Medical/Healthcare materials, High-temperature materials

Anisotropic control of shape and material properties via metal 3D printing ~ A new axis in the creation of high performance metallic devices ~

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Abstract

By utilizing a metal 3D printer, Nakano Laboratory has succeeded in controlling the material properties of metallic materials, especially the crystallographic texture (direction and degree of atomic arrangement), in addition to the precise shape control, and has created many highly functional metallic materials. We have created and commercialized a novel titanium alloy spinal cage based on our original design concept for rapid induction of high-quality bone using a unidirectional micro-groove structure on the cellular order, which can only be realized by utilizing a metal 3D printer. Furthermore, we have achieved high functionality through material control in a wide range of materials, from structural materials such as titanium-, nickel-, and iron-based alloys, to cutting-edge metallic materials, such as high-entropy alloys.

Background & Results

From our research to date, we have realized that it is indispensable for the creation of ultra-high functional materials to express high-functional properties specifically in the required direction by imparting anisotropy. Based on the perspective on anisotropy, our laboratory is promoting the creation of "Materials Science of Anisotropy" to develop materials expressing ultimate high-functional properties and elucidate the mechanism underlining the expression of anisotropy. We recently realized that metal 3D printer is a technology that is extremely well matched to "anisotropy".

The precise shape control capability of 3D printers has made it possible to control the metal surface morphology at the cellular order. The formation of unidirectional micro-groove structures facilitated the alignment of osteoblasts and successfully induced highly oriented and highly strengthened bone (Figure 1). This specific structure has been mounted on a spinal cage, and a nationwide large-scale clinical trial has started in September 2022, already contributing to improving the health and quality of life of many patients.

On the other hand, the precise tuning of solidification behavior in a fine melt pool has enabled extensive control of crystallographic orientation (Figure 2). Single crystal exhibits anisotropy in mechanical functions such as Young's modulus, and the choice of crystallographic orientation allows the selection of varied properties according to the application, even though they are the single material. In addition, laser scanning with a small periodicity realizes a micro-lamellar structure consisting of two layers with different crystallographic orientations and creates resistance to slip deformation at the layer interface, resulting in a significant strengthening.

Thus, the control of anisotropy on the sub-mm and atomic order achieved by metal 3D printers gives metallic materials new high functionality. We will continue to promote research on anisotropy control by metal 3D printers as a priority issue of our laboratory.

Significance of the research and Future perspective

The control of "anisotropic shape and material" by 3D printer, which is made possible by our laboratory, is a 180-degree turnaround in the utilization of 3D printers, which have been focused only on the functionalization based on shape characteristics. The creation of a design strategy based on shape and material anisotropy, which is made possible by 3D printers for the first time, is expected not only to dramatically improve product performance, but also to revolutionize product design guidelines.

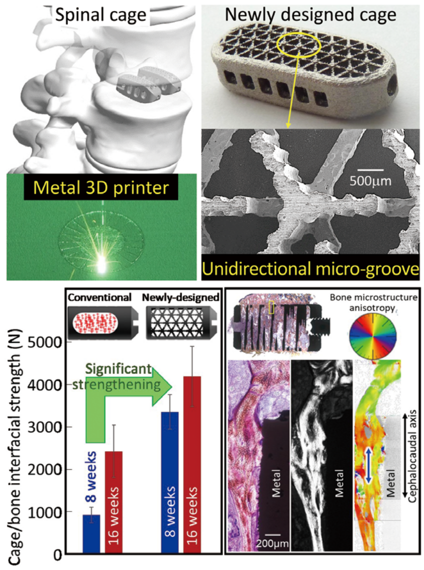

Figure 1. Titanium alloy spinal cage with a micro-groove structure based on the precise shape control capability of a metal 3D printer. The micro-groove structure induces mechanically integrated high quality bone, resulting in a significant increase in strength at the initial implantation period compared to conventional cages.

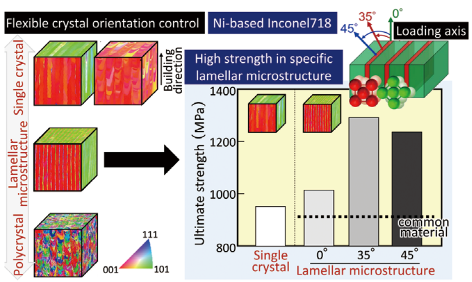

Figure 2. Flexible control of crystallographic texture achieved via metal 3D printer, and unusual strengthening by forming a specific lamellar structure (example of Inconel 718). Further strengthening is achieved by changing the resistance to slip deformation at the layer interface by changing the loading axis.

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