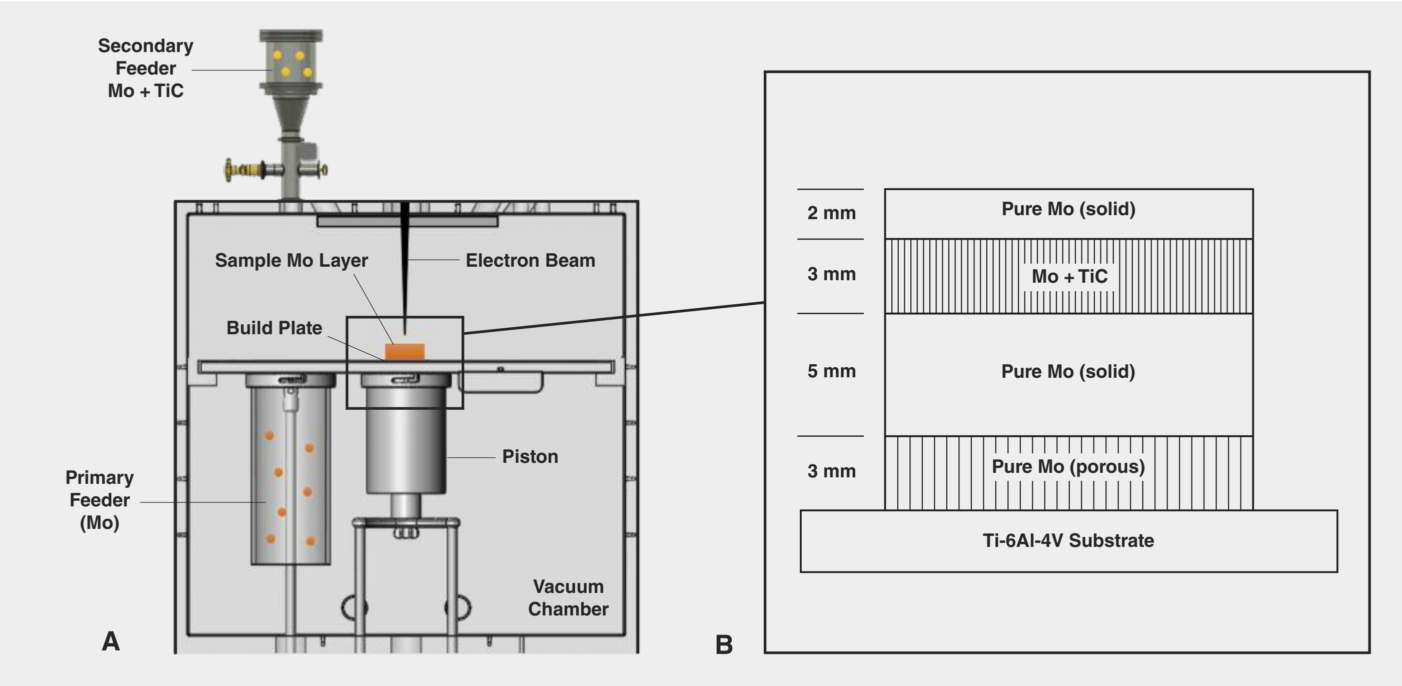
3D printing allows complex shapes to be printed which cannot be fabricated in any other way. These are prototype parts for highly efficient Mo-TiC heat exchangers.

conditions. However, through carefully controlling the 3D print process, Mo-metal and Mo-alloys such as titanium carbide Mo-matrix alloys can result in high quality crack-free parts with consistent properties. Scientists at the Oak Ridge National Laboratory (ORNL) in the southeastern United States are now partnering with external stakeholders to trial Mo-metal and Mo-alloy objects at scale.

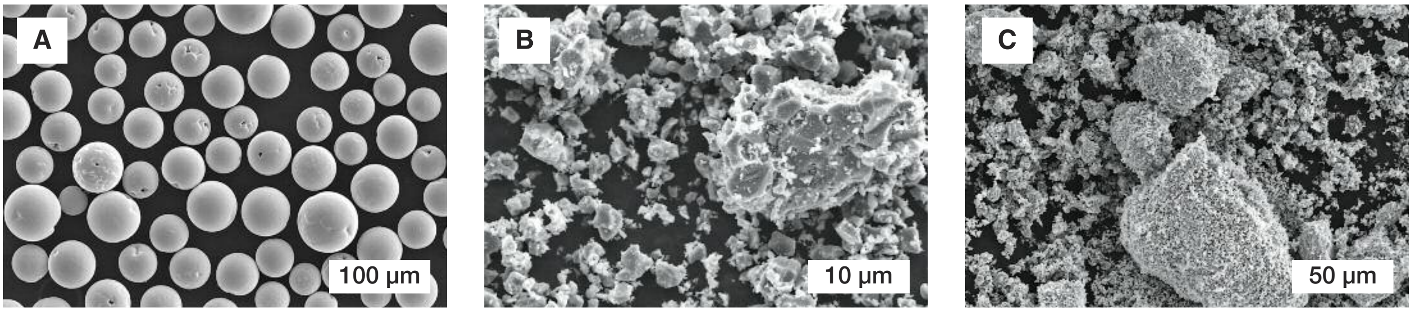
No more slipping through the cracks

This manufacturing process uses an AM method called "powder bed fusion" (PBF) to melt the powdered feed material into a solid. PBF requires either a laser or an electron beam to melt and fuse the powdered constituent. The researchers used the latter method, citing better control over temperature variation during printing. PBF with Mo-metal has yet to be successful at commercial scale due to the defect prone nature of these materials during processing, but recent findings suggest that soon may change.

The researchers demonstrated the ability to print high-quality Mo-metal with unique grain structures not achievable through traditional Mo-metal manufacturing routes. These PBF processing advancements have enabled Mo-metal to be successfully printed into structural parts used in nuclear thermal propulsion systems.



Schematic of the customized electron beam PBF build chamber and secondary feeder (A) and a Mo-Mo + TiC-Mo sandwich sample (B). Source: U.S. Dept. of Energy, Oak Ridge National Laboratory



Molybdenum powder (A), TiC particles (B) and the 60% molybdenum/40% TiC powder created by mechanically alloying the two feedstock powders. © U.S. Dept. of Energy, Oak Ridge National Laboratory

In addition to Mo-metal, the researchers also successfully printed composite matrix Mo-alloy titanium carbide material. In materials science terminology these are known as cermets. To create the cermet, researchers mechanically alloyed feedstock powders of 60% molybdenum powder and 40% titanium-carbide and printed them. After printing, there were no defects detected. Such materials offer the potential to enable advancements in energy systems requiring materials to operate in extreme environments such as super critical CO_2.

Other research teams have also yielded promising results. In 2019, the Beijing Institute of Technology developed 3D printed Mo-metal components for ion thrusters in the aerospace industry. The research group also combined Mo-metal powder with a titanium carbide powder to form a stable, oxidation-resistant composite product. The composite approach seems to yield positive results, not only with pure Mo-metal but also with other Mo-containing alloys. A research team in Singapore mixed titanium diboride nanoparticles with the molybdenum-loaded nickel base alloy Inconel 625, also resulting in better printability. These developments further attest to the future viability of vastly improved 3D printed Mo-metal and Mo-containing alloy components. Such projects demonstrate the unique properties of molybdenum and their increasing value in a decarbonizing world.

Raising the efficiency of thermal powerplants like nuclear reactors depends on the developments of better materials, particularly those with high temperature strength. Molybdenum is arguably the best candidate for the job. The ability to 3D print the material in the shapes required by industry could have major implications for generating more power with fewer resources. (Karlee Williston)