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Editorial

Additive Manufacturing: Experiments, Simulations, and Data-Driven Modelling

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1. Introduction

Additive manufacturing (AM) has profoundly impacted modern engineering and materials science by enabling unparalleled control over microstructures, customization, and material properties [1]. Over the past decade, significant strides have been made in AM technologies, allowing for the fabrication of complex geometries and the integration of advanced materials [2,3]. This editorial provides an overview of recent developments in the field, identifies existing knowledge gaps, and highlights how the studies in this Special Issue address these challenges. We also explore potential avenues for future research that could further enhance the capabilities and applications of AM.

2. Overview of the Contributions

The studies featured in this Special Issue showcase various aspects of AM, including laser additive manufacturing, electrodeposition, and fused filament fabrication, highlighting innovations that enhance material properties, microstructural control, and overall performance. For instance, titanium alloys are crucial in aerospace and biomedical applications due to their high strength-to-weight ratio and excellent corrosion resistance [4]. However, AM of titanium alloys presents challenges, particularly related to grain size and deformation resistance. The researchers in contribution 1 explored the high-temperature flow behavior of titanium alloys and developed predictive models to optimize deformation processes. This research provides essential insights into overcoming the difficulties associated with online rolling processes during AM, contributing to more efficient manufacturing of titanium components. In the realm of wear-resistant materials, another study addresses the need for improved wear resistance in Ni-based composite coatings—contribution 2.

By co-electrodepositing diamond particles into the Ni-matrix, significant enhancements in wear properties were achieved, further validated through simulation studies. The integration of diamond particles led to refined microstructures and increased hardness, demonstrating the potential for durable coatings in demanding applications. Furthermore, surface roughness has been a persistent issue in fused filament fabrication (FFF) 3D printing, limiting its broader adoption. A study introduces laser polishing as an effective technique to significantly reduce surface roughness and improve the mechanical properties of PLA components in contribution 3. This advancement not only addresses a long-standing challenge in FFF but also opens the door to broader applications of 3D-printed plastics with improved surface quality.

Sustainability is another critical area of focus in AM [5]. The exploration of sustainable materials for AM is crucial to reducing environmental impact. The authors in contribution 4 investigate the use of clay in 3D printing for architectural and construction applications. The research highlights the recyclability and adaptability of clay, making it a promising material for eco-friendly construction processes. This work underscores the importance of developing sustainable AM practices that align with circular economy principles. Nanomaterials are also playing an increasingly important role in AM [6]. The integration of these materials in 3D printing can significantly enhance mechanical and thermal properties [7]. In contribution 5, the authors examine the dispersion of graphene oxide in nanocomposites and its impact on 3D-printed parts. The research identifies the optimal dispersion conditions that enhance tensile and compression strength, offering valuable insights for producing high-performance nanocomposite materials. Understanding grain-growth mechanisms is critical for controlling the microstructure and properties of materials during a manufacturing process [8]. One study uses phase-field models to simulate the effects of second-phase particles on grain growth in magnesium alloys (contribution 6). The results provide a theoretical foundation for optimizing annealing treatments and improving the mechanical properties of Mg alloys, widely used in lightweight structural applications. In the area of high-temperature materials, the AM of molybdenum presents significant challenges due to its high melting point and thermal conductivity. The authors in contribution 7 explore the addition of nano-sized SiC particles to molybdenum powder, resulting in significant improvements in density and mechanical properties during laser powder bed fusion. This research demonstrates the potential of nano-particle additions to enhance the AM of refractory metals, which are critical in high-temperature applications. Thermal management during AM is crucial for ensuring component quality [9,10]. A study presents a semi-analytical model for describing laser–ceramic interactions in AM (contribution 8). The model is validated against experimental results, providing a useful tool for predicting thermal distributions during ceramic processing. This work contributes to the precise control of thermal effects in ceramic AM, essential for achieving high-quality components.

This Special Issue also discusses the cooling strategies during friction stir processing (FSP), which is another critical area of research (contribution 9). A comprehensive review of various cooling methods during FSP highlights the effectiveness of different techniques and their impact on material properties. The study provides guidelines for optimizing FSP to achieve the desired microstructural outcomes, vital for enhancing material performance in critical applications. Despite these advancements, several knowledge gaps remain. For instance, the integration of multiple AM techniques to combine the benefits of different processes is still underexplored. Additionally, while significant progress has been made in optimizing material properties through AM, more research is needed on the long-term durability and performance of AM components, particularly in harsh environments. Another gap lies in the scalability of AM processes. While many studies demonstrate promising results at the laboratory scale, translating these findings to industrial-scale production remains a challenge. Furthermore, the environmental impact of AM processes, particularly regarding energy consumption and waste generation, requires further investigation to develop genuinely sustainable manufacturing practices.

3. Future Work

Future research should focus on several key areas to address these gaps. First, the development of multi-material AM techniques could lead to the production of components with tailored properties for specific applications, enabling the fabrication of complex, multi-functional parts that are not feasible with traditional manufacturing methods. Advanced simulation and modeling tools that accurately predict material behavior during manufacturing are also crucial as AM processes become more sophisticated. These tools should include modeling thermal effects, phase transformations, and stress distributions to ensure the reliability and performance of AM components. Scalability and industrial implementation are also critical areas for future research. Efforts should focus on scaling up AM processes while maintaining precision and quality, developing faster, more efficient AM techniques that meet industrial production demands while reducing costs and minimizing environmental impact. Sustainability in AM is another essential focus area. Future research should explore developing sustainable materials and processes for AM, including the use of recycled materials, energy-efficient technologies, and strategies for reducing waste. Finally, long-term studies on the durability and performance of AM components are essential for their adoption in critical applications, such as aerospace and medical devices. Such a research plan should include fatigue testing, corrosion resistance, and the effects of environmental exposure on material properties.

4. Concluding Remarks

The studies presented in this Special Issue contribute valuable insights into the evolving field of AM and material processing. These works lay the foundation for future advancements in the field by addressing current challenges and exploring innovative solutions. Continued research in multi-material AM, advanced simulation, scalability, sustainability, and long-term performance will be crucial in realizing the full potential of AM, driving the next wave of industrial innovation.

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