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In Situ Laue Diffraction Study on Forming Mechanism of Additively Manufacturing Nickel-Based Single-Crystal Superalloy

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Directly printing nickel-based single-crystal (SX) superalloy blades with intricate heat dissipation structures using additive manufacturing is a crucial technology for enhancing turbine front temperatures and reducing production costs [1]. However, this process presents significant challenges. During printing, a focused laser beam rapidly melts the substrate and powders, creating an extreme non-equilibrium metallurgical environment affected by multiple physical fields. Consequently, maintaining the perfection of SX structures becomes challenging. Common issues such as stray grains (SGs) [2] and crystal rotation [3] hinder the additive manufacturing of single crystals.
To address these challenges, we developed an in situ experimental setup for additive manufacturing of SX materials based on the Beijing Synchrotron Radiation Facility 3W1 beamline. Our current primary focus was investigating the internal microstructure evolution mechanism of nickel-based SX superalloy during single-layer laser melting and laser powder bed fusion processes [4]. By employing in situ synchrotron radiation Laue diffraction, we captured transient crystal rotation behavior and the formation process of SGs. Additionally, we conducted thermomechanical coupled finite element simulations and molecular dynamics simulations to further understand the underlying mechanisms.
Our findings reveal that the deformation gradient resulting from localized heating/cooling heterogeneity plays a critical role in crystal rotation, while sub-grain rotation induced by rapid dislocation movement and complex stress fields may be the main mechanism for SGs formation at the bottom of the melt pool. Furthermore, we investigated the influence of substrate orientation on crystal rotation and SGs formation mechanisms during multiple-layer deposition via in situ Laue diffraction.
An in-depth understanding of crystal rotation and SGs formation mechanisms is instrumental in optimizing additive manufacturing approaches to achieve products with SX texture.

Figure 1 (a) Picture of the in situ Laue diffraction system during additive manufacturing process. (b) Time series of the representative Laue diffraction patterns during laser melting processes.

References:
[1] Journal of Laser Applications, 2014, 27(S1): S17004
[2] Acta Materialia, 2021, 205: 116558
[3] Scientific Reports, 2021, 11(1)
[4] Nature Communications, 2023, 14(1): 2961.

I plan to submit also conference proceedings

No

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