Abstract

Biodegradable materials are increasingly explored for internal fracture fixation to eliminate second surgeries and long term complications of permanent implants. Among them, Mg alloys are promising due to their bone-like elastic modulus and good biocompatibility. However, poor mechanical strength and rapid corrosion hinder its clinical use. Moreover, early-stage bacterial infection and biofilm formation further undermine implant stability and overall performance.

In this work, Mg-0.2Zr-0.1Sr-xCe (x = 0, 0.5) was prepared by melting-casting route followed by solutionisation and hot forging to understand the metallurgical and biological effects of Ce addition. The addition of cerium markedly refined the grains in both the as-cast and forged conditions, with the forged specimens showing nearly an order-of-magnitude reduction in grain size. The cerium added alloy in cast condition exhibits continuous network of precipitates, while further thermomechanical processing leads to fine and uniform distribution of precipitates that significantly affect mechanical and corrosion properties. Hot forging and addition of 0.5 wt. % Ce addition raised the yield strength by 1.39 times. Higher fraction of DRX grains, strengthened basal texture and formation of a compact CeO_2 passive layer improved corrosion resistance by 1.68 times. Presence of cerium leads to highest antibacterial activity, without deteriorating cytocompatibility, rather promoted cell proliferation. *In vivo* analysis in rabbit femur exhibited higher bone generation after 2 months of implantation for the cerium added forged alloy without any histological abnormalities.

Variation in forging temperature can alter microstructure and texture evolution and thereby affect the mechanical and corrosion properties of Mg alloy. Therefore, in another work, Mg-0.2Zr-0.1Sr-0.5Ce alloy was forged at three different temperatures (623 K, 723 K and 823 K). The specimen forged at 723 K exhibits strengthened basal texture, higher fraction of DRX grains, that leads to higher strength and superior corrosion resistance among all the specimens. All the specimens exhibited excellent antibacterial activity without deteriorating cytocompatibility. The improved corrosion properties of 723 K specimen leads to higher in vivo bone regeneration at the implant-bone interface observed from in vivo study in rabbit femur.

The corrosion properties of Mg alloy can further be improved by surface modification route that hinder the destructive ions of physiological fluid to come in contact with the substrate. Therefore, in another study, we have coated the forged Mg-0.2Zr-0.1Sr-xCe (x = 0, 0.5) alloy surface with a biocompatible polypyrrole coating followed by stearic acid treatment, which developed a superhydrophobic surface (contact angle ~ 153º), that drastically improved the corrosion resistance (more than 85 % efficacy). The oligodynamic effect of polypyrrole leads to excellent antibacterial activity against gram negative *E. Coli* and gram positive *S. aureus* bacteria. Improved corrosion properties of the coated specimen leads to enhanced cell proliferation and osteogenic differentiation. Hard tissue histology and micro-CT analysis exhibited higher fraction of newly formed callus tissues and highest bone-implant integration across the coated specimen, when implanted in rabbit femur. Efficacy of the material in fracture healing was evaluated by implanting bone plate and screw in a clinically fractured goat tibia. At 3 months, complete fracture healed with no vital organ toxicity was observed for the coated specimen. The present results suggest that Ce addition and polypyrrole coating are effective ways to modulate the corrosion and biocompatibility behaviour making it a potential candidate for internal fracture fixation applications.

On a different note, Mg-0.5Mn-7.3Gd alloy was prepared by casting followed by solutionisation, forging and age treatment at 200 ºC. High resolution transmission electron microscopy (HRTEM) observations confirmed nano-scale Mg_5Gd precipitates and their

subsequent coarsening during transition from peak-aging to overaging. The nature of dislocation-precipitate interaction, size, fraction, and coherency-dependent characteristics of nano-scale Mg_5Gd precipitates are accountable for strengthening in aged specimens. The precipitation-dislocation interaction governed by precipitate-shearing mechanism contributes to pronounced strengthening in peak-aged specimen. The reduced volta potential difference between the galvanic couples (α-Mg and Mg_5Gd), strain energy removal, strengthened basal texture and fine semi-coherent Mg_5Gd precipitate of peak-aged specimen significantly improved the corrosion resistance. All the investigated specimens exhibited strong antibacterial activity, with no sign of cytotoxicity. Micro-CT and hard tissue histology by Masson's trichome staining demonstrated highest bone-implant integration and active callus formation across the peak-aged implant in rabbit femur.

To further improve the corrosion properties, struvite coating was conducted on the peak aged specimen, that able to improve the corrosion properties significantly. For better anchorage of new bone formation, magnesium phosphate bone cement was applied on the coated surface. The mass loss test of the prepared cement revealed less than 10 % after 3 weeks of immersion in HBSS. The long term hydrogen evolution study revealed minimum hydrogen evolution for the cement added coated specimen. *In vivo* study in rabbit femur revealed higher new bone generation for the cement added coated specimen making it a potential candidate for fracture fixation applications. Overall study demonstrated that the optimized thermal treatment along with coating and bone cement can effectively tailor the mechanical and biofunctional properties for successful internal fracture fixation application.

Achieving an optimal balance among corrosion resistance, mechanical strength, and biocompatibility remains a major challenge for biomedical Mg alloys. This study offers insights into processing, compositional optimization, and post-treatment strategies to overcome these issues for internal fracture fixation applications.

Keywords: Mg alloy; Corrosion; Antibacterial; Cytocompatibility; *In vivo*