MANAGEMENT AND PRODUCTION ENGINEERING

Ammin/DIGEP/CIM 4.0 - Additive Manufacturing of Multi Materials: Processability, Production and Performance Analysis

Funded By	Dipartimento DIGEP Competence Industry Manufacturing 4.0 S.C. A R.L. [P.iva/CF:12039730010] Politecnico di TORINO [P.iva/CF:00518460019]

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Context of the research activity	The future of manufacturing technologies is increasingly shaped by Additive Manufacturing (AM) advancements, offering unparalleled opportunities for complex designs, enhanced functionality, and optimized material usage. However, a significant challenge to the widespread adoption of AM in high-performance industrial sectors is the limited understanding of Functionally Graded Materials (FGMs)—materials engineered with gradual variations in composition or structure, enabling customized properties within a single part. This research tackles key challenges related to production efficiency, quality management, and material sustainability—all fundamental aspects of modern industrial manufacturing systems. By investigating the processability of FGMs via AM technologies, this study aims to optimize production strategies, enhance process control, and improve material performance in manufacturing workflows. Furthermore, integrating FGMs in AM represents a significant step toward sustainable and efficient production, reducing material waste while enabling functional optimization in aerospace, biomedical, and automotive engineering sectors. The insights gained will contribute to the development of innovative manufacturing solutions, reinforcing the PhD program's mission to advance scientific knowledge and industrial innovation in production engineering. By bridging the knowledge gap in FGM processability, this research will support the evolution of digital and intelligent manufacturing systems, fostering the next generation of smart production technologies.

	Complex shape industrial components inspired by natural materials, such as bone, are engineered with gradual variations in structure or composition, providing site-specific mechanical and functional properties while eliminating weak points associated with abrupt interfaces in conventional multi-material structures. Widely utilized in high-performance industries such as aerospace, energy, and biomedical engineering, Functionally Graded Materials (FGMs),

Objectives	their processability and production align directly with the PhD program in Management and Production Engineering by supporting reliability, sustainability, and process optimization—key drivers of industrial innovation. Additive Manufacturing (AM) offers an efficient and sustainable approach to producing FGMs, allowing for precise gradient control and minimizing material waste. This research will be conducted within the Interdepartmental Center of Integrated Additive Manufacturing (IAM@PoliTo) and aims to advance the practical implementation and scientific understanding of FGMs in AM through the following key objectives: Survey Current Applications: Analyze existing FGM components produced via metal AM, identifying advantages and limitations of current techniques, particularly in high-performance sectors such as aerospace, biomedical, and energy. Investigate Processability Challenges: Identify critical challenges and process parameters affecting the manufacturability of FGMs, focusing on powder bed fusion (PBF) and directed energy deposition (DED)—two promising techniques for complex metal-based FGMs. Develop Technological Solutions: Propose and test technological and material innovations to overcome processability limitations, enabling the production of robust, high-performance FGM components with optimized mechanical and thermophysical properties. Optimize Process Parameters: Utilize a Design of Experiments (DoE) approach to establish the optimal process parameters for various FGM compositions, improving surface quality, mechanical strength, thermophysical properties and minimizing residual stresses. Characterize FGM Specimens: Conduct comprehensive material characterization of FGM samples produced under different processing conditions, assessing mechanical, thermal, and structural properties and documenting the effects of compositional gradients on material performance. This research includes a six-month secondment at leading institutions such as NCAME at Auburn University (USA) or the Marine Additive Manufacturing Centre at the University of New Brunswick (Canada), providing access to state-of-the-art AM facilities and fostering global collaboration in FGM research. By integrating advanced AM strategies for FGM production, this project strongly aligns with the PhD program's focus on production innovation, efficiency, and sustainability. The research aims to address key manufacturing challenges, enhance industrial adoption of AM-enabled FGMs, and expand their applications across high-tech sectors. Ultimately, this study contributes significantly to manufacturing systems engineering, reinforcing Politecnico di Torino's mission to drive technological advancements in production engineering.

Skills and	The following skills and competencies are essential for successfully conducting this research: Proficiency in Metal Additive Manufacturing: A strong understanding of metal AM processes, including Powder Bed Fusion (PBF) and Directed Energy Deposition (DED), is essential for investigating the processability of FGMs and optimizing manufacturing parameters. Expertise in Advanced Materials Processing and Characterization: In-depth knowledge of materials processing techniques and experience with materials characterization methods are highly desirable for analyzing FGM properties. Familiarity with Machine Learning and Python Programming: Skills in machine learning and proficiency in Python are advantageous, supporting the data-driven aspects of this research, including process optimization and predictive modeling of FGM properties.

Skills and competencies for the development of the activity	Laboratory & Problem-Solving Skills: Laboratory Skills and Problem-Solving Abilities. The candidate should demonstrate strong hands-on lab skills, possess excellent problem-solving abilities, and exhibit a high level of motivation for learning and conducting advanced research in manufacturing and materials engineering. Strong Analytical and Data Interpretation Skills: The ability to analyze complex data sets and interpret results is crucial for developing optimal process parameters, improving production efficiency, and enhancing FGM material properties. Organizational and Teamwork Skills: The candidate should be able to prioritize tasks effectively, work within a multicultural and multidisciplinary research team, manage project deadlines, and contribute to collaborative research efforts in academia and industry. Excellent Communication Skills: Strong written and verbal communication skills are necessary to document research findings, prepare technical reports and scientific publications, and effectively present data and insights to colleagues, collaborators, and industrial partners.