Reviews on Advanced Materials and Technologies, 2025, vol. 7, no. 2, pp. 71–78
DOI: 10.17586/2687-0568-2025-7-2-71-78

Effect of Mg Content on the Structure, Properties and Cytotoxicity of Biodegradable Zn-Fe-Mg Alloys

E.D. Abdrakhmanova [1,2], E.D. Khafizova [1], M.V. Polenok [1], R.K. Islamgaliev [1], Zhen Li [2], Li Li [2], Yingru Liang [2], Meng Zhang [2]

[1] Ufa University of Science and Technology, Zaki Validi Str., 32, Ufa, 450076, Russia
[2] Harbin Engineering University, Nantong Str, No. 145, Harbin Heilongjiang, 150001, China

Received: April 11, 2025 Corresponding author: E.D. Abdrakhmanova

Abstract. Interest in biodegradable materials for temporary implants based on zinc alloys has been growing annually. The Zn-Fe-Mg alloys are of special interest, as each of its constituent elements is independently considered as biodegradable metallic material. This study presents a comprehensive investigation of the Zn-1%Fe-1%Mg and Zn-1%Fe-5%Mg alloys subjected to high-pressure torsion. A comparative analysis was conducted on the microstructure of the alloys in both as-cast and deformed states, highlighting differences in their phase composition, strength and cytotoxicity. When the magnesium content exceeds 3 wt.%, an additional phase ($MgZn_2$) precipitates alongside the existing Mg_2Zn_{11} phase. Deformation processing of the Zn-1%Fe-1%Mg alloy effectively reduces its brittleness and promotes a more homogeneous distribution of the Mg_2Zn_{11} eutectic throughout the sample volume. In contrast, the Zn-1%Fe-5%Mg alloy retains excessive brittleness even after deformation. The addition of magnesium was found also to accelerate corrosion rates. Nevertheless, the strength, corrosion, and cytotoxicity properties of the Zn-1%Fe-1%Mg alloy meet the requirements for biodegradable materials.

Acknowledgements. The work was carried out at the expense of the academic leadership program of the Ufa University of Science and Technology (PRIORITY-2030). The research part of the work was carried out using the equipment of the Core Facility Centre “Nanotech” of Ufa University of Science and Technologies.

Citation: Rev. Adv. Mater. Technol., 2025, vol. 7, no. 2, pp. 71–78

View online: https://doi.org/10.17586/2687-0568-2025-7-2-71-78

View Table of Contents: https://reviewsamt.com/issues

REFERENCES

[1] A.M. Wu, C. Bisignano, S. James et al, Global, regional, and national burden of bone fractures in 204 countries and territories, 1990–2019: a systematic analysis from the Global Burden of Disease Study 2019, *The Lancet Healthy Longevity*, 2021, vol. 2, no. 9, pp. 580–592.

[2] Z. Wang, Y. Zhang, J. Wu, Q. Zhang, Global, regional and country-specific burden of patella, tibia or fibula, or ankle fractures and its prediction to 2035: findings from global burden of disease study 2019, *BMC Public Health*, 2024, vol. 24, no. 1, art. no. 3162.

[3] V.A. Samartsev, I.V. Kadyntsev, E.G. Voluzhenkov, Postoperative extremity metallosteosynthesis complications, *Perm Medical Journal*, 2018, vol. 35, no. 3, pp. 5–8.

[4] X. Tong, X. Shen, Z. Lin, L. Lu, K. Munir, R. Zhou, L. Zhu, Y. Li, J. Ma, C. Wen, J. Lin, In vitro and in vivo studies of a biodegradable Zn-4Ag-0.1Sc alloy with high strength-elongation product, cytocompatibility, osteogenic differentiation, and anti-infection properties for guided bone-regeneration membrane applications, *Chemical Engineering Journal*, 2024, vol. 493, art. no. 152763.

[5] X. Tong, Y. Han, L. Zhu, R. Zhou, Z. Lin, H. Wang, S. Huang, Y. Li, J. Ma, C. Wen, J. Lin, ZnP-Coated Zn–1Cu–0.1Ti Membrane with High Strength-Ductility, Antibacterial Ability, Cytocompatibility, and Osteogenesis for Biodegradable Guided Bone Regeneration Applications, *Advanced Functional Materials*, 2023, vol. 33, no. 31, art. no. 2214657.

[6] T. Kraus, S.F. Fischerauer, A.C. Hänzi, P.J. Uggowitzer, J.F. Löffler, A.M. Weinberg, Magnesium alloys for temporary implants in osteosynthesis: In vivo studies of their degradation and interaction with bone, *Acta Biomaterialia*, 2012, vol. 8, no. 3, pp. 1230–1238.

[7] D. Vojtěch, J. Kubásek, J. Čapek, Iva Pospíšilováб Comparative mechanical and corrosion studies on magnesium, zinc and iron alloys as biodegradable metals, *Materials and Technology*, 2015, vol. 49, no. 6, pp. 877–882.

[8] M.V. Polenok, E.D. Khafizova, R.K. Islamgaliev, The influence of severe plastic deformation on mechanical properties of pure zinc, *Frontier Materials & Technologies*, 2022, no. 3-2, pp. 25–31.

[9] Y. Zheng, X. Xu, Z. Xu, J.Q. Wang, H. Cai, *Metallic Biomaterials: New Directions and Technologies*, Wiley, Peking, 2017.

[10] H. Jin, L. Yang, L. Cui, L. Chen, Y. Lai, H. Guo, Y. Liu, Study on Properties of Zn-xMg (x = 0.5, 0.8, 1) Alloys for Potential Stent Material, *Journal of Materials Engineering and Performance*, 2023, vol. 32, pp. 7468–7479.

[11] J. Bai, Y. Xu, Q. Fan, R. Cao, X. Zhou, Z. Cheng, Q. Dong, F. Xue, Mechanical Properties and Degradation Behaviors of Zn-xMg Alloy Fine Wires for Biomedical Applications, *Scanning*, 2021, vol. 2021, no. 1, art. no. 4831387.

[12] ISO 10993.5-99. *Medical products. Biological evaluation of medical devices — Part 5: Tests for in vitro cytotoxicity*, Standartinform Publ., Moscow, 2014, 10 p. (in Russian).

[13] Z.Z. Shi, X.X. Gao, X.F. Liu, $FeZn_{13}$ intermetallic compound in biodegradable Zn–Fe alloy: Twinning and its shape effect, *Materials Characterization*, 2020, vol. 164, art. no. 110352.

[14] E.D. Abdrakhmanova, E.D. Khafizova, M.V. Polenok, R.K. Nafikov, E.A. Korznikova, Influence of high-pressure torsion on the structure and mechanical properties of Zn–1%Fe–5%Mg zinc alloy, *Frontier Materials & Technologies*, 2024, no. 2, pp. 9–22.

[15] V.D. Sitdikov, E.D. Khafizova, M.V. Polenok, Microstructure, crystallographic texture and mechanical properties of the Zn–1%Mg–1%Fe alloy subjected to severe plastic deformation, *Frontier Materials & Technologies*, 2024, no. 3, pp. 75–88.

[16] Z.O. Králová, R. Gorejová, R. Oriňaková, M. Petráková, A. Oriňak, M. Kupková, M. Hrubovčáková, T. Sopčák , M. Baláž, I. Maskaľová, A. Kovalčíková, K. Koval', Biodegradable zinc-iron alloys: Complex study of corrosion behavior, mechanical properties and hemocompatibility, *Progress in Natural Science: Materials International*, 2021, vol. 31, no. 2, pp. 279–287.

[17] K. Han, I. Ohnuma, K. Okuda, R. Kainuma, Experimental determination of phase diagram in the Zn-Fe binary system, *Journal of Alloys and Compounds*, 2018, vol. 737, pp. 490–504.

[18] C.Yao, Z. Wang, S.L. Tay, T. Zhu, W. Gao, Effects of Mg on microstructure and corrosion properties of Zn–Mg alloy, *Journal of Alloys and Compounds*, 2014, vol. 602, pp. 101–107.
[19] T.A. Vida, T. Soares, R.S. Septimio, C.C. Brito, N. Cheung, A. Garcia, Effects of Macrosegregation and Microstructure on the Corrosion Resistance and Hardness of a Directionally Solidified Zn-5.0wt.%Mg Alloy, *Materials Research*, 2019, vol. 22.
[20] S. Liu, D. Kent, N. Doan, M. Dargusch, G. Wang, Effects of deformation twinning on the mechanical properties of biodegradable Zn-Mg alloys, *Bioactive Materials*, 2018, vol. 4, pp. 8–16.
[21] D.A. Porter, K.E. Easterling, M.Y. Sherif, *Phase Transformations in metals and alloys*, CRC Press, Boca Raton, 2009, 520 p.
[22] Z.Z. Shi, X.X. Gao, H.T. Chen, X.F. Liu, A. Li, H.J. Zhang, L.N. Wang, Enhancement in mechanical and corrosion resistance properties of a biodegradable Zn–Fe alloy through second phase refinement, *Materials Science and Engineering: C*, 2020, vol. 116, art. no. 111197.
[23] D. Lou, M. Zhang, J. Lv, B. Li, X. Wang, J. Shi, Y. Ren, H. Li, G. Qin, Effects of Fe addition on the microstructures and mechanical properties of as-extruded Zn-0.2Mg alloys, *Journal of Alloys and Compounds*, 2021, vol. 896, art. no. 162912.
[24] M.H. Yoo, Slip, twinning, and fracture in hexagonal close-packed metals, *Metallurgical Transasctions A*, 981, vol. 12, pp. 409–418.
[25] Z. Shi, C. Li, M. Li, X. Li, L. Wang, Second phase refining induced optimization of Fe alloying in Zn: Significantly enhanced strengthening effect and corrosion uniformity. International Journal of Minerals, *Metallurgy and Materials*, 2022, vol. 29, pp. 796–806.
[26] E.D. Abdrakhmanova, E.D. Khafizova, M.V. Polenok, R.K. Islamgaliev, H. Yilmazer, Effect of the test regimes on the corrosion resistance of the Zn-1Fe-1Mg alloy. *Materials. Technologies. Design*, 2024, vo. 6, no. 1, pp. 80–90.
[27] E.D. Abdrakhmanova, E.D. Khafizova, M.V. Polenok, V.D. Sitdikov, F.V. Nugamanov, Effect of exposure time in a physiological environment on the corrosion rate of ultrafine-grained Zn-Fe-Mg alloy, *Letters on Materials*, 2025, vol. 15, no. 1, pp. 60–65.
[28] V.D. Sitdikov, E.D. Khafizova, M.V. Polenok, E.D. Abdrakhmanova, Corrosion resistance and biocompatibility of the ultrafine-grained Zn-1%Li-2%Mg and Zn-1.0%Mg-1.0%Fe alloys produced by severe plastic deformation, *Materials. Technologies. Design*, 2024, vol. 6, no. 2, pp. 109–128.
[29] V.D. Sitdikov, E.D. Khafizova, M.V. Polenok, E.D. Abdrakhmanova, Corrosion resistance of ultrafine-grained Zn-1%Li-2%Mg and Zn-1.0%Mg-1.0%Fe alloys, Russian Physics Journal, 2024, vol. 67, pp. 2129–2135.
[30] C. Yao, Z. Wang, S.L. Tay, T. Zhu, W. Gao, Effects of Mg on microstructure and corrosion properties of Zn–Mg alloy, *Journal of Alloys and Compounds*, 2014, vol. 602, pp. 101–107.
[31] P. Xue, M. Ma, Y. Li, X. Li, J. Yuan, G. Shi, K. Wang, K. Zhang, Microstructure, Mechanical Properties, and in Vitro Corrosion Behavior of Biodegradable Zn-1Fe-xMg Alloy, *Materials*, 2020, vol. 13, no. 21, art. no. 4835.
[32] N. Martynenko, N. Anisimova, O. Rybalchenko, M. Kiselevskiy, G. Rybalchenko, N. Tabachkova, M. Zheleznyi, D. Temralieva, V. Bazhenov, A. Koltygin, A. Sannikov, S. Dobatkin, Structure, Biodegradation, and In Vitro Bioactivity of Zn–1%Mg Alloy Strengthened by High-Pressure Torsion, *Materials*, 2022, vol. 15, no. 24, art. no. 9073.

© 2025 ITMO