

Additive Manufacturing of Metallic Materials: Experiments and Modeling

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1. Introduction and Scope

Metal additive manufacturing has transformed the production of complex metallic components by enabling greater design flexibility, material efficiency, and customized fabrication. Advances in technologies such as laser powder bed fusion (LPBF), directed energy deposition (DED), wire arc additive manufacturing (WAAM), and electron beam melting (EBM) have expanded their applications across aerospace, automotive, biomedical, energy, and other high-value industries. Despite these advances, challenges related to process optimization, microstructure control, defect mitigation, mechanical performance, and qualification remain active research areas.

The scope of this Special Issue includes the following:

- Metal additive manufacturing processes (e.g., LPBF, DED, WAAM, EBM);
- Process optimization and parameter development;
- Microstructure evolution and materials characterization;
- Mechanical behavior, fatigue, wear, and corrosion;
- Defect formation, residual stresses, and distortion;
- Numerical modeling, simulation, and digital twins;
- In situ monitoring, sensing, and quality assurance;
- Artificial intelligence and data-driven approaches;
- Post-processing and heat treatment;
- Industrial applications and emerging trends in metallic additive manufacturing.

2. Contributions

This Special Issue presents a diverse collection of research and review articles that advance the field of metallic additive manufacturing through innovations in process optimization, computational modeling, machine learning, materials development, and performance evaluation. Together, these contributions highlight the multidisciplinary nature of additive manufacturing and demonstrate how experimental and numerical approaches can accelerate the development of reliable and high-performance metallic components.

Yu Li et al. investigated the effect of an electrostatic field on the direct laser deposition of Ti–Al–Si coatings using experiments and multiphysics modeling. Their results demonstrated enhanced microstructure refinement, hardness, and wear resistance, highlighting the potential of electrostatically assisted DLD for improving coating performance [Contribution 1].

Saurabh Tiwari et al. developed a physics-informed neural network (PINN) framework for process optimization in laser powder bed fusion (LPBF) of Inconel 718. By integrating physical laws with machine learning, their approach achieved accurate, data-efficient



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prediction of melt pool characteristics and part quality, providing a robust framework for accelerated process qualification and optimization [Contribution 2].

Florian Funcke et al. investigated the use of transfer learning to transfer process knowledge between different laser powder bed fusion (LPBF) machines. Their approach enabled accurate prediction of the mechanical properties of AlSi10Mg using limited training data, providing a time- and resource-efficient strategy for rapid machine calibration and process optimization [Contribution 3].

Moheb Ali Ghayour et al. proposed a systematic methodology for selecting shielding gas compositions in gas metal arc directed energy deposition (GMA-DED) of high-strength low-alloy steels. Their work establishes a practical framework for improving geometrical accuracy and process consistency [Contribution 4].

Moheb Ali Ghayour et al. proposed a systematic methodology for selecting shielding gas compositions in gas metal arc directed energy deposition (GMA-DED) of high-strength low-alloy steels. Their work established a reproducible decision-making framework that balances geometric quality and process efficiency, providing a practical alternative to trial-and-error gas selection [Contribution 4].

Arif Balci and Fatih Alibeyoglu investigated the effects of process parameters on melt-track stability and inter-track fusion in powder-bed arc additive manufacturing of 316L stainless steel. Their work identified optimal processing conditions for improving track continuity, fusion quality, and process stability, providing practical guidelines for efficient PBAAM fabrication [Contribution 5].

Alexander I. Khaimovich et al. proposed a multi-criteria optimization framework for laser powder bed fusion (LPBF) process parameters based on a reward function derived from the Taguchi quality loss function. Their approach improved productivity while reducing process variability and maintaining high mechanical performance, providing a robust strategy for LPBF process optimization [Contribution 6].

Rabiul Islam et al. investigated the combined effects of strut geometry and linear energy density on the tensile properties of laser powder bed fusion (LPBF)-fabricated Ti-6Al-4V thin struts. Their findings identified laser energy density as the dominant factor influencing porosity and mechanical performance, providing valuable insights for the design of lightweight lattice structures [Contribution 7].

Atiqur Rahman et al. developed a physics-informed machine learning framework to predict the mechanical properties of directed energy deposition (DED)-processed low-alloy steels. By integrating simulation-derived features with data-driven models, their approach enabled accurate and interpretable prediction of tensile strength, yield strength, and hardness [Contribution 8].

Muhammad Hussain et al. investigated the fabrication of WC–Cu composite coatings on mild steel using plasma transferred arc welding. Their study demonstrated the potential of this approach to produce functionally graded coatings with refined microstructures for enhanced wear resistance and heat dissipation in demanding engineering applications [Contribution 9].

Nicole Atmadja and Mamidala Ramulu reviewed fatigue crack growth models for electron beam melted Ti-6Al-4V, evaluating current analytical and numerical approaches and highlighting the challenges of predicting fatigue behavior in additively manufactured components with process-induced defects and anisotropic microstructures [Contribution 10].

Mohammad Sayem Bin Abdullah and Mamidala Ramulu reviewed the tribological behavior of electron beam powder bed fused Ti-6Al-4V, summarizing the effects of processing, post-processing, and operating conditions on friction, wear mechanisms,

and wear resistance, while identifying current challenges and future research directions [Contribution 11].

Together, these contributions demonstrate the rapid evolution of metallic additive manufacturing, spanning process innovation, computational intelligence, materials characterization, and performance evaluation. Collectively, they highlight the growing integration of experimental investigations and advanced modeling techniques in addressing current challenges and enabling broader industrial adoption of metal additive manufacturing technologies.

3. Conclusions and Outlook

This Special Issue provides a comprehensive overview of recent advances in the additive manufacturing of metallic materials, highlighting progress in process optimization, computational modeling, machine learning, materials characterization, and performance evaluation. The published papers demonstrate how the integration of experimental investigations with data-driven and physics-based approaches can improve process reliability, material performance, and manufacturing efficiency. The inclusion of both original research and review articles offers a broad perspective on current developments and emerging challenges in metallic additive manufacturing.

Looking ahead, future research is expected to increasingly integrate artificial intelligence, physics-informed machine learning, digital twins, and multiscale simulations with experimental studies to enable intelligent process control and accelerated process optimization. In situ monitoring, real-time quality assurance, and transferable process knowledge across different manufacturing platforms will be essential for improving reproducibility and industrial scalability. Furthermore, continued research on novel materials, advanced process design, defect mitigation, and structure–property relationships will contribute to expanding the application of metal additive manufacturing in aerospace, biomedical, automotive, energy, and other high-value industries.

In conclusion, metallic additive manufacturing continues to evolve rapidly as a multidisciplinary research field that combines materials science, manufacturing engineering, computational modeling, and artificial intelligence. This Special Issue highlights recent achievements while identifying promising directions for future research, contributing to the continued advancement and broader industrial adoption of additive manufacturing technologies.

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Conflicts of Interest: The authors declare no conflicts of interest.

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