

**The doctoral dissertation of M.Sc. Eng. Natalia Puszczkowska titled:
Biodegradable poly(lactic acid)-based piezoelectric composites obtained by
extrusion**

ABSTRACT

The subject of this doctoral dissertation was the development of biodegradable piezoelectric composites based on polylactide (PLA), produced by extrusion. The basis for the research was the observation that PLA has natural piezoelectric properties, but their level is low and insufficient for practical engineering applications. An additional barrier is the slow degradation of PLA under physiological conditions, which limits its use as a material in resorbable implants and other modern biomaterials. For this reason, it became necessary to search for methods of modifying PLA that would allow for a simultaneous increase in piezoelectric activity and acceleration of biodegradation, while maintaining the biocompatibility of the material.

Based on an analysis of the literature on the subject, it has been shown that piezoelectric materials are widely used in technology and medicine, but each type has significant limitations. Classic ceramic materials are characterized by high piezoelectric activity, but they are brittle and non-absorbable, which disqualifies them in many biomedical applications. Polymers such as polyvinylidene fluoride (PVDF) are easy to process, but their biodegradability is limited. Polylactide (PLA), on the other hand, combines biodegradability with biocompatibility, but its natural piezoelectric activity is low. Analysis of the literature also indicated that the methods used to date to modify PLA have not led to a simultaneous improvement in piezoelectric activity and acceleration of degradation. The identified research gap therefore concerned the development of a new composite in which these properties would be effectively combined.

The thesis assumed that the use of riboflavin (RF) as an additive to polylactide and its composites containing barium titanate (BT) would increase the susceptibility of these materials to biodegradation while maintaining the piezoelectric effect. As part of the thesis, the aim was to determine the effect of RF on the degradation process of PLA, as well as on the piezoelectric activity of PLA films and PLA/BT composites. The piezoelectric effect, its stability over time, susceptibility to biodegradation, and preliminary biocompatibility were investigated. These objectives were formulated to verify whether the introduced modification allows for the

production of functional biomaterials that combine piezoelectric properties with improved susceptibility to biodegradation.

Preliminary studies focused on assessing the possibility of producing PLA/BT composites by extrusion and on verifying whether the obtained materials could exhibit a stable piezoelectric effect. Microscopic analyses confirmed the homogeneous distribution of BT particles in the matrix as observed by SEM, and piezoelectric measurements showed a stable piezoelectric effect expressed by the d_{33} coefficient. Microbiological tests indicated limited susceptibility of PLA/BT composites to the action of microorganisms. These results confirmed the validity of further research focused on the role of riboflavin as an additive improving biodegradability.

The main research focused on the role of riboflavin as an additive to PLA and PLA/BT composites. It was shown that the presence of RF increases the piezoelectric activity of materials, enabling a voltage response in shear mode (d_{14}), while accelerating their biodegradation. Degradation tests confirmed a higher mass loss in samples containing RF, and morphological observations revealed degradation processes during incubation. In the case of RF-modified PLA/BT composites, it was found that the addition of riboflavin does not significantly reduce the piezoelectric effect d_{33} , while intensifying the degradation process. Preliminary cytotoxicity tests showed that the obtained materials did not show significant toxicity on healthy cells, which justifies further comprehensive cytotoxicity and biocompatibility studies of the PLA/BT/RF composite.

Based on the conducted research, it can be concluded that the thesis put forward in the dissertation has been positively verified and the assumed objectives of the work have been achieved. The studies confirmed the possibility of combining piezoelectric and biodegradable properties in a single material, and preliminary cytotoxicity tests did not show cytotoxicity under the tested conditions. The developed composites may serve as a starting point for further work on resorbable biomaterials with piezoelectric properties.