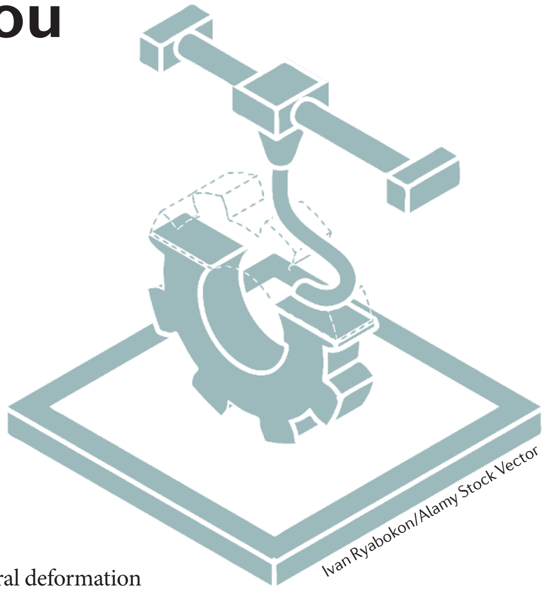
Nature Reviews Materials | Published online 28 Nov 2017; doi:10.1038/natrevmats.2017.81

3D PRINTING

May the strength be with you



Many metals and alloys become stiffer as they become stronger, a phenomenon known as strength–ductility trade-off. But stainless steels with an exceptional combination of strength and ductility can be manufactured using 3D printing, as Morris Wang and colleagues report in *Nature Materials*.

Because of its resistance to corrosion and oxidation, austenitic stainless steel is used in numerous applications, ranging from kitchen tools to nuclear power plants. However, this material has low yield strength, that is, it starts deforming irreversibly when relatively small forces are applied. Strengthening the material comes at the expense of a lower tensile ductility, leading to rupture at smaller elongations, or it requires treatments that cannot be easily applied to components with the degree of complexity needed for practical applications.

Additive manufacturing has a huge potential for building components with complex geometries in a cost-effective manner, but optimization is still needed to enable its widespread use for the production of high-performance materials. "A majority of materials made using this technology have very poor mechanical performance owing to porosity and residual stress issues," explains Wang. "Our group has engaged in studies of high-performance materials for nearly two decades, and now we succeeded in manufacturing a hierarchical microstructure in stainless steels, a type of 'extreme microstructure' that can lead to super strength and ductility."

The steels are produced with a technique in which a laser is used to melt the powdered metal, and the samples are printed from a computer-aided design file. The layer-by-layer deposition allows for the precise tailoring of the microstructure, so that extreme non-equilibrium structures can be obtained. A combination of theory and experiments enabled the optimization of the laser parameters for the production of high-quality samples with very low porosity, a yield strength up to three times that of conventional stainless steels, a larger tensile elongation to failure and uniform tensile elongation. "It is an exciting discovery that additive manufacturing can produce materials that are substantially better than those manufactured by conventional methods, such as casting and forging," remarks Wang.

The investigation of the structure–property relationship of the 3D-printed steels revealed that they exhibit multiple length scales, spanning nanometres to sub-millimetres, and chemical heterogeneity. Moreover, a large fraction of low-angle grain boundaries, a broad grain size distribution and unusual grain shapes are observed, accompanied by cellular structures that are commonly found in alloys grown using this type of additive manufacturing. Several deformation mechanisms acting at different strains provide a progressive work-hardening mechanism. These heterogeneous microstructures are determinant for the strength, ductility and hardening of the material.

"Our next step would be to apply our strategy to other metals and alloys," says Wang. "There are well over 5000 different types of alloys that currently cannot be 3D printed, let alone achieve a good performance." Another direction the group is interested in is the investigation of the corrosion resistance of the 3D-printed stainless steels.

Giulia Pacchioni

> "It is an exciting discovery that additive manufacturing can produce materials that are substantially better than those manufactured by conventional methods"

ORIGINAL ARTICLE Wang, Y. M. *et al.* Additively manufactured hierarchical stainless steels with high strength and ductility. *Nat. Mater.* http://dx.doi.org/10.1038/nmat5021 (2017)