RESEARCH ARTICLE

Biodegradable Zinc-Magnesium Alloy Scaffolds with Controlled Porosity for Bone Tissue Engineering

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Abstract: This work reports the design, fabrication, and in vitro evaluation of biodegradable Zn-3Mg alloy scaffolds with graded porosity produced by selective laser melting (SLM). Three scaffold architectures with porosities of 45%, 60%, and 75% were designed using triply periodic minimal surface (TPMS) gyroid topology. Mechanical testing revealed that the 60% porosity scaffold achieves a compressive strength of 48 MPa and elastic modulus of 3.2 GPa, closely matching the properties of cancellous bone. In vitro degradation studies in simulated body fluid (SBF) demonstrated a controlled corrosion rate of 0.18 mm/year, with the formation of biocompatible hydroxyapatite surface layers. Cell culture experiments with MC3T3-E1 osteoblasts confirmed excellent cytocompatibility with >92% cell viability after 7 days.

1. Introduction

Metallic biomaterials for orthopedic implants and bone tissue scaffolds ideally should degrade in vivo at a rate matching new bone formation, eliminating the need for secondary removal surgery. Among biodegradable metals, zinc-based alloys have gained recent attention due to their moderate degradation rate (between rapidly corroding Mg and slowly degrading Fe alloys), essential biological role as a trace element, and favorable antibacterial properties.

Additive manufacturing, particularly selective laser melting (SLM), enables the fabrication of complex scaffold geometries with precisely controlled porosity and pore interconnectivity — features that are critical for nutrient transport, cell migration, and neo-vascularization within the scaffold.

2. Experimental

Zn-3Mg (wt%) pre-alloyed powder (particle size 15-45 μm) was produced by gas atomization. SLM was performed using a Concept Laser M2 system with optimized parameters: laser power 100 W, scan speed 600 mm/s, hatch spacing 80 μm, layer thickness 30 μm. Three TPMS gyroid scaffold designs were created in nTopology with target porosities of 45%, 60%, and 75%.

Table 1. Designed vs. measured scaffold parameters after SLM fabrication

Scaffold	Target Porosity (%)	Measured Porosity (%)	Strut Thickness (μm)	Pore Size (μm)
G-45	45	43.8 ± 1.2	420 ± 15	380 ± 22
G-60	60	58.5 ± 1.8	310 ± 12	520 ± 28
G-75	75	73.2 ± 2.1	200 ± 18	680 ± 35

3. Results and Discussion

The compressive stress-strain behavior of the three scaffold designs was evaluated and compared with the mechanical properties of natural bone. The G-60 scaffold demonstrated the best balance between mechanical performance and biological requirements.

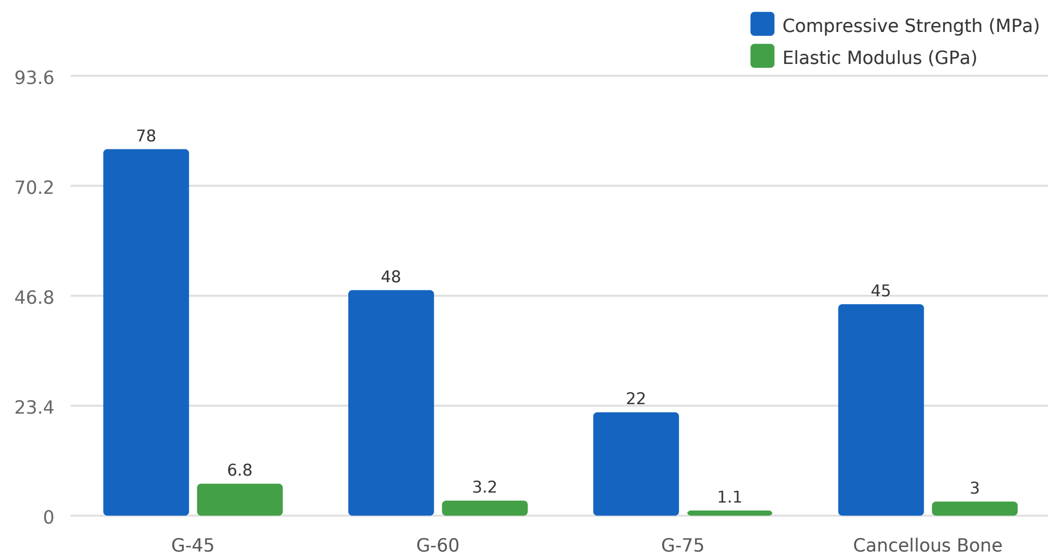

Figure 1. Compressive strength and elastic modulus of Zn-3Mg scaffolds compared to natural bone ranges (shaded region represents cancellous bone properties)

The in vitro degradation behavior was monitored over 8 weeks in simulated body fluid at 37°C. pH measurements, mass loss, and ion release were recorded at weekly intervals. The degradation rate of the G-60 scaffold was 0.18 mm/year, which falls within the clinically acceptable range for orthopedic applications.

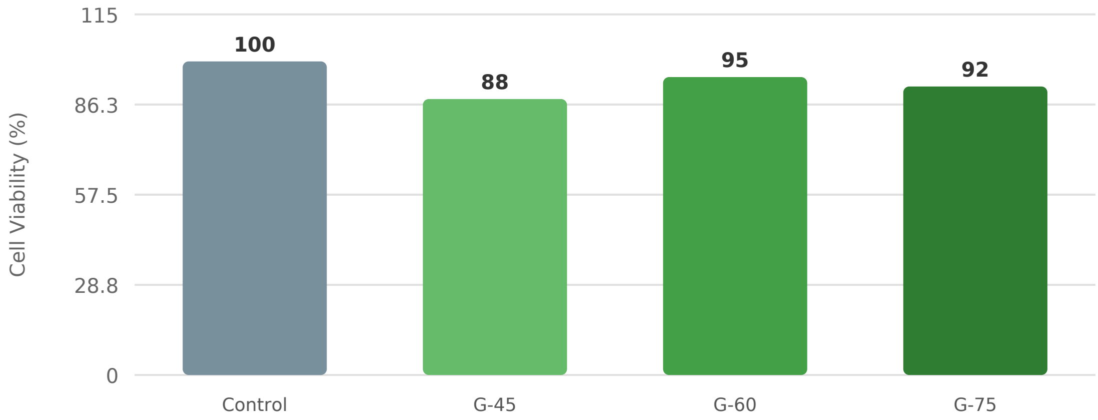

Figure 2. Cell viability (%) of MC3T3-E1 osteoblasts cultured on scaffolds and control surfaces over 7 days

4. Conclusions

Biodegradable Zn-3Mg alloy scaffolds with TPMS gyroid architecture were successfully fabricated by SLM with precise porosity control. The G-60 scaffold (60% porosity) offers the optimal combination of cancellous-bone-matching mechanical properties, controlled degradation rate, and excellent cytocompatibility, making it a promising candidate for load-bearing bone defect repair applications.

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