

Abstract

The aim of this doctoral dissertation was to develop, manufacture, and functionally verify a prototype of a patient-specific knee joint orthosis made of a novel type of multi-layered composite (MLC), combining low weight with high stiffness and mechanical strength. The orthosis design was based on a hybrid material system in which a spatial core, manufactured using additive manufacturing (3D printing) technology, was reinforced with external textile structures and subsequently impregnated with an epoxy resin.

Within the scope of the research, two main reinforcement technologies were employed: a braided structure made of carbon fibers and tailored fiber placement (TFP) embroidery using glass fibers, arranged in accordance with the principal load directions along the surface of the core. The adopted methodology included a literature review, experimental investigations, mathematical and numerical modeling (finite element method, FEM), as well as implementation activities resulting in the fabrication of a functional orthosis prototype. Mechanical testing of composite specimens with various material configurations was conducted, together with an analysis of the formability of textile reinforcements on the spatial core and an evaluation of interlaminar adhesion quality. Computed tomography (micro-CT) was used to analyze the internal structure of the composites.

Mathematical models were successfully applied to describe the mechanical properties of the investigated composite structures. The developed numerical model was validated against experimental results, demonstrating high agreement and enabling the simulation of various material modification variants.

As a result of the conducted research, a lightweight, functional, and mechanically robust knee orthosis was developed, precisely adapted to the anatomical shape of the user's limb. It was demonstrated that the proposed MLC composite with textile reinforcement can be effectively applied in modern orthotic solutions that integrate additive manufacturing technologies, materials engineering, and compliance with regulatory requirements. The obtained results provide a foundation for further development of products for which conventional mold-based manufacturing is not economically justified due to their individualized nature.