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Advances in Testing and Numerical Modelling of Composite Materials

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Raul Duarte Salgueiral Gomes Campilho[1,2]*

[1]*ISEP - School of Engineering, Polytechnic of Porto, R. Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal*

[2]*INEGI-Institute of Science and Innovation in Mechanical and Industrial Engineering, Pólo FEUP, Rua Dr. Roberto Frias, 400, 4200-465 Porto, Portugal*

***Corresponding Author:** Raul Duarte Salgueiral Gomes Campilho, ISEP - School of Engineering, Polytechnic of Porto, R. Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal; INEGI-Institute of Science and Innovation in Mechanical and Industrial Engineering, Pólo FEUP, Rua Dr. Roberto Frias, 400, 4200-465 Porto, Portugal.

Fiber-reinforced composites are engineered materials that derive their enhanced properties from the combination of the fibers and matrix. The integration of carbon, glass, or aramid fibers with a matrix material forms a composite that exhibits superior mechanical properties compared to traditional materials. Actually, the fibers provide the composite with high strength and stiffness, while the matrix material, often of polymeric, metallic, or ceramic nature, binds the fibers together and ensure load transfer. This fiber/matrix synergistic combination results in a material with a superior strength- and stiffness-to-weight ratios and improved mechanical performance. The extensive utilization of these materials in different industries justifies the need for continuous advancements in this topic to reduce costs and assure design confidence, aiming to make these materials applicable in a larger number of applications [1]. In the aerospace industry, composite materials are extensively used in aircraft structures, reducing weight and fuel consumption while maintaining structural integrity. The automotive sector benefits from composites in the form of lightweight components, enhancing fuel efficiency and overall performance. In the construction industry, composite materials contribute to the development of durable and corrosion-resistant structures, as primary structural elements or for reinforcement of existing structures. Sports equipment, such as tennis rackets and golf clubs, capitalizes on the exceptional strength and design flexibility offered by composite materials.

Recent developments in composite material research focus on improving performance, cost-effectiveness, and sustainability. Innovations in fiber technology, matrix materials, and manufacturing processes enable the deployment of composites with enhanced properties. The integration of nanomaterials and advanced manufacturing techniques, such as automated fiber placement and 3D printing, has further expanded the design possibilities and applications of composite materials [2].

In static testing, advancements have been done in different fields [3]. Digital image correlation (DIC) has been used to capture deformations and crack growth. Integration of acoustic emission testing with machine learning algorithms has improved the identification of specific failure modes. Advanced thermographic techniques, such as lock-in thermography and pulsed thermography, were tailored to offer improved sensitivity and resolution to detect subtle defects. In dynamic testing, the incorporation of servo-hydraulic testing systems with high-speed cameras was developed to facilitate a more accurate representation of real-world loading conditions. The integration of instrumented impactors with advanced sensors in drop weight impact testing was set to provide detailed data on impact energy, force, and deformation. Implementation of shearography in dynamic testing made possible the real-time monitoring of damage evolution during impact. Other developments include the use of DMA in conjunction with other testing methods, such as rheometry and spectroscopy, to obtain a more comprehensive understanding of dynamic behavior.

Numerical modeling plays a fundamental role in understanding and predicting the behavior of composite materials, complementing experimental testing. Finite Element Analysis (FEA) is a widely used numerical technique that simulates the response of composite structures under various loading conditions. FEA allows researchers and engineers to assess stress distribution, deformation, and failure modes, providing deep understanding into the material's performance. Recent advancements in numerical modeling include the incorporation of multiscale modeling, allowing for a more accurate representation of the complex interactions between fibers and the matrix at different length scales. Computational tools based on machine learning algorithms are also emerging as powerful tools to predict the material properties, optimize designs, and reduce the time and cost associated with traditional trial-and-error approaches [4].

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