Abstract

This habilitation thesis is focused on advanced composite materials reinforced with textile structures, being oriented toward their development, characterization, modelling and optimization for modern technical applications, in correlation with the present requirements regarding sustainability and recycling. The interest for this research direction is determined by the need of using materials with low weight, superior mechanical properties, structural adaptability and suitable functional behavior under complex loading conditions. At the same time, the development of new materials is directly influenced by the current requirements concerning the reduction of environmental impact, waste valorization and the integration of circular economy principles.

The general objective of the research is the investigation and development of advanced composite materials reinforced with textile structures, by highlighting the role of textile architecture in defining the mechanical behavior, by using numerical and mathematical methods for describing and optimizing these structures, as well as by extending the research toward sustainable solutions and recycling. The proposed scientific approach aims to correlate the results obtained through experimental, numerical and statistical methods, so that the development of composite materials is treated in a unitary way, from design and manufacturing to analysis, optimization and valorization.

The performed researches have highlighted the importance of three-dimensional textile structures used as preforms for composite materials intended for technical applications, especially for those involving mechanical and dynamic loads. The influence of the structural architecture, fiber type and polymeric matrix on the behavior of composite materials was analyzed, the results emphasizing the essential role of three-dimensional knitted sandwich structures in controlling the mechanical anisotropy, increasing the structural stiffness and improving the capacity of energy absorption and dissipation during impact. Also, statistical optimization methods were used for identifying the structural and technological parameters with significant influence on the final performances of the material.

An important research direction was represented by the analysis of impact behavior and by the numerical modelling of textile composite materials. By using the finite element method, the distributions of stresses, strains and displacements in the composite structure were investigated, highlighting the influence of the impactor position and of the three-dimensional architecture on the way in which mechanical loads are propagated and on the mechanisms of energy dissipation. In parallel, mathematical relations useful for describing the geometry of three-dimensional textile structures and for supporting the design process of technical textiles with complex shapes were developed. The approach was also extended toward interdisciplinary applications, by using three-dimensional reconstruction and geometrical analysis in biomedical contexts.

Another relevant aspect of the thesis is the investigation of innovative solutions for increasing the performance of textile and composite materials used in protection applications. Textile materials impregnated with shear thickening fluids were analyzed, following the influence of the fluid composition and of coupling agents on the interaction between fibers and dispersed particles, as well as on the behavior at impact and penetration. The results confirmed that the proper association between textile architecture, applied treatments and matrix type can significantly contribute to the increase of functional performances of the developed materials.

The thesis gives special attention to the sustainable dimension of the research, by valorizing textile and polymeric wastes in the development of new composite materials. Composite materials based on textile wastes with high content of polyester fibers and polymeric wastes based on polypropylene were produced by thermoforming, in the form of panels intended for construction applications. These materials were proposed as sustainable alternatives for conventional products, being analyzed both from the point of view of processing and of the obtained properties. At the same time, the possibility of recycling these composites by grinding and reprocessing was demonstrated, confirming the potential of their reintegration in successive technological cycles.

In the same direction of sustainability, the research regarding mechanical recycling of polylactic acid wastes for obtaining filaments used in 3D printing was also included. This approach highlights the potential for valorization of polymeric materials in additive manufacturing and contributes to the extension of the thesis perspective toward current technological solutions, characterized by material efficiency and waste reduction.

The original personal contributions are outlined by the integrative approach of the development of textile composite materials, in which the design of the reinforcement architecture is correlated with experimental characterization, numerical modelling, mathematical analysis, statistical optimization and sustainability principles. Through this approach, the textile structures are treated as active elements in designing the behavior of composites, while the material performance is analyzed in relation with the possibilities of recycling and reuse.

Overall, the thesis supports the definition of a personal research direction in the field of advanced textile composite materials, defined by the integration of textile design, experimental characterization, numerical modelling and sustainability principles.