Role of Zinc in Mg-based alloys for Orthopedic Applications

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Statement of Purpose: Biodegradable metals have attracted interests for orthopedic applications because of the potential to eliminate the burdens to perform secondary surgery. Magnesium-based (Mg-based) alloys are potential candidates and studies using Mg-based alloys have been carried out. Zinc(Zn) is popularly chosen as alloying element to increase the corrosion resistance of Mg-based alloys. Although previous studies using zinc as alloying elements have shown good results, zinc's effect to the alloy system is still not well understood. The purpose of this study is to provide information about the use of zinc in magnesium-based alloys that is sustainable for future researches. In current study, the performances of Magnesium-Zinc-Manganese (Mg-Zn-Mn) alloys at 5% and 1% zinc levels were compared by *in vitro* methods. Mg-Zn-Mn alloy was chosen because similar compositions were studied before and results were good. Manganese is commonly used as alloying element to remove impurities in alloys. The content of manganese in this study was kept constant at 1%.

Methods: Sample preparation: Mg-5Zn-1Mn and Mg-1Zn-1Mn alloys were produced in forms of rods of 10mm diameter by hot extrusion. For *in vitro* experiments, the rods were sliced and grinded to produce consistent surfaces. Before the experiments, all the samples were immersed in 35% chromic acid (H_2CrO_4) to remove the oxide formed on the surfaces of the samples. The samples were cleaned in acetone and ethanol sonication before use. The compositions of the samples were verified by EDX.

In vitro tests were used to compare the two alloys. The tests included 1) Indirect contact test for cytotoxicity: metal samples were immersed in medium for different periods of time (t=24h, 48h, 72h) and the extracts were collected for MTT assay to test for cytotoxicity. 2) Immersion test (mass loss method) for corrosion rate. Samples were incubated in Earle's Balanced Salt solution (EBSS) for 1 day, 3 days, and 7 days respectively. The changes in weight were recorded. 3) Tensile and compression tests, and EDX for material characterization.

Results: 5% zinc and 1% zinc samples showed similar mechanical performances. In cyctotoxicity test, cell proliferation rates were low for both alloys when the extracts were undiluted. And the cell proliferation rates increased as the extract became more diluted. 5% zinc samples' extracts showed slightly lower cell proliferation rate compared with 1% zinc samples' extracts. A large amount of hydrogen gas bubbles were observed in the 5% zinc samples' extracts as in Figure 1. Fast hydrogen evolution brought rapid increase in pH value to the local environment, thus cells did not proliferate well. From the observation in the cytotoxicity test, higher degradation rate in 5% zinc sample was expected in the immersion test. In the immersion experiment, corrosion was observed in both samples. 5% zinc sample appeared to be more corroded and localized corrosion was observed on the surface of the sample. However, the difference in mass loss was not big, which may due to the short immersion time.

Figure 1. Alloy samples in medium for 72 hours. (left to right) 5% zinc sample, 1% zinc sample, medium only (control) The color of the medium changed from red to colorless indicating an increase in pH values.

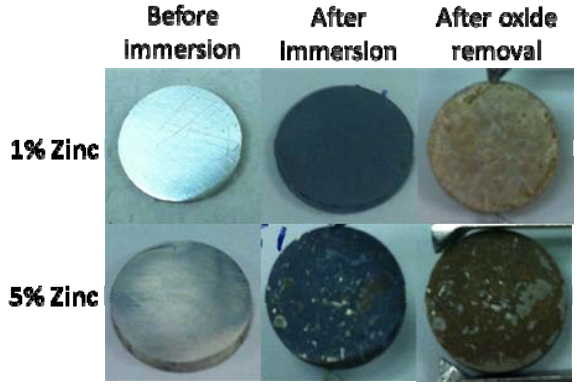

Figure 2. Appearances of the samples after 7 days of immersion in EBSS.

Conclusions: In this *in vitro* study, 5% zinc samples were shown to be less corrosion resistant while the mechanical properties and cytotoxicity were similar to that of 1% zinc samples'. It can be concluded that when zinc is at higher level, the corrosion resistance is lower. In this case, 1% zinc alloy is a relatively better candidate as biodegradable metal for orthopedic applications. Further experiments using varying zinc levels between 1% to 4% should be used to investigate if there is a trend follows in terms of degradation rates and cytotoxicity. *In vivo* study should be performed to determine if this *in vitro* finding is applicable to *in vivo* situation and to what extent.

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