MECHANICAL ENGINEERING

DIMEAS - Multi-physics meso-scale models for the analysis and design of variable stiffness composites

Funded By	Dipartimento DIMEAS

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Context of the research activity	Drawing inspiration from the LOUD project, which focuses on multi-scale continuous and non-local models for failure analysis in 3D printed composites, this research will address the challenges associated with understanding the mechanical behavior of composites with varying stiffness properties. By integrating finite element modeling and multi-physics simulations, this study will contribute to the advancement of composite material design with significant implications for aerospace structures, additive manufacturing, and sustainable processes.

	Composite materials, consisting of reinforcing fibers embedded in a matrix material, offer significant advantages in terms of their high strength-to-weight ratio and tailored mechanical properties. However, the stiffness properties of composites are typically homogeneous throughout the single ply, limiting their potential for optimal performance in various applications. To overcome this limitation, there is a growing interest in developing variable stiffness composites that can adapt their stiffness properties locally to better suit the specific requirements of different regions within a structure. This project proposal aims to address the challenges associated with the analysis and design of such variable stiffness composites. In this context, the main objectives of this research project are: 1) To develop multi-physics meso-scale (tow) models for the analysis of variable stiffness composites, taking inspiration from the LOUD project's approach to multi-scale modeling and failure analysis in 3D printed composites. 2) To investigate the mechanical behavior of variable stiffness composites under different loading conditions and environmental factors. 3) To optimize the design of variable stiffness composites for enhanced performance in specific applications, such as aerospace structures. 4) To contribute to the advancement of composite material design and enable the development of lightweight and efficient structures with tailored stiffness characteristics. The proposed research will involve mainly the following activities: a) Literature Review: Conduct a comprehensive review of existing literature

Objectives	on variable stiffness composites, multi-physics modeling techniques, and related research in the field of composite materials. b) Model Development: Develop multi-physics meso-scale models that can accurately capture the mechanical behavior of variable stiffness composites at the tow scale. This will involve integrating high order finite element modeling (1D, 2D), computational mechanics, and multi-physics simulations to simulate the complex interactions between different materials and their coupling effects. c) Material Characterization: Perform experimental testing and characterization of composite materials with variable stiffness properties. This will involve 3D printing and testing samples with varying fiber orientations, fiber volume fractions, and other factors influencing stiffness variations. d) Validation and Verification: Validate the developed multi-physics models by comparing the simulation results with experimental data. This step is crucial to ensure the accuracy and reliability of the models in predicting the mechanical behavior of variable stiffness composites. e) Parametric Studies: Conduct parametric studies to investigate the effects of different design parameters on the mechanical performance of variable stiffness composites. This will involve systematically varying parameters such as fiber orientation, fiber volume fraction, and matrix material properties to optimize the design for specific applications. f) Optimization: Employ optimization techniques to find the optimal distribution of stiffness properties within the composite structure. The objective will be to achieve enhanced structural performance, such as improved load-carrying capacity, reduced weight, and increased structural efficiency. g) Application Analysis: Apply the developed models and optimized designs to real-world applications, with a focus on aerospace structures. Evaluate the performance of variable stiffness composites in terms of structural integrity, fatigue resistance, and other relevant criteria. h) Dissemination: Publish the research findings in reputable international journals and present them at conferences and workshops. Engage in knowledge sharing activities to contribute to the scientific community and promote the impact of the research.

Skills and competencies for the development of the activity	The ideal candidate for this PhD scholarship should possess a strong background in aerospace/mechanical engineering or a related field. Key competences include knowledge of composite materials, finite element analysis, computational mechanics, and multi-physics modeling. Excellent analytical and problem-solving skills, as well as proficiency in programming languages and simulation software, are essential. Effective communication, teamwork, and a strong motivation for research are also desired qualities.