

Methodical Screening of Corrosion Mechanisms of Iron Alloys for the Manipulation of Degradation Rates

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INTRODUCTION: Biodegradable iron and iron based alloys have been studied and initially were used in cardiovascular stents [1 ENREF 7]. A common aspect of literature data on biodegradable iron is a rather low corrosion rate and this is also reported in the first in vivo studies using pure iron. The addition of alloying elements may significantly affect the degradation rates. Hermawan et al. tested various Fe-Mn alloys with 20 – 35 % manganese showing increased corrosion rates compared to pure iron [2 ENREF 17]. Further improvements have been achieved by a Fe10Mn1Pd alloy, and Liu et al. recommended Co, W, C and S as alloying elements to increase degradation [3 ENREF 14, 4 ENREF 18]. Our own results showed that the addition of carbon increases the degradation rate, and small amounts of phosphorus did not have any negative effects neither on the cytotoxicity nor on the corrosion properties [5 ENREF 19]. However, all results indicate, that further control of the degradation rate of iron alloys is needed. Thus, in the present work aimed at a systematic utilization of known corrosion mechanisms. Therefore, the material was designed that way that the various corrosion mechanisms could be specifically addressed.

METHODS: Samples with diameter of 10 mm and height of 5 mm were manufactured by mixing carbonyl iron (BASF, mean particle size 4 µm) and the respective ferroalloy powders (Fe₃P, FeSi, FeW, FeN), graphite, or MnS-powders. Furthermore iron alloys with a continuous cathodic phase were synthesized by infiltrating Ag-foams (Alantum Europe, Germany) with carbonyl iron powders. All samples were treated by spark plasma sintering (FCT-HP D 250/1) with varying heating rates and temperatures. The samples were grinded, polished and positioned in an electrochemical measuring cell. As electrolyte a simulated body fluid (after Kokubo [6], 37 °C, pH 7.4) with a TRIS buffer was used. The polarization resistance was detected by using a potentiostat (AMEL) with a measuring rate of 5 mV/s. Finally, the current-density-potential curves were analysed by Stern-Geary method.

RESULTS: The results of the polarization measurements are shown in Fig.1. In comparison to the pure iron reference the lowest polarization resistance levels are detected when silicon in low amounts or tungsten is used as alloying element. Furthermore, rather low polarization resistance is obtained when continuous silver phases are realized. In contradiction, high resistance is measured when silver is used as spot-like precipitation phase only. Only slight effects have been achieved by alloying with carbon or MnS.

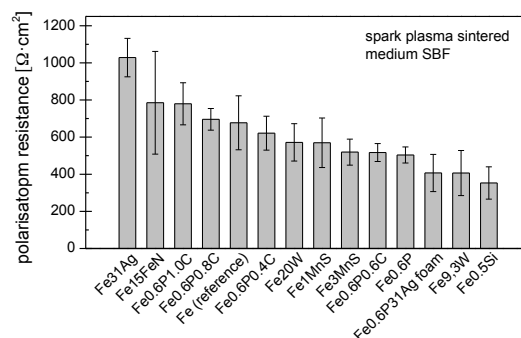


Fig. 1: Polarization resistance of various powder metallurgical iron alloys in simulated body fluid.

DISCUSSION & CONCLUSIONS: General considerations suggest, that a surface corrosion is favourable in order to obtain homogeneous implant degradation. Thus, in particular small amounts of silicon, but also tungsten induce the desired features. Intergranular corrosion also may be addressed by adding carbon or phosphorus. Furthermore, the addition of MnS (which is known to induce pitting corrosion) had no significant effect in the present short-term measurement. Galvanic corrosion only could be realized when continuous cathodic phases have been generated, spot-like precipitations had no significant effect. In conclusion, the results show that the systematic activation of specific corrosion mechanisms may be an appropriate tool in order to tailor the corrosion properties of biodegradable iron implants.

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