MANAGEMENT AND PRODUCTION ENGINEERING

DIGEP - Advanced additive manufacturing method for material properties control

Funded By	Dipartimento DIGEP

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Context of the research activity	The demand for ultra-performance components is intensifying, driven by the growing awareness that each component's lifecycle—from production to operation—impacts energy consumption. High-performance components aim to achieve multiple goals, including energy efficiency, enhanced performance, reduced emissions, minimized operating costs, and advancements in sustainability, innovation, and competitiveness. Consequently, scientific research into advanced manufacturing processes for these efficient components and structures is an increasingly dynamic and rapidly evolving field. Research priorities include developing composite materials, multifunctional components, nano- and micro-structured products, sustainable and biodegradable materials, and structures designed for energy conservation and management, as well as meta-structures. However, significant constraints still limit the full application of these advancements, particularly in the realms of production processes and quality control techniques. For instance, innovations such as reinforcing components within the same ply with varied fibre orientations can optimise material use, allowing components to withstand multiple load conditions with minimal fibre usage. Further potential lies in achieving localised control over additive manufacturing processes. Ideally, localised control strategies could enable differentiated process management not only along the build direction but also within each layer, opening the door to components with customisable, programmable properties. An example of this is demonstrated in a recent patent from the Polytechnic of Turin (WO2022259196A1), which introduces an advanced additive manufacturing approach for creating zones of differential density to control properties like fracture flow, fracture programming, and thermal or electrical conduction—achieved by tailoring the component's microarchitecture without altering its overall design.

Objectives	This PhD research aims to advance additive manufacturing techniques to produce ultra-performance components with programmable, differential properties, focusing on applications in composite and metallic materials. The project will investigate unconventional strategies for localised control within the additive manufacturing process, such as selective reinforcement deposition in composites and point-melting methods for metals. This research identifies key industrial applications in, e.g., aerospace, renewable energy storage and energy conversion where such advanced components can offer substantial benefits. The research includes methodologies to optimise and adapt production systems—both hardware and software—to support these novel advanced component processing strategies. The project's core objectives include: • Process Optimisation and Adaptation: Identify and refine manufacturing processes that can accommodate the new unconventional processing strategies, adapting the production system to achieve high precision and efficiency. • Predictive Numerical Strategies: Develop advanced numerical methods capable of predicting process behaviours under non-standard material processing techniques, validated through experimental trials. • Mechanical Characterisation and Quality Control: Conduct numerical-experimental characterisation of products with differentiated mechanical, thermal, or electrical properties, establishing new quality control methodologies that address the complexity of these advanced components and potentially surpass current computer tomography scanning limitations. • Accelerated Development Approaches: Develop approximate solutions for faster product development by integrating process physics, empirical data, and numerical results—potentially utilising hybrid models such as physics-informed neural networks. Ultimately, this research seeks to pioneer adaptable, efficient manufacturing pathways to create components with localised, programmable properties tailored to specific industrial needs. The outcomes are anticipated to contribute to sustainable, competitive, and highly efficient manufacturing practices, providing the industry with innovative tools to meet the growing demands for performance and sustainability.

Skills and competencies for the development of the activity	The candidate must have excellent knowledge of production systems, in particular regarding additive manufacturing processes. The candidate must possess knowledge of the technologies and methodologies intended for dimensional and surface characterisation (e.g. measuring machines, CT-scan) and mechanical characterisation (e.g. tensile tests). The candidate must have advanced knowledge of CAD modelling. Knowledge of numerical and statistical methods (such as finite element analysis, topological optimization) and related analysis software (e.g. Matlab and Inspire) is required.