Carbon nanostructures in a biopolymer matrix – influence of functional groups in cellulose acetate derivatives on the electrical conductivity, microstructure, and mechanical properties of the composite

In light of growing environmental challenges and progressing climate change, there is an increasing demand for modern yet sustainable materials capable of replacing conventional plastics in various technological applications. Of particular importance are solutions that combine advanced functionality, such as electrical conductivity, with biodegradability and environmental safety. This research project focusses on the development of such materials: thin-film conductive composites based on natural biopolymers and carbon nanostructures.

The matrices used in the designed materials will consist of selected derivatives of cellulose, a natural polymer found, among other sources, in plant cell walls. The study will examine three types: cellulose acetate (CA), cellulose acetate propionate (CAP), and cellulose acetate phthalate (CAPh). Although their chemical structures differ only in the type of functional groups present, these variations significantly affect their physicochemical behaviour, including solubility, film-forming capability, and interactions with conductive additives. These subtle structural differences may lead to substantial differences in the performance of the final composites.

The conductive phase will be provided by advanced carbon nanostructures, including single- and multi-walled carbon nanotubes (SWCNTs and MWCNTs), graphene flakes, and graphene oxide. These materials exhibit a unique set of properties—high electrical conductivity (up to 10^6 S/m), excellent mechanical strength, and resistance to chemical and thermal degradation. Because of their high aspect ratio, they can form percolating, three-dimensional conductive networks at very low filler concentrations. This allows for a reduction in the amount of conductive material required while maintaining favourable mechanical and optical properties of the composite. Such an approach enables the design of lightweight, flexible, and metal-free conductive layers.

The main objective of this project is to investigate how the chemical structure of biopolymers affects the physicochemical properties of thin-film composites containing carbon nanostructures. Special attention will be paid to understanding how different functional groups in the polymer matrix influence the formation of conductive networks based on carbon nanotubes and graphene. The study will involve a comprehensive analysis of key parameters such as electrical conductivity (both at room temperature and cryogenic temperature), mechanical properties, microstructure, and environmental stability. The project also includes an assessment of reproducibility and scalability, which are essential for evaluating the practical application potential of the developed materials.

This research aligns with the current trend of green electronics, a field that focusses on reducing the environmental footprint of electronic components and devices. The composites developed in this project could be applied in the future in areas such as biodegradable electrodes, conductive layers for flexible sensors, electromagnetic shielding, or disposable components in medical electronics.

The outcomes of the project will include not only the development of new materials with advanced functional properties but also a deeper understanding of how the chemical structure of biopolymers governs their behaviour in the presence of carbon nanostructures. These findings may serve as a foundation for future applied research and technological development in modern materials science, which covers electronics, sensing technologies, and biomedical applications.