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Guest Editorial

Special Section on Probabilistic Digital Twins in Additive Manufacturing

Additive manufacturing (AM) has made enormous progress over the past decade, as it is capable of producing complex parts with significantly fewer fabrication constraints compared with existing manufacturing technologies over a broad dimensional scale. AM's innate manufacturing flexibility has a significant impact on time and cost savings, as well as inventory, supply chain management, assembly, and maintenance for demanding engineering applications. Complicated AM process variability is one of the greatest obstacles in performance evaluation, quality control, and certification of additively manufactured materials and products, and thus hinders the widespread implementation of AM techniques. Digital twin, as a digital replica of a production system or an active unique product characterized by certain properties or conditions, has great potentials in overcoming the quality variability and reliability issues in AM processes. With the development of probabilistic digital twins in AM and uncertainty management techniques, it becomes possible to realize robust and reliable AM process by optimizing process parameters, detecting, and monitoring process faults, reducing the computational burden for multiscale modeling, and dealing with the large volume of in situ sensor data. This special issue is dedicated to recent advances in the field of digital twins and uncertainty management with application in additive manufacturing.

We would like to express our sincere gratitude to Professor Michael Beer and the editorial board for their support. There are five full research papers in this special issue to highlight recent advances in uncertainty quantification, surrogate modeling, reliability-based design under uncertainty, and system fault diagnosis, and their applications in additive manufacturing. To quantify the uncertainty of the process–property–structure linkage for fused filament fabrication (FFF) parts, Moon et al. proposed a data-driven physics-based methodology to predict the mechanical properties of FFF parts using Bayesian inference. The geometry and variance in process parameters are considered to quantify uncertainties in the mechanical properties of FFF parts. By sampling the posterior distribution using the Hamilton Monte Carlo method, the proposed methodology can provide more accurate predictions of the mechanical properties by considering the influence of geometry, process parameters, and uncertainty in the AM process. In AM process, it remains challenging to deal with high-dimensional image input data to quantify the epistemic uncertainty of surrogate models. To overcome this limitation, Du et al. developed a new uncertainty quantification methodology based on the new concept of combining convolutional neural network and Gaussian process regression. This ensures that the surrogate model considers both input-related aleatory uncertainty and model-related epistemic uncertainty when used for prediction, enhancing confidence in image-based AM simulations and informed decision-making. With the advanced additive manufacturing techniques (three-dimensional holographic lithography), researchers have demonstrated that silicon anode can be fabricated as three-dimensional bicontinuous porous microstructures. However, the uncertainties are inherent in the AM process, making it crucial to systematically consider them in the silicon anode design to improve the battery's performance and reliability. Wang et al. developed a digital twin to investigate the optimal design for silicon anode under the uncertainties of additive manufacturing and battery usage. By developing multiphysics finite element models of the silicon anode lithiation process, surrogate models were built to reduce computational costs, and the reliability-based design optimization was employed to find the best design point for the silicon anode. Finally, the Pareto optimal front of the silicon anode designs was obtained and validated, showing over 10% improvements in the silicon anode's total capacity and rate capability. To further explore the potential of digital twins for Industry 5.0, Atil Emre reviewed the critical technologies in digital twins to overcome the issues raised by Industry 4.0. To construct the digital twins for fault diagnosis of mechanical transmission systems, Qiu et al. proposed a hierarchical fault diagnosis method for machinery systems. The proposed hierarchical fault diagnosis approach has achieved a good performance both in classification of the faults in the fault library and identification of the faults outside the fault library.

We hope everyone enjoys reading these papers and that they stimulate further advances in the field of digital twins in additive manufacturing. We extend our sincere gratitude to all the authors who responded to our call for papers and contributed outstanding research articles. Additionally, we would like to thank all the reviewers for their time and effort in reviewing the submissions.

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