Innovative and functional composite and gradient biomaterials reinforced with core-shell microparticles: fabrication, structure, and properties

Statistics indicate a dramatic increase in the demand for long-term implants. In 2007, more than one million hip replacement surgeries were performed. In addition, it was also reported that 10-15% of implantation procedures failed within the first 10 years. The American Dental Association indicates that 113 million North American adults have lost at least one tooth. This situation leads to increased efforts by doctors and scientists to create a biomaterial with optimal structure and properties for long-term bone and dental implants. The first main problem is the composition of the alloy, especially the presence of additives such as Al or V, which are harmful to the human body. Great interest in alloys based on low-toxic elements (e.g. Nb, Zr, Ta) is visible in the world's leading research centers and industrial concerns in the USA, Asia, and Western Europe. The mechanical mismatch between the human bone and the material from which the implant is made is the second serious defect of this material, which affects the protective effect against excessive stress and premature loosening of the implant.

The main aim of the interdisciplinary project is to develop an innovative metal-to-metal gradient composite and material for potential biomedical use, where the reinforcing phase will be core-shell particles. The aim of the authors of the research project will be to find the relationship between the production technology, chemical composition, and structure of the new type of biomaterials. A review of the literature shows that no comprehensive approach to the production of core-shell multifunctional biomaterials has emerged to date. The assumptions of the project provide for two closely related ways of development. The first of these will be the production of core-shell materials based on titanium by mechanical alloying and characterization of the obtained particles. The obtained results will be used to assess the influence of milling parameters and characteristics of the starting material on the formation of core-shell structural particles. As a consequence, the optimal parameters of production processes will be determined, which will allow for obtaining core-shell particles based on titanium. The second way of development, closely related to the previous one, will be to determine the possibility of producing composite and gradient materials by powder metallurgy, in which the reinforcing phase is core-shell particles, which will provide a specific material construction from three areas with different structure, microstructure and mechanical properties in the nano- and micro areas. Particular emphasis will be placed on the broadly understood characteristics of the materials obtained. Composites and gradient materials based on low-toxic elements (e.g. Zr, Ti, Nb) reinforced with light core-shell molecules that exhibited a zonal structure, with reduced Young's modulus and hardness changes in three ranges, are likely to be widely used to develop new functional materials and become a research area in materials science.

The obtained material will be thoroughly examined for structure, microstructure, and properties. Studies of the structure and phase composition will be carried out by X-ray diffraction. The analysis of X-ray data will be carried out by the Rietveld and Willamson-Hall method. Transmission electron microscopy (TEM) by the JEM-3010 method JEOL will be used to determine the atomic structure and phase composition from the microareas of the selected samples. The powder morphology and microstructure of the samples after annealing will be studied using the JEOL JSM 6480 (SEM) scanning electron microscope. The first tests of the mechanical properties of the structural particles of the core and sintered samples will be carried out using the MCT3 micromechanical testing device (micro combi tester) and the Hysitron Tribointender Ti950 nano testing device, which will allow the analysis of sample morphology, hardness and elastic modulus from micro and nanoareas. Biological and electrochemical aspects of materials in simulated physiological solutions (e.g. Tyrode's solution, Ringer's solution, artificial saliva) will also be defined. Studies of the impact of particle strengthening, parameters of the production process of composites and gradient materials on their bioactivity, and the ability to form biofilm will also be presented.

The results will be presented orally or by posters at international conferences and published in peer-reviewed journals with international reach. The interdisciplinary nature of the project indicates the creation of a scientific group that will work at all levels of material analysis to obtain a full and advanced state of knowledge in this field.