Simulation of Mechanical Compression of Bone Tissue Engineering Scaffolds

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Introduction

Significance:

- Bone Tissue Engineering Scaffolds are 3D-printed structures that could degrade in the body and provide surface area for stem cell attachment, proliferation and differentiation.
- Porous scaffolds show promise to enhance osteogenesis due to increased nutrient and waste transport.
- Porosity design needs to have desirable mechanical characteristics.

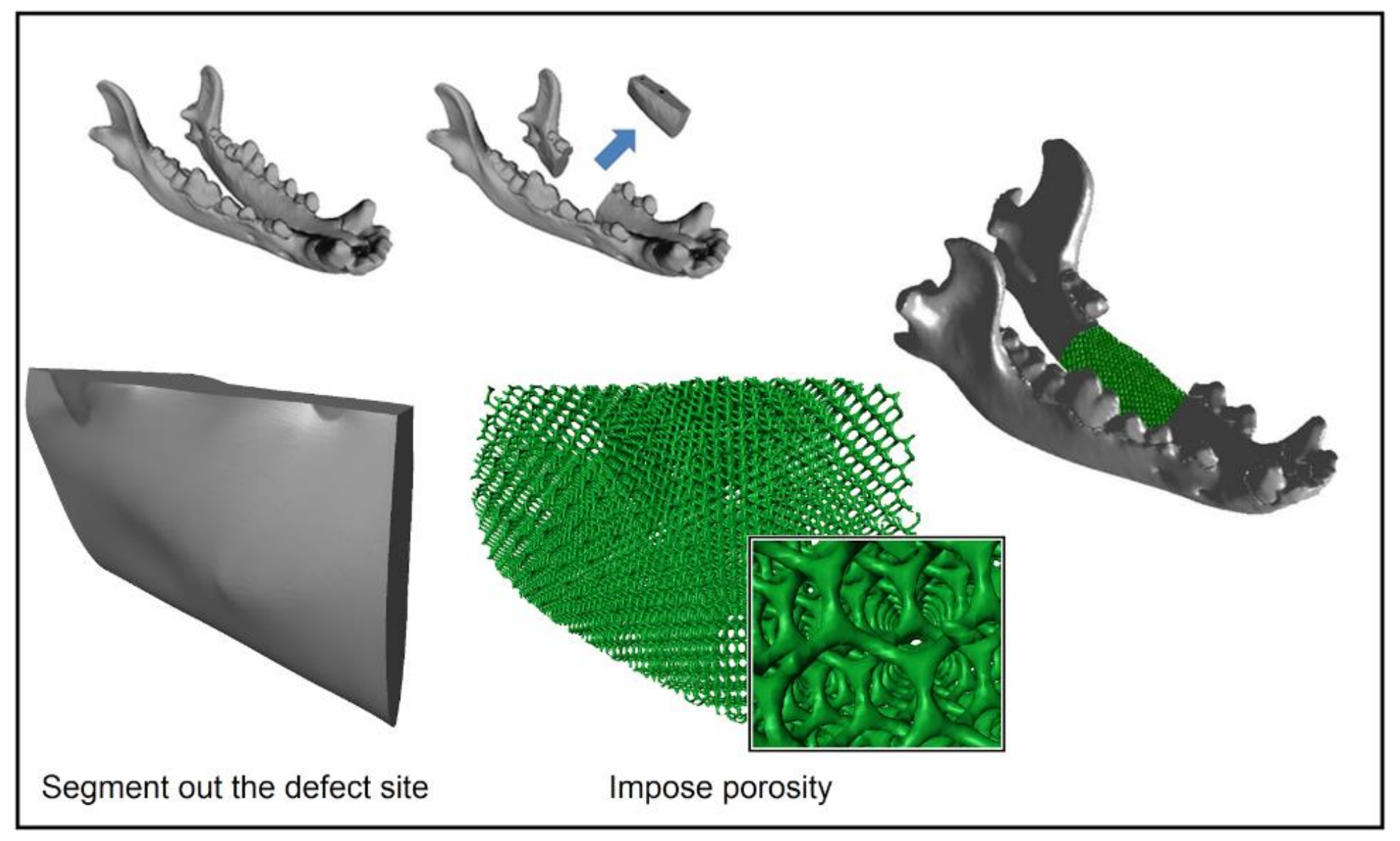


Figure 1: Work Flow to Create a Porous Implant

Hypothesis:

- Gyroid-type Schoen's Triply Periodic Minimal Surfaces (TPMS) scaffold has better mechanical integrity than that of a scaffold with orthogonal pore channels.

Goals:

- Assess the mechanical behavior of the two scaffold designs
- Conduct compression simulations using finite element analysis software ABAQUS (Dassault Systèmes/ABAQUS Inc.)
- Statistical analysis of the stress at each point on the discretized surface to quantify the behavior of stress across the structures of the scaffolds.

Materials and methods:

Computer Aided Designs (CAD) of Scaffold Structures

- A distance field method [1] and gyroid-type triply periodic minimal surface (TPMS) were used to generate TPMS scaffolds
- Orthogonal scaffolds were generated from an octahedral unit structure.
- Uniform "plates" on top and bottom of scaffold were created to assist with setting up boundary conditions in compression simulations

Table 1: Scaffold Parameters

Parameter	Value
Height	4 mm
Diameter	4 mm
Strut Dimension	200 um
Porosity	88.22%
Material's Young Modulus	75 MPa
Poisson's Ratio	0.3

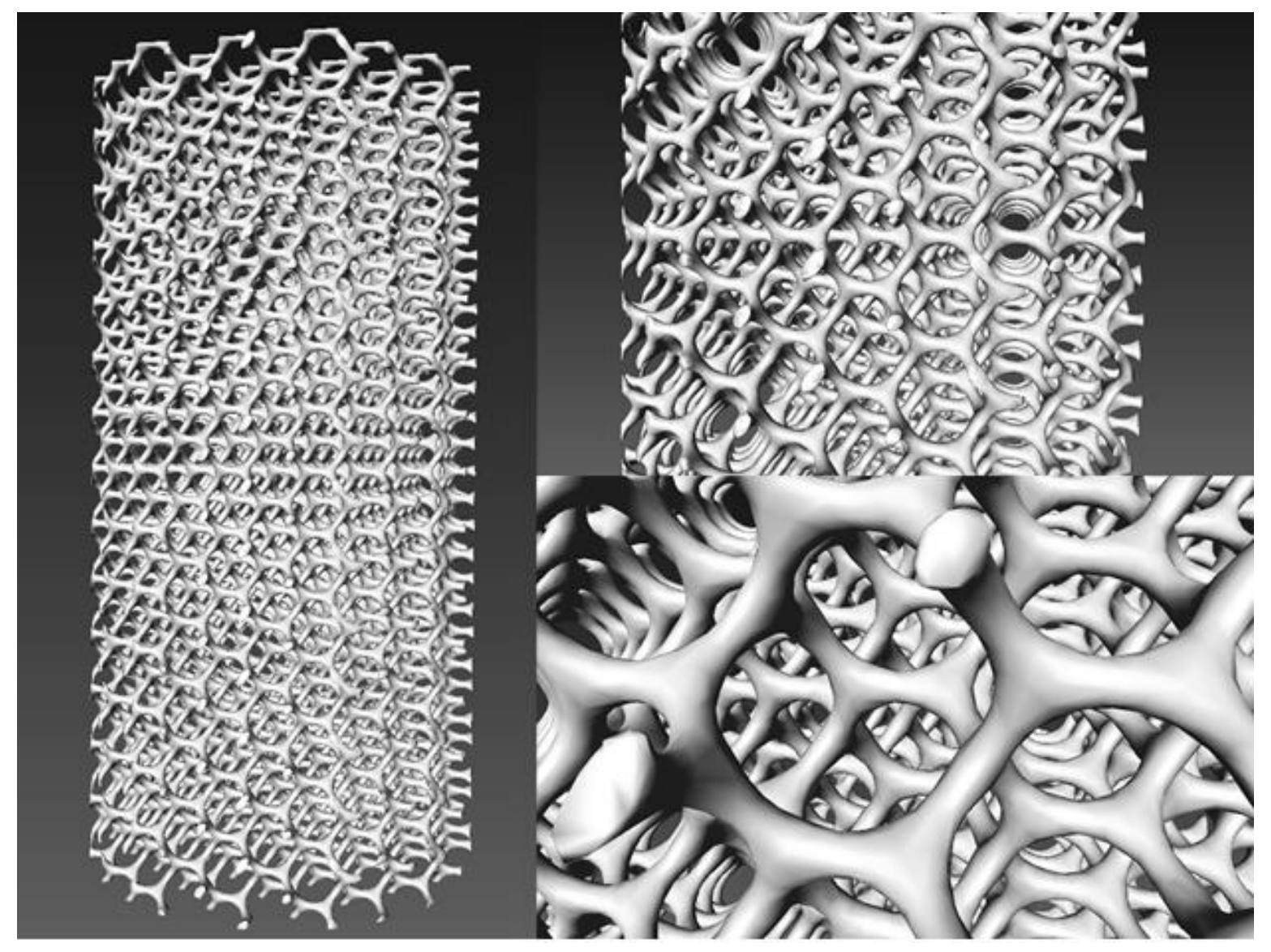
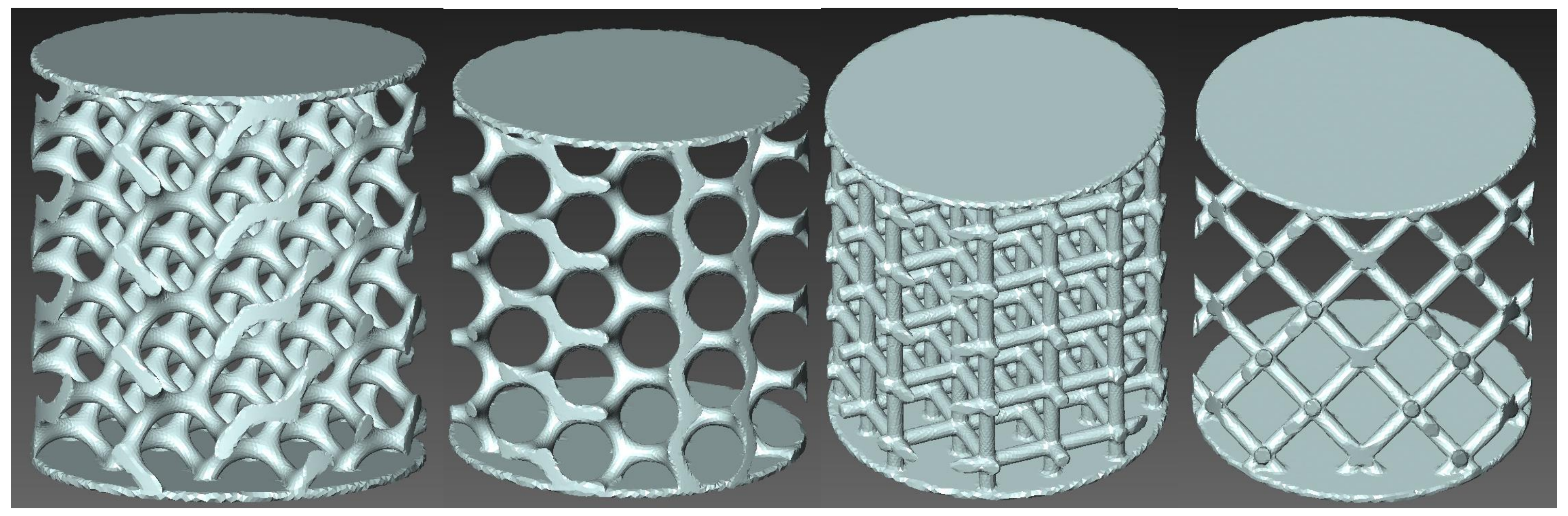


Figure 2: Gyroid Structure



Gyroid - 1 Gyroid - 2 Orthogonal - 1 Orthogonal - 2

Figure 3: CAD models of scaffolds

Table 2: Comparison of Scaffolds' Dimensions

Scaffold Structure	Actual Volume (mm^3)*	Surface Area (mm^2)*	SA/V ratio
G Surface – Direction 1	8.27	153.7	18.59
G Surface - Direction 2	8.18	152.4	18.63
Orthogonal - Direction 1	8.61	165.1	19.18
Orthogonal - Direction 2	8.33	158.3	19.00

*The plates were included in the measurement of volume and surface area of the scaffolds

Compression Simulations

- The STL files were remeshed and refined in Amira Software (FEI, Hillsboro, OR)
- The average number of faces of the 4 structures is around 150,000 faces
- In ABAQUS simulations, the bottom plate is fixed and the top plate is displaced towards the bottom.

Table 3: Boundary Conditions of the Plates

Plate	Boundary Conditions (BCs)
Top	Encastre, except for axial direction
Bottom	Encastre

Table 4: Displacement and Strain

Displacement	Strain
0.1 mm	2.5%
0.2 mm	5%
0.4 mm	10%

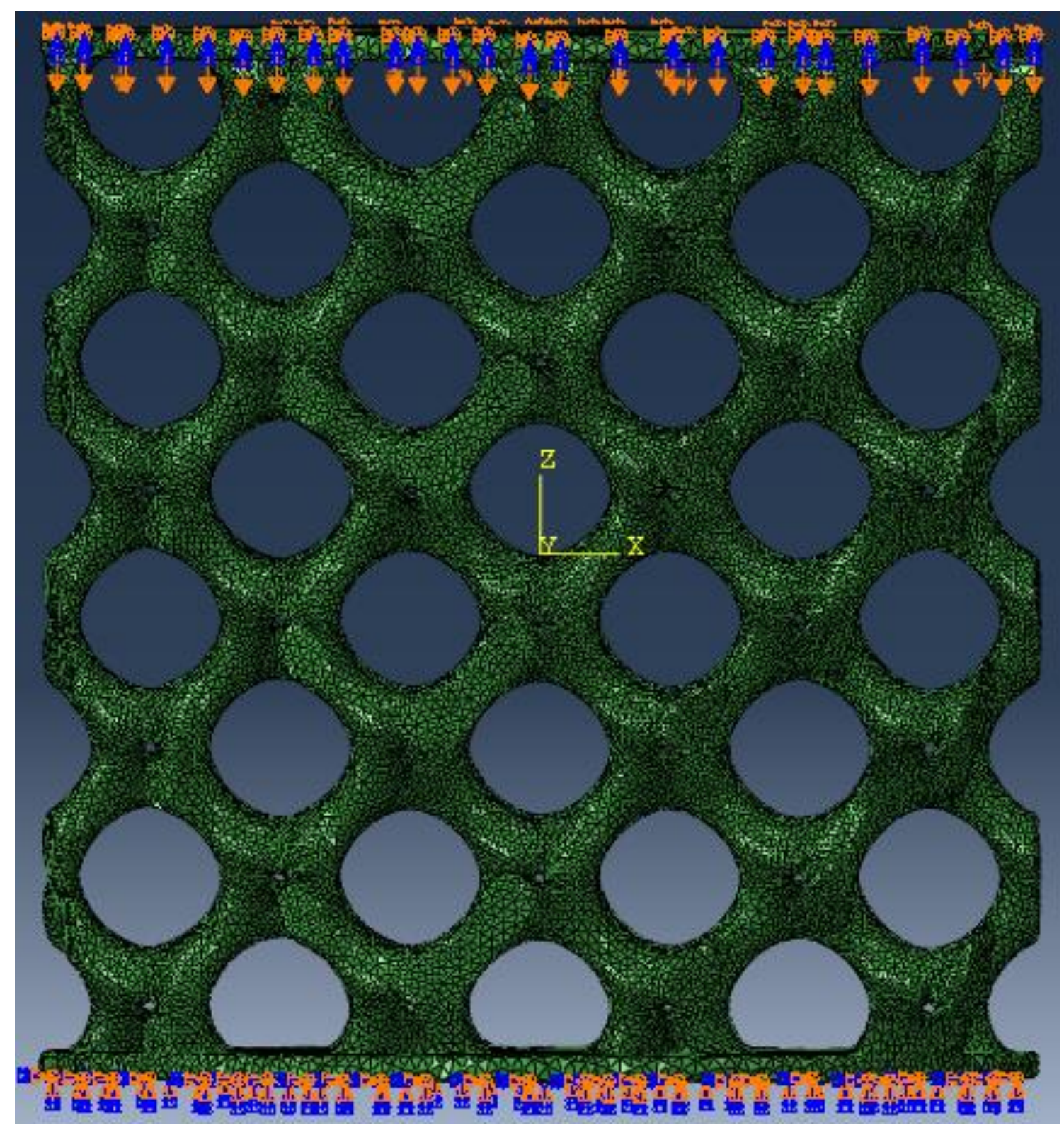


Figure 4: BCs of the Top and Bottom Plates

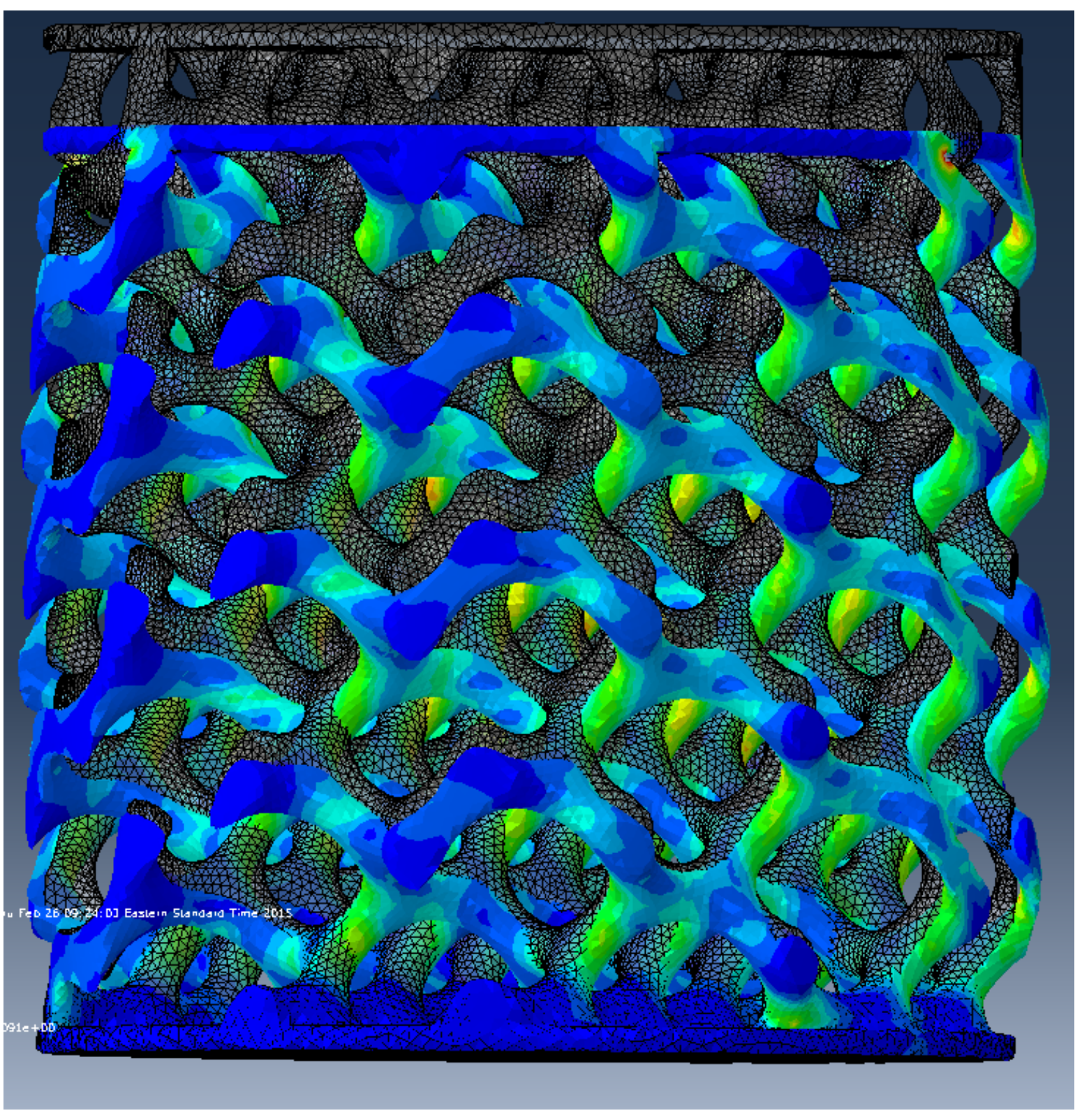
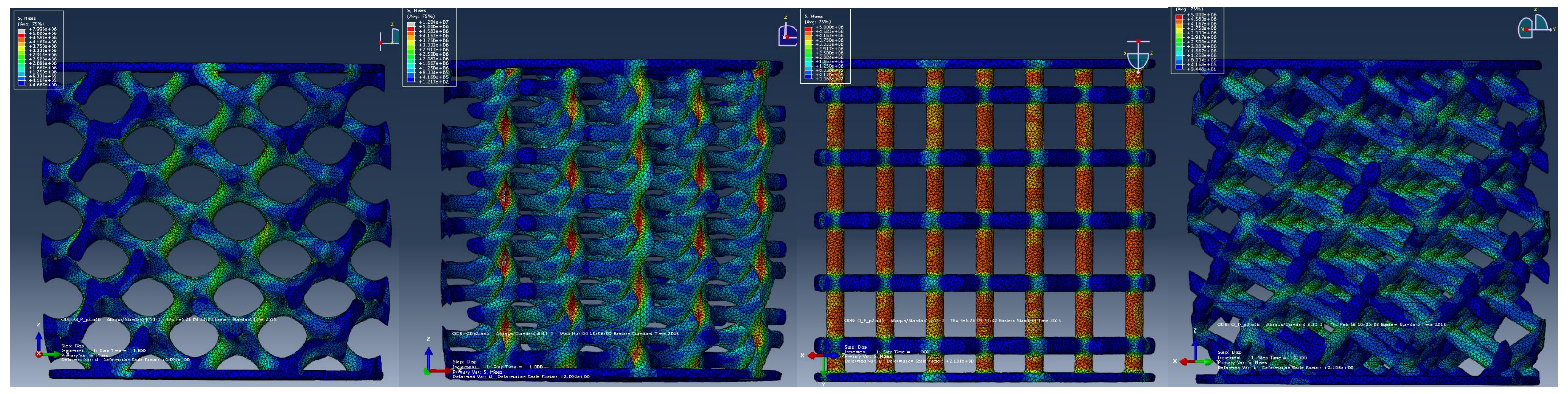


Figure 5: Compression of a scaffold at 5% strain

Results



Gyroid - 1 Gyroid - 2 Orthogonal - 1 Orthogonal - 2

Figure 5: Von Mises Stress Visualizations at 5% Strain

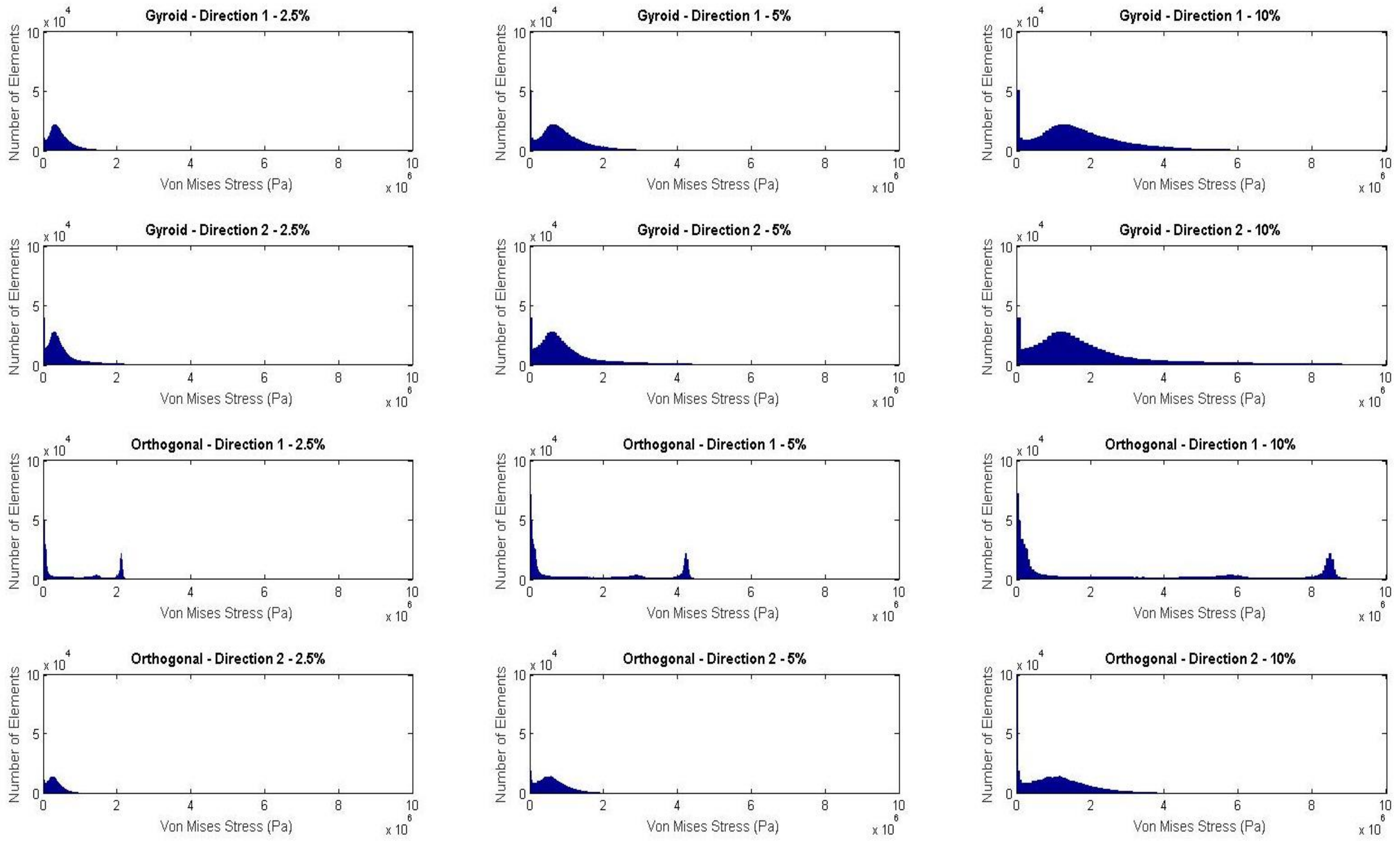


Figure 6: Histograms of the Stress Results

Conclusions

- Stress distribution in G Surface scaffolds is more independent of load direction (more isotropic) than that of orthogonal scaffolds.
- Orthogonal 1 has a disruptive distribution. Orthogonal 2 is the best structure mechanically.
- More stable mechanical behavior can help with scaffold handling, cell seeding and culturing, implantation, and degradation of the scaffolds.
- Experimental compressions of the scaffolds will be conducted to validate the simulation results.

References

1. Yoo DJ. Porous scaffold design using the distance field and triply periodic minimal surface models. Biomaterials;32(2011):7741-7754

Acknowledgments

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