

Summary

The aim of this dissertation is to develop innovative thermoset matrix composites reinforced with synthetic materials and dedicated for operation under cryogenic conditions. The research was carried out in cooperation with Zakłady Tworzyw Sztucznych IZO-ERG, in response to the growing demand for composite materials intended for applications in extreme environments. The newly developed composite was designed for technologically advanced sectors where materials are exposed to extremely low temperatures. Potential application areas include aerospace, space exploration, the automotive industry, and the marine sector. A particularly relevant field of implementation involves cryogenic systems, such as tanks for cryogenic fuel storage, transfer installations, research infrastructure components, and other devices requiring high reliability and operational stability under extreme conditions.

The scientific achievement of this work is the selection of the optimal material solution from among eight different resin compositions, comprising epoxy resin, hardener, solvent, and catalyst, as well as the determination of processing parameters leading to the fabrication of an epoxy-glass laminate with optimized mechanical, thermal, and electrical properties. The development of a multilayer composite material with unique functional characteristics expanded the company's product portfolio, directly enhancing its competitiveness in the global market. The introduction of this new product line by IZO-ERG enriched the range of advanced materials manufactured in Poland, while simultaneously strengthening the company's prestige and position both domestically and internationally.

In the first stage of mechanical testing, impact strength was evaluated, allowing for the preliminary assessment of reference materials and the selection of the most promising composite variants for further analyses. Subsequently, a comprehensive set of mechanical tests was performed, including three-point bending, tensile strength, Young's modulus determination, four-point bending, and fracture toughness. In parallel, thermal analyses were carried out, such as thermal conductivity, DMTA, DSC, TGA, TMA, and emissivity analysis. For comparative purposes, electrical tests were also performed to determine optimal parameters for materials applied as insulators. Finally, results obtained for laboratory-scale samples were compared with those produced on an industrial scale. Considering current environmental requirements and European Union regulations, life cycle assessment (LCA) and carbon footprint analyses were also conducted.

The best performance was achieved for the composites EP_4_2, EP_AD_1, and EP_AD_2, which exhibited high impact resistance, flexural strength exceeding 700 MPa, and stable Young's modulus at cryogenic temperatures. These materials demonstrated low thermal expansion, high stiffness (up to 16 GPa), and met electro-insulating requirements, achieving dielectric strength values of 25–29 kV/mm. The LCA results confirmed a lower environmental impact of resin A compared to resin B.

The EP_4_2_ind composite, manufactured under industrial conditions, exhibits superior mechanical, thermal, and electrical properties compared to its counterpart produced under laboratory conditions. These differences result from the use of modern industrial equipment, which enables process automation and precise control of manufacturing parameters.

Moreover, the EP_4_2_ind material achieves slightly better performance than the two best laboratory-based solutions, EP_AD_1 and EP_AD_2, by approximately 1.83% and 1.36%, respectively. It can therefore be inferred that scaling up the production of these composites to industrial conditions would further enhance their functional properties.

The findings confirm the dissertation's central thesis: the development of an original multilayer thermoset-matrix composite with high mechanical, thermal, and electrical performance, combined with stability across a wide temperature range, extends the service life and reliability of components designed for cryogenic environments.