Title of Project : Crystal growth under conditions over 1M K/s, 10M K/m, 1 m/s

KOIZUMI Yuichiro
(Osaka University, Graduate School of Engineering, Professor)

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【Purpose and Background of the Research】

Additive manufacturing (AM) technologies, also known as 3D printers (3DP), have been put to practical use. 3DP is generally characterized by the ability to manufacture arbitrary-shaped parts directly from CAD data. However, powder-bed fusion (PBF) type 3DP, in which metal powders are fused to form parts with lasers, has also been found to be able to control the internal microstructure of metal parts and improve the material properties. Single-crystal-like material with strong crystal orientation texture have been obtained, and polycrystalline material with low crystal orientation have been obtained by changing the process conditions. However, the reasons for them have not been clarified yet. The key to understanding them is its unique solidification conditions in PBF type 3DP, represented by the cooling rate of 1 M K/s, the temperature gradient (G) of 10 M K/m, and the growth rate (R) of 1 m/s. Crystal grain microstructure significantly different from those obtained by conventional solidification process are expected be obtained under conditions above these levels, which may greatly improve the properties of materials.

In this study, we will elucidate the characteristic crystal growth behavior in PBF-type 3DP by using digital twin science, a research method to reveal phenomena that cannot be measured directly by using computer simulations that are matched with experimental observation data and will explore the world of solidification crystal growth under conditions beyond the range of the conventional solidification map, i.e., the diagram showing the relationship between G, R and material structure. The purpose of this research is to establish a theory for developing metal 3DP as a method for controlling material properties.

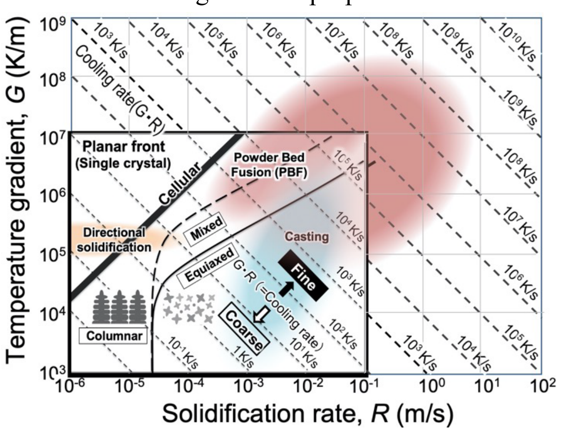

Figure 1. Solidification map showing the range of solidification condition in PBF-type additive manufacturing process.

【Research Methods】

Various metals with different physical properties and crystal structures are irradiated with electron beams or lasers for 3DP, and solidification microstructures are observed. Computer simulations that match with the observations are conducted to elucidate the crystal growth behavior. Besides G and R, flow velocity U and solidification direction Φ are evaluated. The law behind the relationship between the physical property and directional growth and grain refining will be explored to elucidate the key factors for obtaining single crystals and fine grains by PBF-AM.

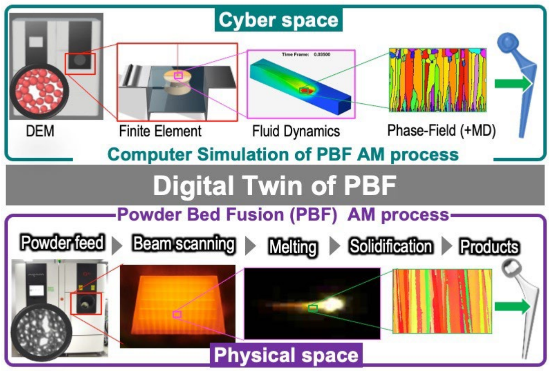

Figure 2. Digital twin (Cyber-Physical System) of PBF AM process

【Expected Research Achievements and Scientific Significance】

Novel knowledge of crystal growth will be obtained for solidification conditions which are quite different from those for conventional solidification processes. Furthermore, it is expected to become possible to fabricate single crystals and fine grains site specifically. It will realize multi-functional parts and the development of new materials which contribute to the sustainable development of society.

【Publications Relevant to the Project】

・ Y. Miyata, M. Okugawa, Y. Koizumi, T. Nakano: "Inverse Columnar-Equiaxed Transition (CET) in 304 and 316L Stainless Steels Melt by Electron Beam for Additive Manufacturing (AM)", Crystals 11 (2021), 856.
・ Y. Koizumi: "Chapter 3. Selective Electron Beam Melting" in Multi-dimensional Additive Manufacturing, edited by S. Kirihara and K. Nakata, (2020), Springer.

【Homepage Address and Other Contact Information】

http://www.mat.eng.osaka-u.ac.jp/msp3/
ykoizumi@mat.eng.osaka-u.ac.jp