

## Abstract

The doctoral dissertation consists of two integral parts.

The first part comprises a literature review presenting a concise history of composite materials, along with a characterization of matrices and fillers used in polymer matrix composites, with particular emphasis on epoxy-based systems. As a continuation and extension of the long-established body of knowledge, the most recent research trends and applications of polymer matrix composites, including epoxy resin matrices, are discussed. Hybrid structures are also presented as an advantageous alternative to conventional binary composites. Particular attention is devoted to commonly applied methods for testing these advanced materials and determining their properties, including the calculation procedures used to characterize them, with special emphasis on mechanical and thermal properties.

The second part of the dissertation contains experimental study.

The experimental section describes the fabrication process of epoxy composites exhibiting mechanical and thermal properties that make them suitable for applications in mechanical engineering. In the first stage of the study, the polymer matrix (Epidian 52 epoxy resin) was modified with a single additive, resulting in binary composites/nanocomposites. In the second stage, two modifiers were introduced to obtain hybrid composites. Various amounts of one of four modifiers (in binary systems) or two of four modifiers (in hybrid systems) were employed, namely: a polymer modifier—polyurethane (Desmocap 12); nanoclays—layered montmorillonites (MMT) with modified surface (Nanomer I.28E) or unmodified surface (Cloisite Na<sup>+</sup>); and untreated carbon nanotubes (CNT). The components of the compositions were dispersed in a two-step process using mechanical stirring followed by ultrasonic mixing (sonication).

Binary composites (Epidian 52 containing various amounts of one modifier: Desmocap 12, Nanomer I.28E, Cloisite Na<sup>+</sup>, or CNT) were prepared using different sonication times, and their mechanical properties were determined. At this stage, the optimal modifier content and sonication time ensuring the most advantageous impact strength, three-point bending strength, and crack propagation resistance were identified. Based on the evaluated properties of the binary composites, the material exhibiting the most favorable mechanical performance was selected for further investigation. This provided the basis for defining the so-called optimal modifier content and processing parameters (sonication time) that ensured the best mechanical properties of the prepared materials.

Subsequently, epoxy resin containing the optimally selected nanofiller (Nanomer I.28E, Cloisite Na+, or CNT) and varying amounts of one of the remaining modifiers was dispersed under the previously established optimal conditions for binary composites, leading to the preparation of hybrid nanocomposites. Their mechanical and thermal properties were then evaluated. The properties of the obtained materials were analyzed with consideration given both to the occurrence of synergistic effects between the applied components and to the structural characteristics of the resulting composites. Based on the obtained results, potential application directions were proposed for the developed nanocomposites characterized by thermal resistance and satisfactory mechanical performance.

An additional aspect of the study involved the analysis of thermomechanical test results in terms of the relationships between the applied modifiers (their type and content) and the potential interactions among the components used.

Moreover, statistical design of experiments (DoE) methods was applied and their usefulness was confirmed in comparison with conventional experimental approaches.

Thus, the main objective of the dissertation, namely, the development of hybrid epoxy composites characterized by mechanical and thermal properties suitable for applications as machine components or in other areas of mechanical engineering—was achieved. The scientific objective was also fulfilled through an attempt to elucidate the complex interaction mechanisms between the nanocomposite constituents responsible for the improvement of mechanical and thermal properties critical from a practical standpoint.

A preliminary assessment of the wear resistance of hybrid composites exhibiting synergistic effects was also conducted. Furthermore, numerical analysis was performed to model the distribution of stresses and strains within the material. The results obtained provide a basis for establishing future research directions concerning this material system.

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