Mechanical and corrosion properties of Mg based alloys considered for medical applications as biodegradable materials

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Magnesium and its alloys are considered as suitable biodegradable materials which can be gradually dissolved in organism without production of toxic compounds. The present study is oriented on new group of possible biodegradable materials based on Mg-LMM (Mg- low melting metals) alloys. Due to the limited information about the effect of Ga, Sn and In on mechanical and corrosion properties, structure studies, mechanical and corrosion testing were performed. Corrosion behaviour of materials was studied using measuring of weight changes, Mg ions release and also by EIS technique in SBF (simulated body fluid) that is close in composition with human plasma. The obtained results indicate positive effect of both Ga and Sn on tensile and compressive properties, compared to the almost neglectable effect of In. On the contrary, all materials were characterized by decreased corrosion resistances compared to pure Mg. Mainly structure conditions were responsible for observed differences in corrosion rates.

Keywords: magnesium, tensile properties, compressive properties, corrosion

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References

[1] SEITZ, Jan-Marten, WULF, Eric, FREYTAG, Patrik, BORMANN, Dirk, et al. The Manufacture of Resorbable Suture Material from Magnesium. *Advanced Engineering Materials*, 2010, 12(11), 1099-1105.

[2] KRAUSE, Annett, HÖH, Nina, BORMANN, Dirk, KRAUSE, Christian, et al. Degradation behaviour and mechanical properties of magnesium implants in rabbit tibiae. *Journal of Materials Science*, 2010/02/01 2010, 45(3), 624-632.

[3] THOMANN, M., KRAUSE, Ch, BORMANN, D., VON DER HÖH, N., et al. Comparison of the resorbable magnesium . alloys LAE442 und MgCa0.8 concerning their mechanical properties, their progress of degradation and the bone-implant-contact after 12 months implantation duration in a rabbit model. *Materialwissenschaft Und Werkstofftechnik*, 2009, 40(1-2), 82-87.

[4] NOVAKOVA, Lucie, HOMOLA, Petr AND KAFKA, Vaclav Microstructure Analysis of Titanium Alloys after Deformation by means of Asymmetric

[5] Incremental Sheet Forming. *Manufacturing technology*, 2012, 12(13), 201-206.

[6] WITTE, Frank, HORT, Norbert, VOGT, Carla, COHEN, Smadar, et al. Degradable biomaterials based on magnesium corrosion. *Current Opinion in Solid State and Materials Science*, 2008, 12(5–6), 63-72.

[7] AMBROSE, Catherine G. AND CLANTON, Thomas Oscar Bioabsorbable Implants: Review of Clinical Experience in Orthopedic Surgery. *Annals of Biomedical Engineering*, 2004, 32(1), 171-177.

[8] WITTE, F., KAESE, V., HAFERKAMP, H., SWITZER, E., et al. In vivo corrosion of four magnesium alloys and the associated bone response. *Biomaterials*, 2005, 26(17), 3557-3563.

[9] WAIZY, Hazibullah, DIEKMANN, Julia, WEIZBAUER, Andreas, REIFENRATH, Janin, et al. In vivo study of a biodegradable orthopedic screw (MgYREZr-alloy) in a rabbit model for up to 12 months. *Journal of Biomaterials Applications*, January 3, 2013 2013.

[10] WANG, Guixue, GE, Shuping, SHEN, Yang, WANG, Honggang, et al. Study on the biodegradability and biocompatibility of WE magnesium alloys. *Materials Science and Engineering: C*, 2012, 32(8), 2190-2198.

[11] STAIGER, Mark P., PIETAK, Alexis M., HUADMAI, Jerawala AND DIAS, George Magnesium and its alloys as orthopedic biomaterials: A review. *Biomaterials*, 2006, 27(9), 1728-1734.

[12] EDDY JAI POINERN, Gérrard, BRUNDAVANAM, Sridevi AND FAWCETT, Derek Biomedical Magnesium Alloys: A Review of Material Properties, Surface Modifications and Potential as a Biodegradable Orthopaedic Implant. *American Journal of Biomedical Engineering*, 2013, 2(6), 218-240.

[13] KRAUS, Tanja, FISCHERAUER, Stefan F., HÄNZI, Anja C., UGGOWITZER, Peter J., et al. Magnesium alloys

for temporary implants in osteosynthesis: In vivo studies of their degradation and interaction with bone. *Acta Biomaterialia*, 2012, 8(3), 1230-1238.

[14] XIN, Y., HU, T. AND CHU, P. K. In vitro studies of biomedical magnesium alloys in a simulated physiological environment: a review. *Acta Biomater*, Apr 2011, 7(4), 1452-1459.

[15] DALIBOR, Vojtěch, JIŘÍ, Kubásek AND MILENA, Voděrová Structural, mechanical and in vitro corrosion characterization of as-cast magnesium based alloys for temporary biodegradable medical implants. *Manufacturing technology*, 2012, 12(13), 201-206.

[16] LICHÝ, Petr, BEŇO, Jaroslav AND CAGALA, Michal Inoculant Addition Effect on Thermomechanical and Thermophysical Properties of Mg-Sr Magnesium Alloy. *Manufacturing technology*, 2013, 13(1), 64-67.

[17] YANG, M. B. AND PAN, F. S. Effects of Sn addition on as-cast microstructure, mechanical properties and casting fluidity of ZA84 magnesium alloy. *Materials & Design*, Jan 2010, 31(1), 68-75.

[18] LIU, Xianbin, SHAN, Dayong, SONG, Yingwei, CHEN, Rongshi, et al. Influences of the quantity of Mg2Sn phase on the corrosion behavior of Mg–7Sn magnesium alloy. *Electrochimica Acta*, 2011, 56(5), 2582-2590.

[19] NAYYERI, G. AND MAHMUDI, R. Effects of Sb additions on the microstructure and impression creep behavior of a cast Mg-5Sn alloy. *Materials Science and Engineering a-Structural Materials Properties Microstructure and Processing*, Jan 15 2010, 527(3), 669-678.

[20] GU, X., ZHENG, Y., CHENG, Y., ZHONG, S., et al. In vitro corrosion and biocompatibility of binary magnesium alloys. *Biomaterials*, Feb 2009, 30(4), 484-498.

[21] FENG, Y., WANG, R. C. AND PENG, C. Q. Influence of freezing rate on microstructure and electrochemical properties of Mg-2%Ga alloys. *Transactions of Nonferrous Metals Society of China*, May 2011, 21(5), 1047-1051.

[22] LIU, HongBin, QI, GuoHong, MA, YuTao, HAO, Hai, et al. Microstructure and mechanical property of Mg–2.0Ga alloys. *Materials Science and Engineering: A*, 2009, 526(1-2), 7-10.

[23] MELNIKOV, P., TEIXEIRA, A. R., MALZAC, A. AND COELHO, M. D. Gallium-containing hydroxyapatite for potential use in orthopedics. *Materials Chemistry and Physics*, Sep 15 2009, 117(1), 86-90.

[24] TANAKA, A., HIRATA, M., KIYOHARA, Y., NAKANO, M., et al. Review of pulmonary toxicity of indium compounds to animals and humans. *Thin Solid Films*, Mar 31 2010, 518(11), 2934-2936.

[25] GALE, W. F. AND TOTEMEIER, T. C. Smithells Metals Reference Book (8th Edition). In.: Elsevier.

[26] XIN, Y., HU, T. AND CHU, P. K. In vitro studies of biomedical magnesium alloys in a simulated physiological environment: A review. *Acta Biomaterialia*, 2011, 7(4), 1452-1459.

[27] ATRENS, Andrej, LIU, Ming AND ZAINAL ABIDIN, Nor Ishida Corrosion mechanism applicable to biodegradable magnesium implants. *Materials Science and Engineering: B*, 2011, 176(20), 1609-1636.

[28] BRATSCH, S. G. Standard Electrode-Potentials and Temperature Coefficients in Water at 298.15-K. *Journal of Physical and Chemical Reference Data*, 1989, 18(1), 1-21.

[29] HASSAN, S. AND GUPTA, M. Effect of different types of nano-size oxide particulates on microstructural and mechanical properties of elemental Mg. *Journal of Materials Science*, 2006, 41(8), 2229-2236.

[30] XU, D. K. AND HAN, E. H. Effects of icosahedral phase formation on the microstructure and mechanical improvement of Mg alloys: A review. *Progress in Natural Science-Materials International*, Oct 2012, 22(5), 364-385.

[31] JAMESH, M., KUMAR, Satendra AND SANKARA NARAYANAN, T. S. N. Corrosion behavior of commercially pure Mg and ZM21 Mg alloy in Ringer's solution – Long term evaluation by EIS. *Corrosion Science*, 2011, 53(2), 645-654.

[32] WANG, M. Y., XU, Y. J., JING, T., PENG, G. Y., et al. Growth orientations and morphologies of alpha-Mg dendrites in Mg-Zn alloys. *Scripta Materialia*, Oct 2012, 67(7-8), 629-632.

[33] ZHANG, X. L., CHEN, G. AND BAUER, T. Mg-based bulk metallic glass composite with high bio-corrosion resistance and excellent mechanical properties. *Intermetallics*, Oct 2012, 29, 56-60.

[34] ZUCCHI, F., GRASSI, V., FRIGNANI, A., MONTICELLI, C., et al. Electrochemical behaviour of a magnesium alloy containing rare earth elements. *Journal of Applied Electrochemistry*, 2006, 36(2), 195-204.

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