Finite element analysis of Elastic Property of Biomedical Co-Cr-Mo Lattice Structure Fabricated by Electron Beam Powder Bed Fusion

Our objective is to apply finite element analysis to compute equivalent modulus of cellular lattices of biomedical Co-Cr-Mo-alloy with optimization shape. Firstly, the finite element analysis (FEA) model is established to predict effective elastic tensor of a 4×4×4 cells based on experimental boundary conditions. Effective elastic tensor predicted by FEA simulation is compared with experimental results. For ρ =0.3, the results of elastic tensor prediction show that computational model achieves good agreement with experimental data to some extent. However, for ρ =0.2, there exists some difference between experimental data and computational model in x direction.

With a view to developing a biocompatible and reliable material to be embedded in femoral bone, cellular lattice structures with high strengths and low Young's moduli (*E*) are highly desired. Additive manufacturing (AM) of cellular lattices are promising candidates owing to the tunability of mechanical properties. We applied finite element analysis based on Dirichlet boundary conditions to obtain the effective elastic properties of cellular lattices of biomedical Co-Cr-Mo-alloy with optimized shape for different relative densities (ρ). Boundary condition $u_z = 0$ mm is applied at the bottom surface and $u_z = -1$ mm is applied at the top surface. To eliminate rigid body displacement, two points at bottom are fixed. Triangular mesh is generated in this case with 2,997,440 elements. The material properties employed in the FEA are shown in Table 1.

The distribution of total von-Mises stress evaluated by FEA for ρ=0.2 is shown in Fig. 1.
In this case, we apply

$$\varepsilon_z = 1,\ \varepsilon_x = \varepsilon_y = \gamma_{yz} = \gamma_{xz} = \gamma_{xy} = 0 \qquad (2)$$

The strain energy S is

$$S = \frac{1}{2} E_z \varepsilon_z^2 \cdot V \qquad (3)$$

where V is volume of cells. According to Eq. (3), the equivalent modulus of cells in z direction is derived from the strain energy obtained thru FEA, and the resulting value is shown in Table 2. Similarly, equivalent elastic modulus in x direction is obtained and resulting value is given in Table 2. The equivalent modulus in the z direction obtained for from FEA can agree with experimental result to some extent, with error around 16.4%. However, in x direction, there exists a relatively large difference between experimental and numerical results, with error around 39%.

Table 1. Material properties used for FEA

E_Z (GPa)	E_X, E_y (GPa)	G_{xz}, G_{zy} (GPa)	ν_{xy} (–)
150	200	50	0.15

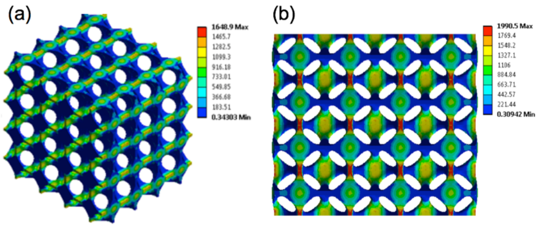

Fig. 1 Finite element result from compression in z-direction showing (a) bird's eye view, (b) von Mises stress, and (c) strain energy.

For ρ=0.3, similar procedure is conducted using FEA, and the equivalent moduli obtained can be found in Table 3. It is obvious that elastic modulus E_z from FEA achieves great agreement with experimental data, with error less than 5%. For elastic modulus E_x, experimental result is higher than FEM results, with error less than 15%.

Table 2. Equivalent modulus for ρ=0.2

	Experiment (GPa)	Numerical (GPa)	Error (%)
E_z	11.2	9.36	-16.4
E_x	20	12.09	-39.5

Table 3. Equivalent modulus for ρ=0.3

	Experiment (GPa)	Numerical (GPa)	Error (%)
E_z	17.6	18.03	2.4
E_x	26.8	23.24	-13.28

References

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Keywords: biomedical, cellular (material form), mechanical properties
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