Ultrasound strengthens 3D printed metal alloys

Ma Qian of the Royal Melbourne Institute of Technology (RMIT), Australia, and co-workers reported in *Nature Communications* (doi:10.1038/s41467-019-13874-z) that applying ultrasound during three-dimensional (3D) printing of the titanium alloy Ti-6Al-4V, widely used in aerospace and biomechanical applications, could improve its mechanical strength. They determined that the mechanism of the enhancement originated from the refinement of grain size and regulation of grain orientation in the alloy by ultrasonic agitation.

The use of ultrasound addressed a long-lasting challenge in fusion-based, metal 3D printing—reducing the structural anisotropy of the printed materials. Fusion-based 3D printing constructs 3D metal components through layer-by-layer additive manufacturing using a laser or other high-energy beams, which favors vertical epitaxial growth of coarse metal grains, referred to as columnar grains. The columnar grain structure leads to structural anisotropy and reduces the mechanical strength of the printed metals or alloys. Qian and his co-workers considered that interrupting the epitaxial growth could be the key to strengthening the printed metals. Their expertise in solidification processing led to the solution of ultrasound treatment, a method used in metal welding and casting to obtain metals with refined and randomly oriented metal grains.

Qian's group demonstrated that ultrasound treatment significantly changed the microstructure of 3D printed Ti-6Al-4V alloy. The researchers deposited the alloy onto a vibrating (frequency: 20 kHz) ultrasonic stage. Although the mechanism was not entirely clear, the researchers believe that the ultrasound produced tiny air bubbles in the molten metal during printing. Subsequently, these bubbles exploded and emitted intense and localized shock waves that impeded the growth and parallel alignment of grains, leading to fine grains aligned equally in all directions.

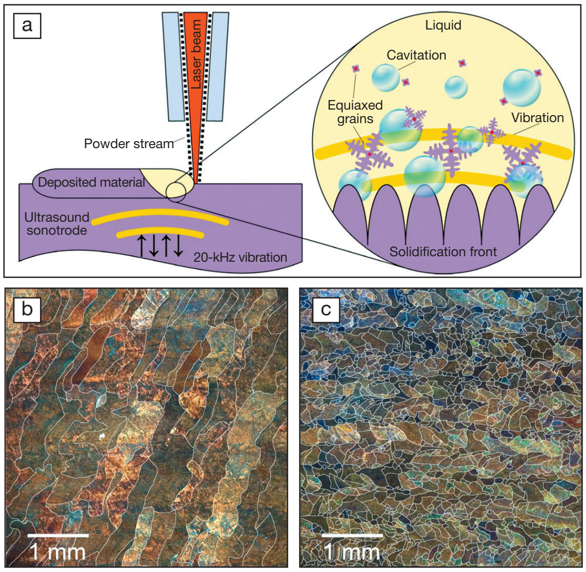
The mechanical properties of Ti-6Al-4V printed with ultrasound were appreciably improved over those of the conventionally 3D printed counterpart. Tensile tests revealed that tensile strength and yield stress both increased by 12% compared to the same alloy printed without ultrasound, reaching 1137 ± 4 MPa and 1094 ± 18 MPa, respectively. The break of grain-orientation anisotropy and reduction of the grain size both strengthened the printed alloy.

The technique could be adapted to other metal alloys (e.g., Ni-based superalloy Inconel 625) and to constructing advanced structures, such as structurally gradient alloys.

Ottman Tertuliano of Stanford University, whose research involves nanoparticle-enabled metal 3D printing, says, "Manipulating microstructure within a complex architecture is the holy grail of metal additive manufacturing....The fundamental scientific impact of the study lies in promoting nucleation during solidification via a possible metal-independent activation of cavitation within the melt. The broad scientific merit is in modulating ultrasound to enable site-specific microstructural control in a manner unachievable by traditional metal processing." Tertuliano was not involved in this study.

Qian says, "We hope the idea demonstrated in this article could eventually become a commercially useful process for 3D printing of small metal parts. For this purpose, we have just completed the design of a much more powerful ultrasonic system and will test the system under different printing conditions."

Tianyu Liu



(a) Scheme of the ultrasound-assisted 3D metal printing setup. (b and c) Polarized light microscope images showing the microstructures of Ti-6Al-4V printed (b) without and (c) with ultrasound. Credit: *Nature Communications*.