Development of biodegradable ZK40, WX11, and WX41: Novel Mg based alloys for orthopedic applications

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Statement of Purpose: Current orthopedic reconstructions using Ti, Co-Cr, and Fe-based inert biometal implants tend to cause long-term complications related to metallosis from the undesirable wear and debris formation. The concept of using Mg alloys as implant materials have hence gained considerable attention in the field of orthopedics due to its biodegradability and density being similar to human bone [1]. Pure Mg is known to exhibit *in vivo* and *in vitro* biocompatibility. However, rapid corrosion of Mg alloys result in physiologically unfavorable amounts of hydrogen gas evolution leading to premature mechanical failure in *in vivo* experiments. Novel Mg-4wt.%Zn-0.5wt.%Zr (ZK40), Mg-1wt.%Y-0.6wt.%Ca (WX11), and Mg-4wt.%Y-0.6wt.%Ca (WX41) were thus developed and suitable solution treatment conditions were investigated to enhance the corrosion resistance, mechanical properties, and biocompatibility of these new alloys.

Methods: Pure magnesium and other high purity alloying elemental ingots/shots/granules were first melted in an induction furnace followed by re-melting in an electrical resistance furnace between ~700-780°C. The liquid metal was then poured into a mild steel mold. The as-cast alloys were further solution treated (T4) at 300°C (for ZK40) and 525°C (for WX11 and WX41), and subsequently quenched in water. Indirect MTT (3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide) assay was used to assess the cytotoxicity of the degradation product after 72 h immersion of sectioned specimens in culture medium. 10%, 25%, 50%, and 100% extract media were added to the 24 h cultured MC3T3 cell, and MTT assay was performed after 72 h [2]. Immersion corrosion measurements were performed using DMEM with 10% FBS and the media volume to surface area ratio was maintained at 20 ml/cm^2 in conformation with ASTM G31-72. Tension and compression tests were also performed in accordance with ASTM standard practice for tensile testing (ASTM-E8-04) and compressive testing (ASTM-E9-09).

Results: In Figure 1, indirect MTT assay assessing extract medium containing the degradation product after 72h immersion of the as-cast and heat-treated alloys, ZK40, WX11, and WX41 exhibited cell viability comparable to pure Mg which is known to be biocompatible in *in vivo* experiments. Since the cell viability over 75% in the 25% extract media is regarded as biocompatible in the assessment of Mg alloys due to cell death induced by high osmolality in 100% and 50% extract media [2], MTT result after 72h thus showed that both as-cast and heat-treated ZK40, WX11, and WX41 alloys were biocompatible. Immersion corrosion result in Figure 2, demonstrate corrosion rates of as-cast and T4-treated ZK40, WX11, and WX41 alloys after week 1 to be more comparable to pure Mg and as-drawn AZ31 but increased after week 2. Mechanical strength values of as-cast and heat-treated ZK40, WX11, and WX41 alloys were larger than pure Mg but as-drawn AZ31 exhibited higher tensile and compression strengths (see Figure 3).

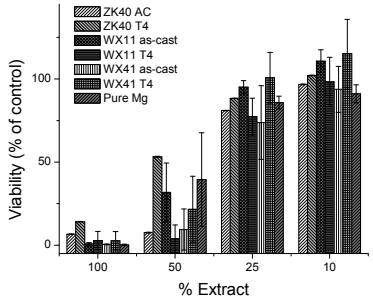

Figure 1. MTT assay result of as-cast ZK40, T4-treated ZK40, as-cast WX11, T4-treated WX11, as-cast WX41, T4-treated WX41, and pure Mg.

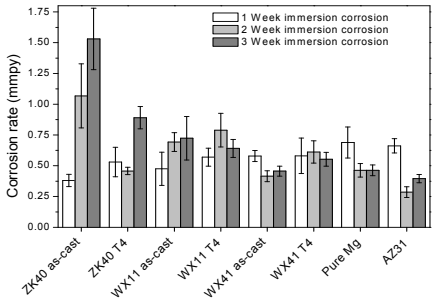

Figure 2. Immersion corrosion result of as-cast ZK40, T4-treated ZK40, as-cast WX11, T4-treated WX11, as-cast WX41, T4-treated WX41, pure Mg, and AZ31.

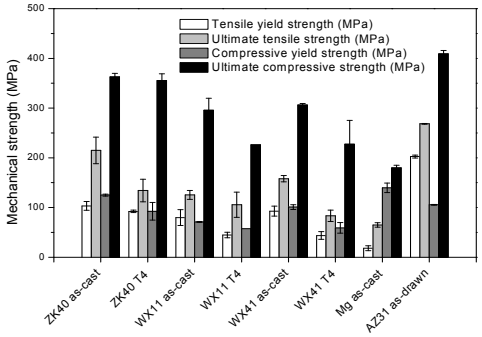

Figure 3. Mechanical strength of as-cast ZK40, T4-treated ZK40, as-cast WX11, T4-treated WX11, as-cast WX41, T4-treated WX41, pure Mg, and AZ31.

Conclusions: Biocompatible, corrosion resistant ZK40, WX11, and WX41 alloys with good mechanical properties were developed for biodegradable orthopedic devices. T4-treatment did not significantly improve the properties of the alloys. It is envisaged that hot extrusion or rolling will improve these characteristics of the alloys.

References:

[1] Staiger MP. Biomaterials. 2006. 27:1728-1734.
[2] Fischer J. MSEB. 2011; 176:830-834.