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Combination of biodegradable Zn- and Mg-based alloys using multi-material Additive Manufacturing: challenges and opportunities

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Introduction

Biodegradable metals, particularly zinc (Zn) and magnesium (Mg) alloys, offer significant potential for biomedical applications, especially in temporary implants that gradually degrade within the body. Recent studies demonstrate the feasibility of additive manufacturing (AM) of both materials to address patient-specific solutions with high geometric complexity[1,2]. This study explores the innovative combination of Zn- and Mg-based alloys using multi-material AM techniques based on process of Laser Powder Bed Fusion (LPBF), aiming to synergize the unique properties of these materials for optimized performance in medical devices. In addition to the locally differing mechanical properties, the objective is to achieve selective degradation in which some parts of the component dissolve faster than others and create a novel actuation mechanism within the body. Our investigations include iterative recoating parameter studies, the identification of a suitable build plate material as well as the fabrication of first multi-material specimens.

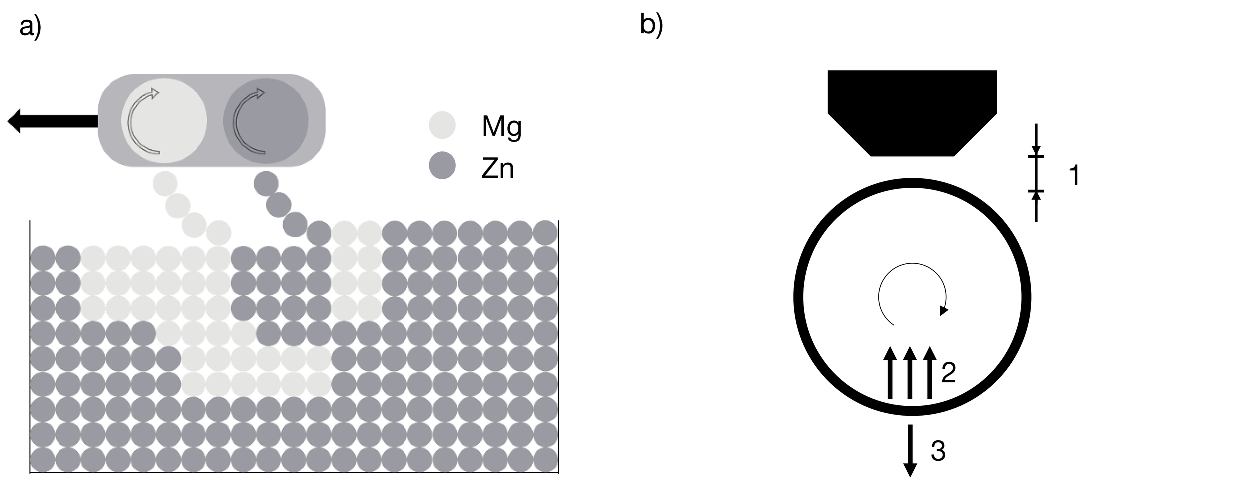

Fig. 1: a) drum-based multi-material recoating approach PEO-process; b) recoating parameters: 1 - height of the hopper unit, 2 - suction pressure, 3 - ejection pressure

Materials and Methods

Gas atomized, pre-alloyed Zn1Mg and WE43MEO powder was used to carry out the tests. All specimens were manufactured using a modified LPBF system from Aconity 3D GmbH with the option to integrate a drum-based recoating module from Schaeffler Aerosint SA allowing a layer wise combination of two different powder materials (Fig. 1 a). To study the deposition accuracy of the recoating module the parameters of the system were varied including the ejection and suction pressure as well as the height of the hopper unit (compare Fig. 1 b). The layer thickness was measured using a wet film comb. Additionally, the optimum build plate material was identified fabricating a total of 48 cuboid specimens with different volume energy density as well as support structure geometries. In a next step, both materials were printed on top of each other (Fig. 2) by variation of the bonding parameters between both materials targeting to produce samples with a crack free bonding interface.

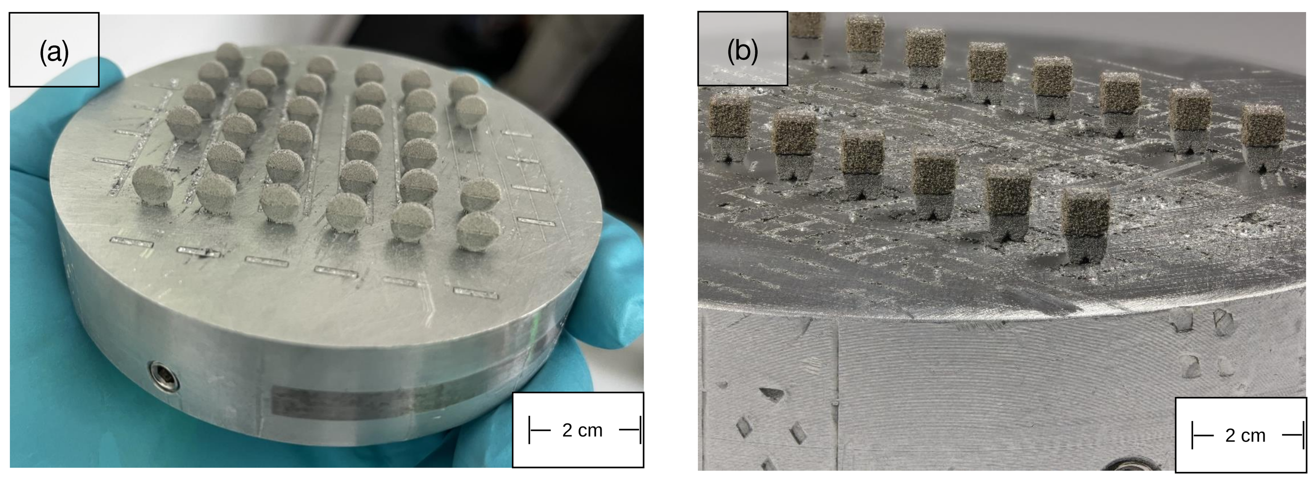

Fig. 2: a) multi-material Zn-Mg coins; b) multi-material Zn-Mg cuboid specimens

Results

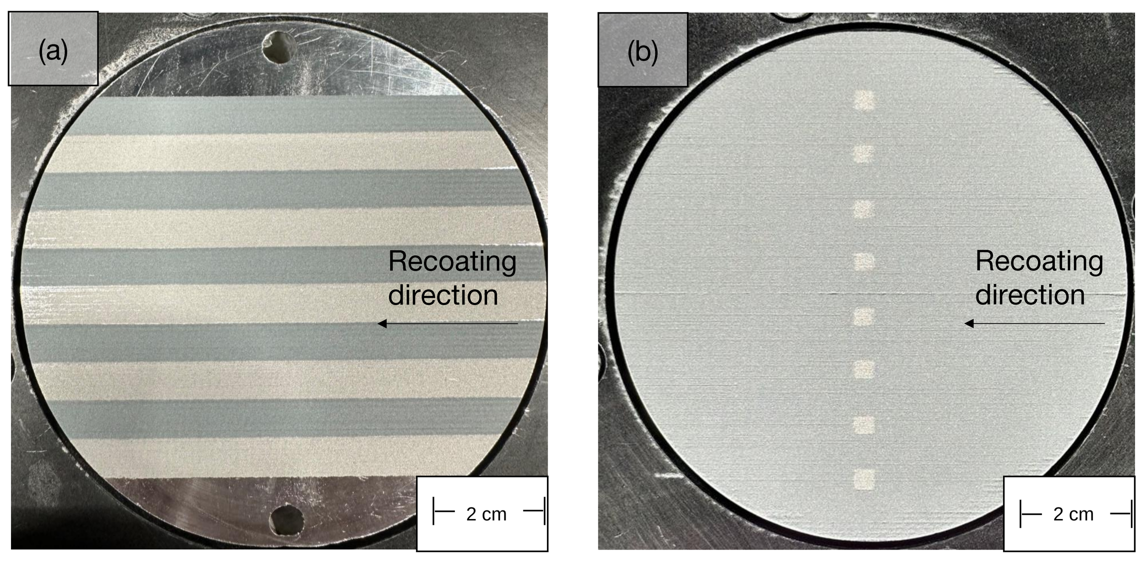

Fig. 3: layer wise powder deposition of Zn1Mg and WE43MEO powder using optimized parameters of the drum-based recoating module combining a) stripes of 7 mm width; b) 3 mm squares of WE43MEO and remaining Zn1Mg

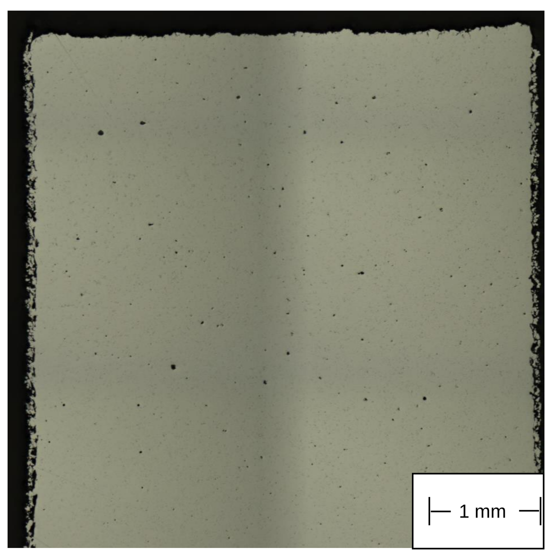

Fig. 4: cross section image of Zn1Mg cuboid specimen printed on a WE43 build plate with a relative density of 99,74%

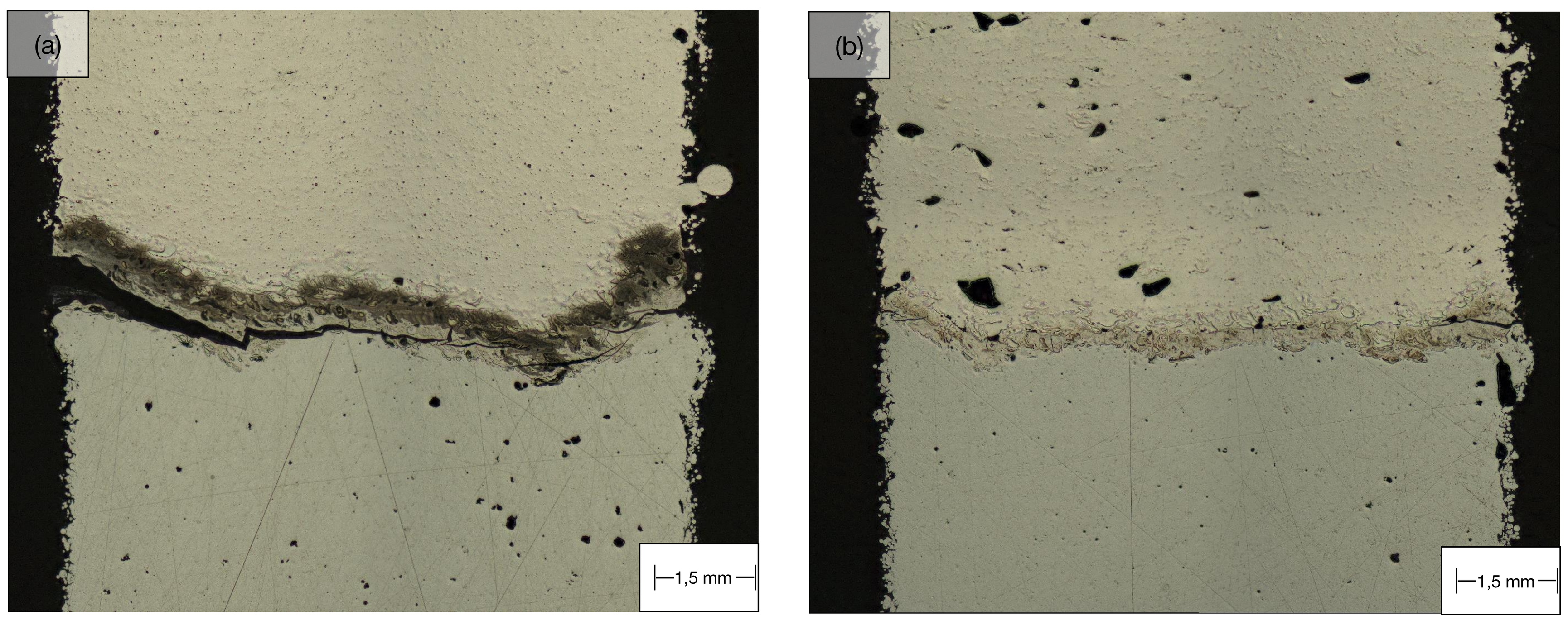

Fig. 5: a) multi-material Zn-Mg cuboid specimen with insufficient bonding interface including cracks; b) multi-material Zn-Mg cuboid specimen with sufficient bonding interface without cracks

Figure 3 shows images of the layer wise powder deposition of Zn1Mg and WE43MEO powder using the drum-based recoating module. In this context, the layer thickness and the dimensional accuracy was optically investigated. Stripes with a width of 7 mm show a layer thickness of 30 µm in the center of the build plate. However, a decreasing gradient is observed in recoating direction especially for the WE43MEO stripes (Fig. 3 a). The dimensional accuracy was evaluated by depositing eight WE43MEO squares of 3 mm length and remaining Zn1Mg powder (Fig 3 b). The squares show an anisotropy of 16,67% between recoating direction and perpendicular to the recoating direction leading to a reduced reproducibility within one layer deposition. To identify a suitable build material for multi-material LPBF processing, WE43MEO samples are printed on a Zn1Mg build plate and vice versa. While the first combination leads to process abortion due to insufficient bonding of the samples, it is feasible to manufacture Zn1Mg samples on a WE43MEO build plate. An exemplary cross section image of a Zn1Mg cuboid specimen is shown in Figure 4 showing a relative density of 99,74%.

The bonding behavior of both powder materials was evaluated using cross section images (Fig. 5). Using the optimum WE43MEO processing parameter on the one hand leads to a high relative density of 99,9% of the top part. On the other hand, a burning effect is observed on the whole bonding interface generating a consecutive crack at the bonding zone and an increase of gas pores in the Zn1Mg bottom part (Fig. 5 a). The opposite is shown in Fig. 5 b, as the Zn1Mg bottom part remains with high relative density and the bonding interface is homogeneous without defects. However, the WE43MEO remains with significantly decreased relative density suggesting a gradual adjustment of the LPBF parameters during processing.

Discussion and Conclusion

The aim of this study was to show the challenges and opportunities of the multi-material LPBF processing of biodegradable Zn1Mg and WE43MEO alloys. A sufficient build plate material was found as both materials were manufactured with a reproducible relative density > 99.5% on a WE43 plate. Moreover, the general feasibility of combining both powder materials in printing direction was shown leading to a sufficient bonding interface without defects. Additional parameter studies will be carried out to increase the relative density outside of this bonding interface. In further investigations the mechanical and degradation properties will be determined. The parameter optimization of the drum-based recoating unit led to a layer wise combination of both powders representing the basis of the processing within one layer which will be studied. Future studies will focus on increasing the dimensional accuracy of the deposition as well to extend the geometric flexibility towards application orient prototypes.

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REFERENCES: [1] M. Li et al. (2021): Microstructure, mechanical properties, corrosion resistance and cytocompatibility of WE43 Mg alloy scaffolds fabricated by laser powder bed fusion for biomedical applications, Materials Science & Engineering C, 119, pp. 1-17
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