Chapter 13
Role of Magnesium and Its Composite for Biomedical Application:
A Future Demand

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ABSTRACT

Owing to their biodegradability, superior mechanical properties, and excellent in-vitro/in-vivo biological compatibility, magnesium (Mg) alloys have attracted tremendous attention as innovative body-absorbable biomaterials. Mg-based alloys application and classification based on mechanical strength and corrosion resistance for biomedical implants are discussed in this book chapter. In addition, the effect of alloying elements: Zn, Ca, and RE-elements for property enhancement in Mg alloys has been also presented. Mg-Zn-Ca alloys, show improved tensile strength and corrosion behavior appropriate to bone implants whereas Mg-RE alloys offer superior strength and ductility more suited towards demanding higher performance applications. This review will also consider the difficulties in controlling Mg alloy corrosion rate so that it does not proceed at a dangerous and predictable pace within the body. The possibilities of magnesium alloys to change the face of the biomaterial area with degradable implants give rise to many exciting options for future medical advancements.

1. INTRODUCTION

Emerging as a technology-profound frontier in biomaterials science, the development of magnesium (Mg) alloys for medical applications is propelled by their remarkable biocompatibility, mechanical properties and special biodegradation in physiological environment. Such properties make Mg alloys ideal for temporary implanted medical devices, such as orthopedic screws and plates, cardiovascular stents, and for scaffolds in tissue engineering. Unlike conventional inert metals (e.g., titanium and stainless steel), Mg alloys biodegrade into biodegradable by-products; thus, secondary removal surgeries would not be required after implantation, minimizing late complications associated with permanent implants (Farzad

DOI: 10.4018/979-8-3373-0055-9.ch013

Badkoobeh et al., 2023). In addition, their mechanical properties like elastic modulus and compressive strength are similar to those of natural bone which may reduce the stress shielding effects and improve patient outcomes (Zhang, C et al., 2018).

Nevertheless, Mg alloys suffer from intrinsic challenges, like high corrosion rates, hydrogen gas dissolution and local alkalization during corrosion, all of which may negatively moderate their behavior. Over the past ten years a vast deal of research has been directed at tailoring alloy concentrations, as well as designing alloy compositions containing biocompatible elements, such as zinc (Zn) calcium (Ca) and rare earth (RE) metals. These form an alloy capable of enhancing corrosion resistance, mechanical integrity, and biological response, facilitating the use of Mg alloys in the clinic (Qi, L et al., 2024). Together with using advanced surface modifications, coatings and s fabrication processes, e.g., additive manufacturing, Mg alloys have now increased their potential by allowing the generation of patient-specific implants with modulated degradation rates and complex 3D architectures (Zhang, Y et al., 2022).

Applications of Mg alloys in orthopedics have been well-studied with considerable clinical progress to date. Slightly more recent studies have focused on Mg-based screws and plates due to promising outcomes in the fixation of fractures in load-bearing bones. Three months post-surgery, the screws had maintained satisfactory healing and controlled degradation was observed for twelve months with the usage of Mg-Y-RE-Zr alloy screws for medial malleolar fractures in humans (Sharma, S. K et al., 2024). Apraising of Mg-Zn-Ca alloy pins for distal radius fractures in children showed fast osteointegration as well as no harmful inflammatory reaction emphasizing the biocompatibility and safety of Mg-Zn-Ca alloy pins.

In the cardiovascular field, Mg-based bioresorbable stents have made great strides, and so far, they have achieved regulatory approval in several nations. This type of device provides short-term support to closed arteries and then degrades without harm as the vessel heals, leading to fewer risks from permanent foreign material in the body, such as late stent thrombosis. In 2024, a large-scale study reported the procedural success rate and long-term clinical outcomes of a new generation of Mg stents: In patients with coronary artery disease, high procedural success rates and good long-term prognosis were reported, with restenosins rates lower than that of polymer-coated stents (Singh, J et al., 2024).

Mg alloys have recent applications ranging from scaffolds in tissue regeneration in ortho-maxillo-facial surgery. For adequate healing with consecutive bone generation and vascularization, coordination of these two processes is crucial. In a preclinical study, the initial successful potential of porous Mg scaffolds was demonstrated as carriers for the growth of cells and as biophysical inductors of both osteogenesis and angiogenesis in 2024 (Tipan, N et al., 2024). The two groups used the polymer to fabricate scaffolds via additive manufacturing techniques that exhibited optimal porosity and mechanical strength to facilitate nutrient transport and infiltration by cells and would degrade in concert with the regeneration of tissue (Mamidi, N et al., 2022). Similarly, Mg-Zn-Mn alloys show good corrosion resistance and mechanical properties, rendering them a great candidate of load-bearing applications (Yuste, I et al., 2023).

However, the current path for clinical translation of Mg alloys is still rather low, despite initial promising outcomes. In addition, Mg-based implants can not only have slow degradation rate resulting in early mechanical failure, but also can lead to rapid degradation so that too much hydrogen gas generated which may cause the soft tissue irritation and delaying healing process as well. (Mg alloys, and inert) Multi-layer coatings and micro-alloying are considered to be effective in preventing this phenomenon. Additionally, they require numerous in vitro and in vivo to establish standardize testing conditions and reproducibility.

An additional important area of investigation is to study the long-term biological impact of Mg degradation products on human tissues. Magnesium ions and hydroxides are typically deemed safe; however,

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