Aerospace industry, Automobile industry, Smart society

Prediction of solute element segregations in additive manufactured nickel-based superalloy

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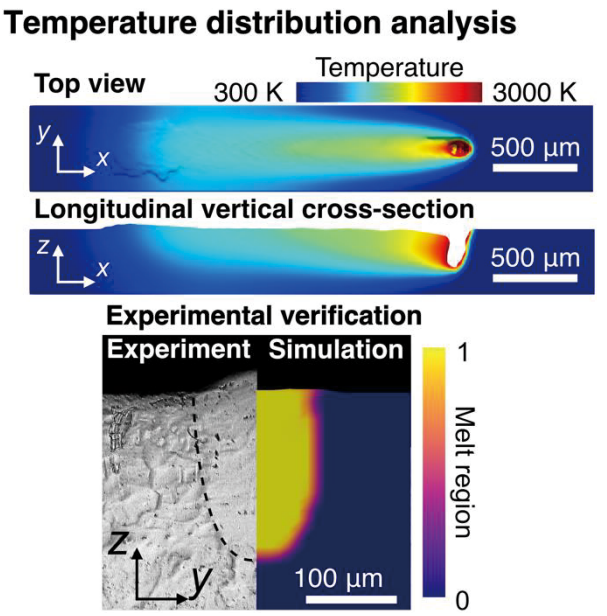
Abstract

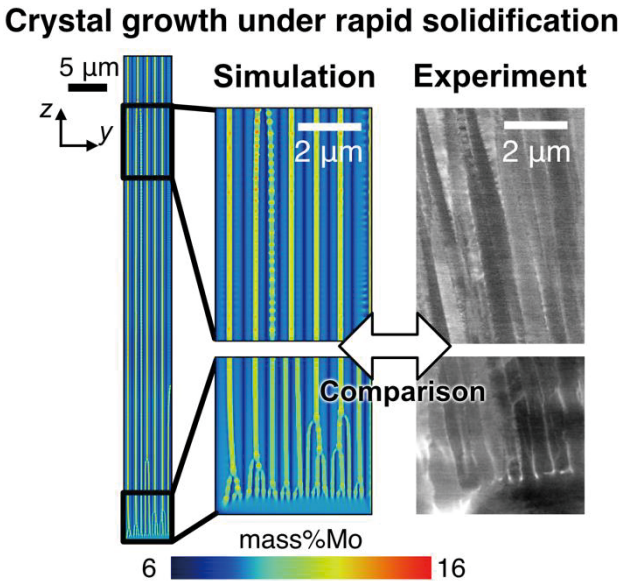
In powder-bed fusion (PBF) type additive manufacturing of Ni-based superalloys, the segregation in element distribution significantly affects the mechanical properties and is an important issue in reliable material design. In this study, we combined temperature field analysis by computational thermo-fluid dynamics simulation and element distribution prediction by phase field method to predict the local element distribution segregation formed during solidification under high cooling rate conditions of up to 10^8 K s^{-1} unique to PBF of Ni-based superalloys. Furthermore, we proposed a new alloy design guideline to suppress cracks by evaluating the effect of the predicted element distribution on the susceptibility to cracking.

Background & Results

Ni-based superalloys are widely used as gas turbine components for power generation and aircraft jet engines because they have high heat resistance and excellent environmental resistance. Recently, there has been extensive research into using the PBF-type AM technique to further increase the usable temperature of Ni-based superalloys. However, there is an issue concerning solute segregation: the solidification occurs under the rapid cooling conditions up to 108 K s-1 in the LPBF process. It causes strong solute segregation, and the segregated regions are suggested to be related to the hot cracks in LPBF-fabricated parts. Therefore, an understanding of solute segregation is essential for the fabrication of reliable LPBF-fabricated parts while avoiding cracks.

In this study, we performed the phase field simulations coupled with the computational thermo-fluid dynamics simulation to predict the solute-element segregation during the PBF process. The predicted microstructures reproduced the cell structures observed in the experiment. Furthermore, we found the solute-element distribution is highly dependent on the microstructure formation mechanism, and we proposed a novel guideline for the suppression of the cracking based on the cracking susceptibility evaluation of each segregated region.





Significance of the research and Future perspective

The established method can be used to systematically evaluate the relationship between alloy composition and crack susceptibility, which can lead to the prediction of deformation and fracture of components. Furthermore, it enables us to design novel alloys for the PBF process that significantly reduce the probability of cracks that are the starting point of component fracture, thereby reducing the need for trial and error in experiments and making it possible to search for optimal alloy compositions within a simulation space. In addition, it is suggested that the element distribution prediction method will impact a wide range of fields, including aerospace, automobiles, and energy. Furthermore, it is expected to contribute to the accelerated development of novel Ni-based superalloys optimized for the PBF process by combining prediction and data science methods.

Patent

Treatise
Okugawa, Masayuki et al. Solute segregation in a rapidly solidified Hastelloy-X Ni-based superalloy during laser powder bed fusion investigated by phase-field and computational thermal-fluid dynamics simulations. Addit. Manuf. 2024, 84, 104079. doi: 10.1016/j.addma.2024.104079
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URL https://rd.iai.osaka-u.ac.jp/en/855871fe68b292d8.html

Keyword nickel-based superalloy, additive manufacturing, solute element segregation, computational thermal-fluid dynamics simulation, phase-field method