

**Electrochemical Characterization of
corrosion mechanisms on Mg-Y-RE alloy in
“Biological Relevant” Environments**

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Metallic materials including stainless steel, titanium alloys, and cobalt-based alloys constitute, due to their high strength, ductility, and good corrosion resistance, an important class of materials in hard tissue replacement, especially load-bearing implants for the repair or replacement of diseased or damaged bones tissues. But, all these metallic materials are not biodegradable in the human body, so a second surgical procedure may be necessary after the tissues have healed. Thus a strong body of research focuses now on new biodegradable metallic implants, which dissolves in biological environment after a certain time of functional use. They constitute an appropriate solution because of cost, convenience and aesthetic reasons favorable to patients. Magnesium is one of the essential elements in the human body and has the advantage to be biodegradable [1,2]. So its corrosion susceptibility can also be used positively for bioabsorbable implant applications. Mg alloys corrode fast in most electrolytes and coating usually aims at a good corrosion protection. For degradable implants, a different approach with two challenges is necessary: i) an understanding of the microscale corrosion mechanisms; ii) temporary corrosion protection for at least a few months. The purpose of this study is to focus on a better understanding of the electrochemical corrosion mechanisms of an Mg-Y-RE alloy in artificial body fluids. Detailed information on corrosion processes provides the key to effective life prediction of the implant.

Because of potential use of Magnesium alloys for different types of implants, different types of physiology solutions were considered and they should simulate the different environments that an implant can be in contact with in different medical application fields. Artificial Plasma [3] is related to blood contact and the buffered Simulated Body Fluid (SBF), for implants where blood contact is less probable. Influence of further addition of serum or proteins will be discussed.

For these investigations, Electrochemical Impedance Spectroscopy (EIS) is a powerful method to investigate electrochemical processes on samples that do not show high corrosion resistance. Figure 1 presents EIS characterization of a Mg-Y-RE alloy envisaged as implant material after 24h immersion in AP. The spectra indicated the presence of two processes: localized attack (fast charge transfer measured at high frequency around 10 kHz) and slower uniform dissolution (Z modulus impedance value at low frequency). A qualitative comparison of the uniform dissolution rate for AP and SBF can be obtained by considering the impedance amplitude value Z at low frequency (10 mHz). This real value, also called polarization resistance, is however still influenced by localized corrosion processes that can occur in parallel, so over interpretation of the data should be avoided. However, as shown in figure 2, the uniform corrosion dissolution rate is 20-30 times higher for the aggressive SBF compared to AP, and this is a major concern when prediction of implant life is necessary.

The influence of the critical parameters (buffering ability, hydrodynamics, etc...) has been further investigated. This study evidenced that the type of attack

is critical for implant degradation. For the Mg-Y-RE alloys, the physiological media represent environments at the boundary between uniform and localized corrosion susceptibility where small changes in ionic concentration and buffering ability can promote one or the other corrosion type. No dominant aggressive species could be identified, the influence of chloride for example is not as critical as for corrosion resistant material and will be discussed in this contribution [3].

However, those electrochemical techniques cannot provide local element-specific and online *in situ* information at the same time. To overcome this drawback, a novel analytical technique based on a micro-capillary set-up connected to ICP-MS has been used to follow on-line elemental dissolution during the corrosion processes. For example, two stages of dissolution of the Mg-Y-RE alloy have been evidenced during the first few minutes of immersion in 0.154M NaCl adjusted to pH 7.4. The main advantage of this technique compared to other methods is the availability of time-resolved and element-specific analysis to propose reaction models for electrochemical reactions and surface oxide formation.

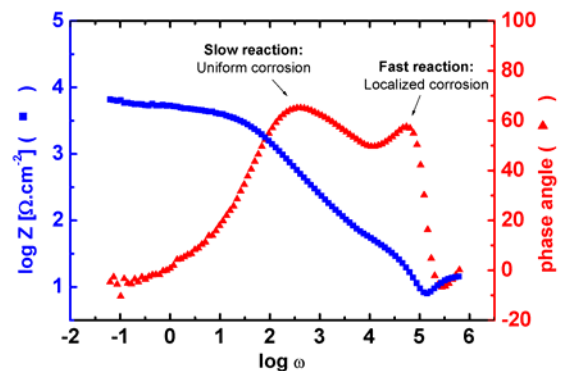


Figure 1: EIS impedance spectra of Mg-Y-RE alloy after 24h immersion in AP

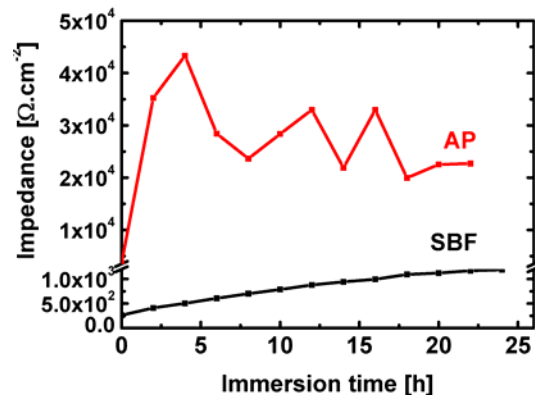


Figure 2: Impedance values measured at $f = 0.01\text{Hz}$ of a bare surface Mg-Y-RE alloy as a function of immersion time in AP compared to SBF

References:

- [1] G.O. Hofmann, Archives of Orthopedic and trauma surgery 143 (1995) 123.
- [2] F. Witte, J. Fischer, J. Nellesen, H.A. Crostack, V.Kaese, A. Pisch, F. Beckmann, H. Windhagen, Biomaterials 27 (2006) 1013.
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