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Research on Mimicking the Body Environment in the Degradation Processes of Permanent and Biodegradable Implants

1. Mimicking the in-vivo degradation process in-vitro (Jan Pinc)

Despite the relatively long history of research on permanent implants, challenges remain in reliably mimicking the body environment to minimize the use of animal models. These challenges also extend to biodegradable materials, where the processes are even more complex due to the gradual dissolution of the implant. Two distinct factors are often overlooked in available studies, leading to discrepancies between in-vitro and in-vivo results: the experimental conditions and the design of the implants. The reasons for these discrepancies are clear. Conditions such as oxygen concentration, dynamic stress, flow, organic components, and the architecture of the surrounding environment play crucial roles, as does the interaction between these factors. Moreover, testing is frequently conducted using bulk materials rather than materials shaped and dimensioned like the actual implants. This mismatch in testing conditions appears to be a critical factor in enhancing the predictability of degradation processes for both permanent and biodegradable implants. To address these issues, our focus has been on constructing a device capable of mimicking the maximum number of these conditions. By comparing the results obtained from this device with in-vivo experiments, we aim to achieve more precise and reliable experimental in-vitro models.

2. Mg-based biodegradable materials (Drahomír Dvorský)

Our research group has focused on the development and optimization of preparation methods for various magnesium alloys, including heat treatments, extrusion processes, and powder metallurgy techniques. A significant portion of our work has focused on enhancing the properties of magnesium alloys through powder metallurgy, with specific attention to the surface treatment of powder particles. For instance, we introduced a surface modification technique using HF treatment, which resulted in the formation of a continuous MgF_2 coating on the particles. This coating significantly improved the corrosion resistance of the magnesium alloys.

In more recent work, our focus has shifted towards magnesium alloys containing long-period stacking ordered (LPSO) phases, particularly Mg-Y-Zn alloys. These alloys, after appropriate heat treatment, can develop a unique microstructure known as the Mille-Feuille structure. This structure consists of nanoplate precipitates uniformly distributed within the grains of the material. The presence of these precipitates plays a crucial role in enhancing the mechanical properties of the material, contributing to both its strength and ductility. A key area of our current research is the exploitation of deformation kinks, which significantly enhance the strength of the material. These kinks are generated through thermomechanical processing of the LPSO-containing alloys. By carefully optimizing the conditions for kink formation and dynamic recrystallization, we aim to achieve an ideal combination of high strength and high ductility in the final material. This approach holds great promise for developing advanced magnesium alloys with superior mechanical properties for a variety of applications.

3. Zn-based biodegradable materials (Jaroslav Čapek)

Our research of Zn-based biodegradable materials is closely connected with UCT and its majority is performed in the frame of mutual projects and collaborations. Since 2018, we have been intensively focused on the development of a Zn-Mg-Ca/Sr for applications as biodegradable bone implants. We focused on the influence of extrusion conditions on microstructure development and final mechanical performance. Selected materials were further characterized regarding their corrosion and in-vitro and in-vivo biological response. Besides the material development and characterization, we focused on the investigation of recrystallization, deformation, creep and corrosion mechanisms of those materials. A summary of the main results will be presented.

Based the obtained results and knowledge, we have oriented to the design and investigation of metastable phases containing Zn-based composites prepared by powder metallurgy and on the surface treatment of Zn-based materials more recently.

Powder metallurgy allows modifying of material structure more precisely and modifying mechanical, corrosion and biological performance and is a promising way to overcome the drawbacks of the conventionally fabricated Zn-based alloys. On this topic, we closely collaborate with UCT and more details will be presented by David Necas.

Recently, we have focused on the surface treatment of Zn-based biodegradable materials. The surface plays a crucial role in the interaction with the environment, especially in the early post-implantation period, which is determining not only for the biocompatibility of the material. Furthermore, the microstructure of the (sub-)surface plays a significant role on their resistance to fatigue and corrosion stress cracking. Therefore, the surface treatments are worth of interest. In other to adumbrate the suitable directions and possibilities in this topic, we performed preliminary studies on laser shock peening, surface nanostructuring via ion implantation, chemical and electrochemical functionalization. The progress, issues, prospect and opportunities of collaboration in this topic will be presented and discussed.