IMAGE-BASED SIMULATION OF LATTICE STRUCTURES PRODUCED BY LASER POWDER BED FUSION

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Keynote

UNIVERSITEIT iYUNIVESITHI STELLENBOSCH UNIVERSITY 100

Research group 3D INNOVATION

CPAM

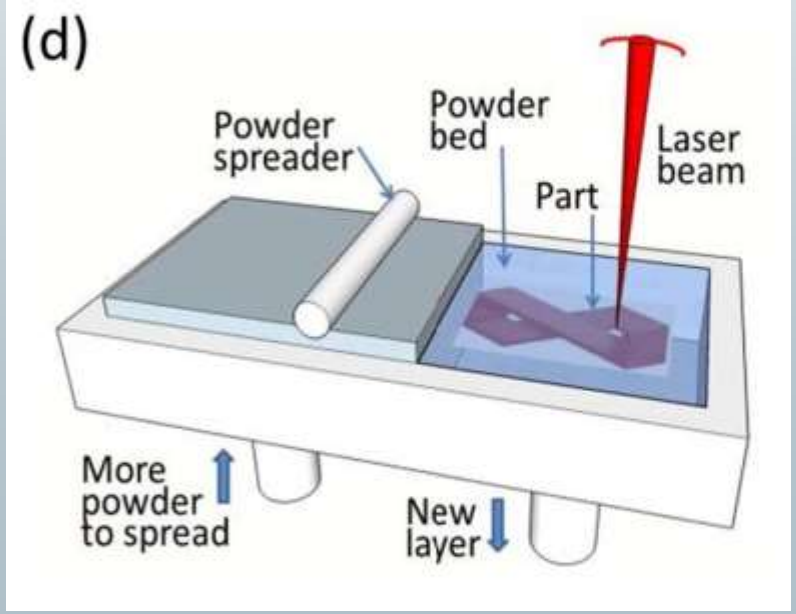
CT FACILITY STELLENBOSCH

Outline

→ Additive manufacturing
→ X-ray tomography for AM
→ Biomimicry and cellular structures
→ Lattice structures by L-PBF
→ Image based simulations of lattices
→ Conclusions

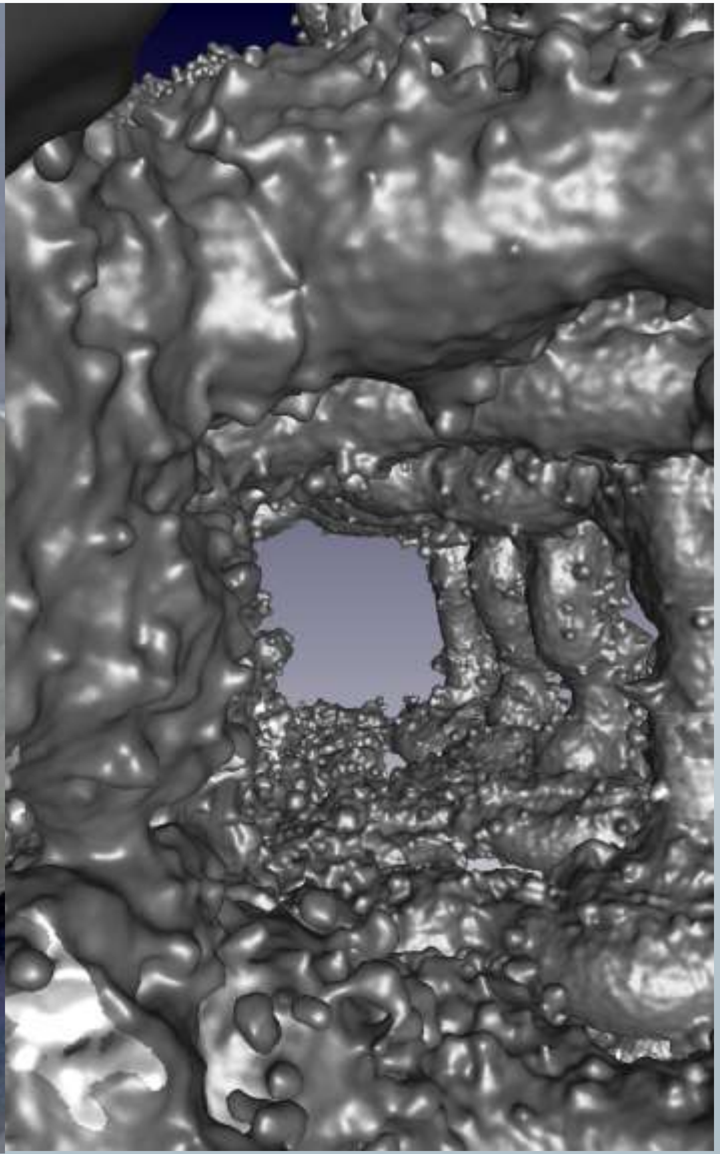
Additive manufacturing

→ Additive manufacturing (AM) / 3D printing has grown over the last decade, way past the original "prototyping" use
→ Today it is possible (and proven) to manufacture mission-critical parts
→ Various materials are possible, the most well studied metals for AM are Ti6Al4V, AlSi10Mg, and various steels
→ Laser powder bed fusion is the most widely used and best developed AM method, with the highest complexity possible in produced parts



From: DebRoy, T., et al. 2018. Additive manufacturing of metallic components–process, structure and properties. Progress in Materials Science, 92, pp.112-224.

Medical implants by L-PBF



https://www.youtube.com/channel/UCXFx_JBZVAewNE3JqM1grYA

X-ray tomography for additive manufacturing

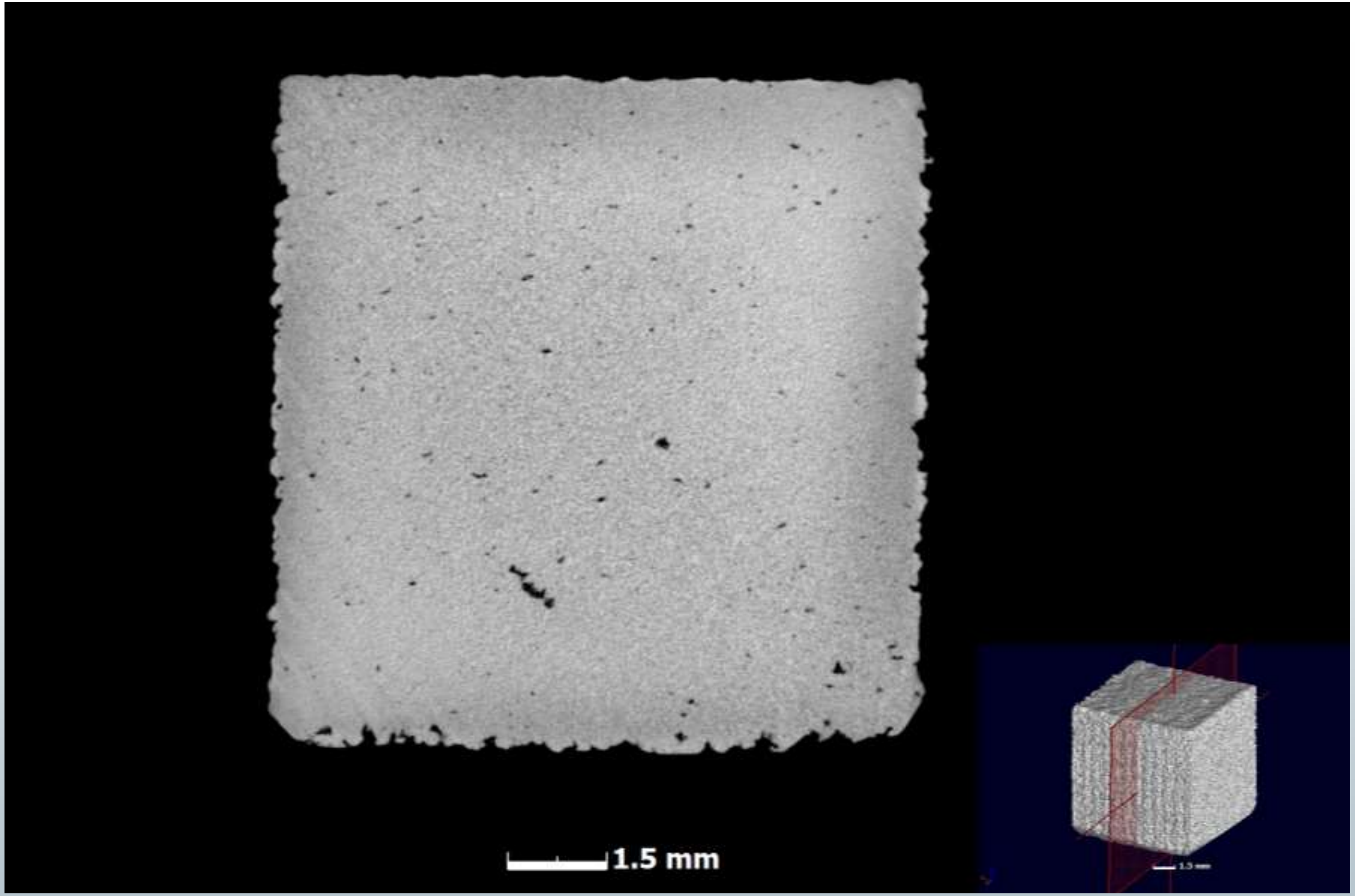
→ **Widely known already for non-destructive and quantitative analysis of AM parts for:**

- **Porosity**
- **Dimensional measurement**

→ **Other newer uses are:**

- **Analysis of powder feedstock for quality – size, shape and porosity**
- **Density**
- **Time-lapse or 4D CT**
- **Surface roughness/topography**
- **Simulations – FEM**
- **Multiscale CT, etc.**

*** X-ray microcomputed tomography in additive manufacturing: a review of the current technology and applications. *3D Printing and Additive Manufacturing*, *5*(3), pp.227-247. Du Plessis, A., Yadroitsev, I., Yadroitsava, I. and Le Roux, S.G., 2018. https://www.liebertpub.com/doi/abs/10.1089/3dp.2018.0060**



* du Plessis, A. and le Roux, S.G., 2018. Standardized X-ray tomography testing of additively manufactured parts: A round robin test. *Additive Manufacturing*, *24*, pp.125-136.
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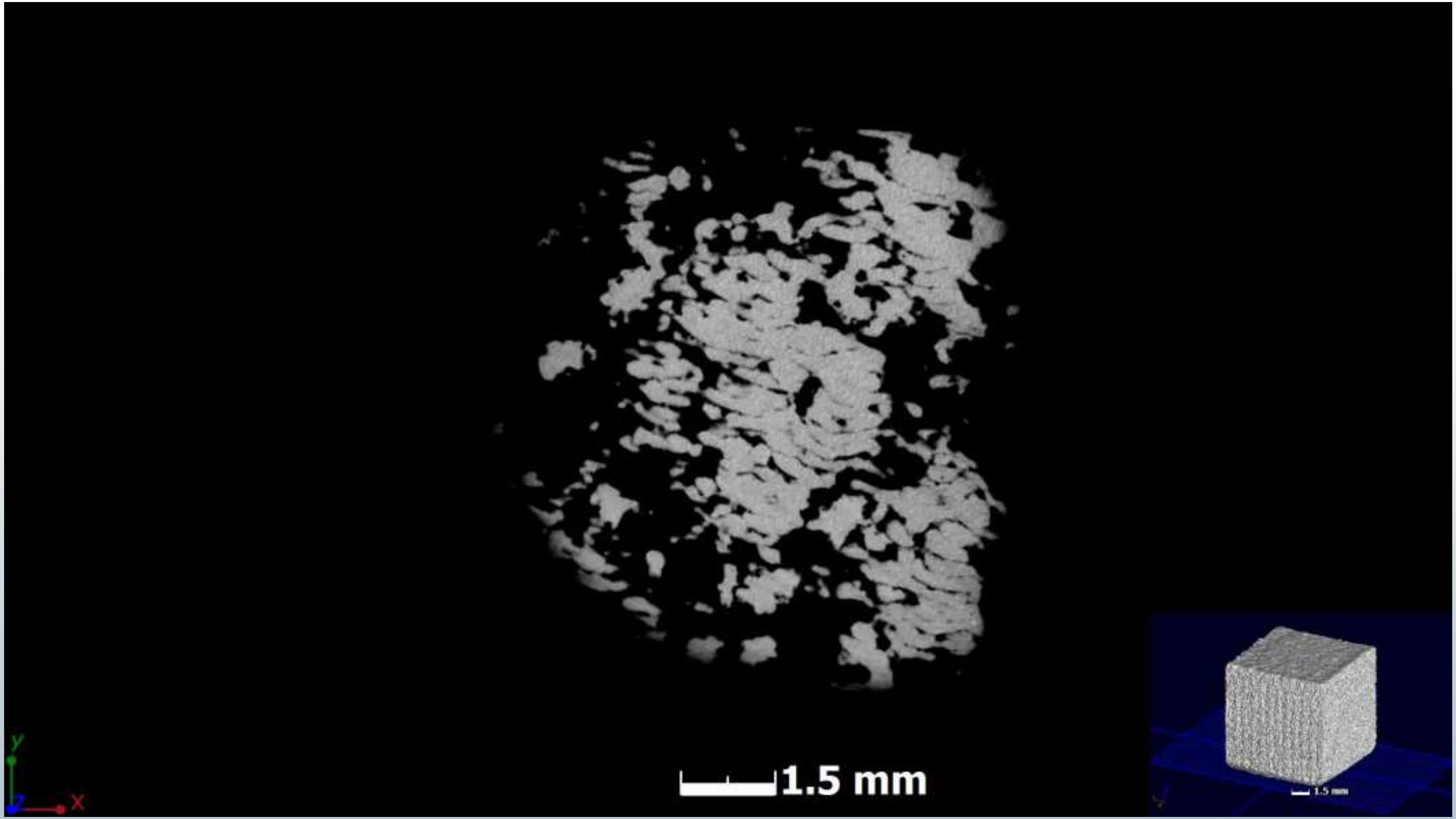

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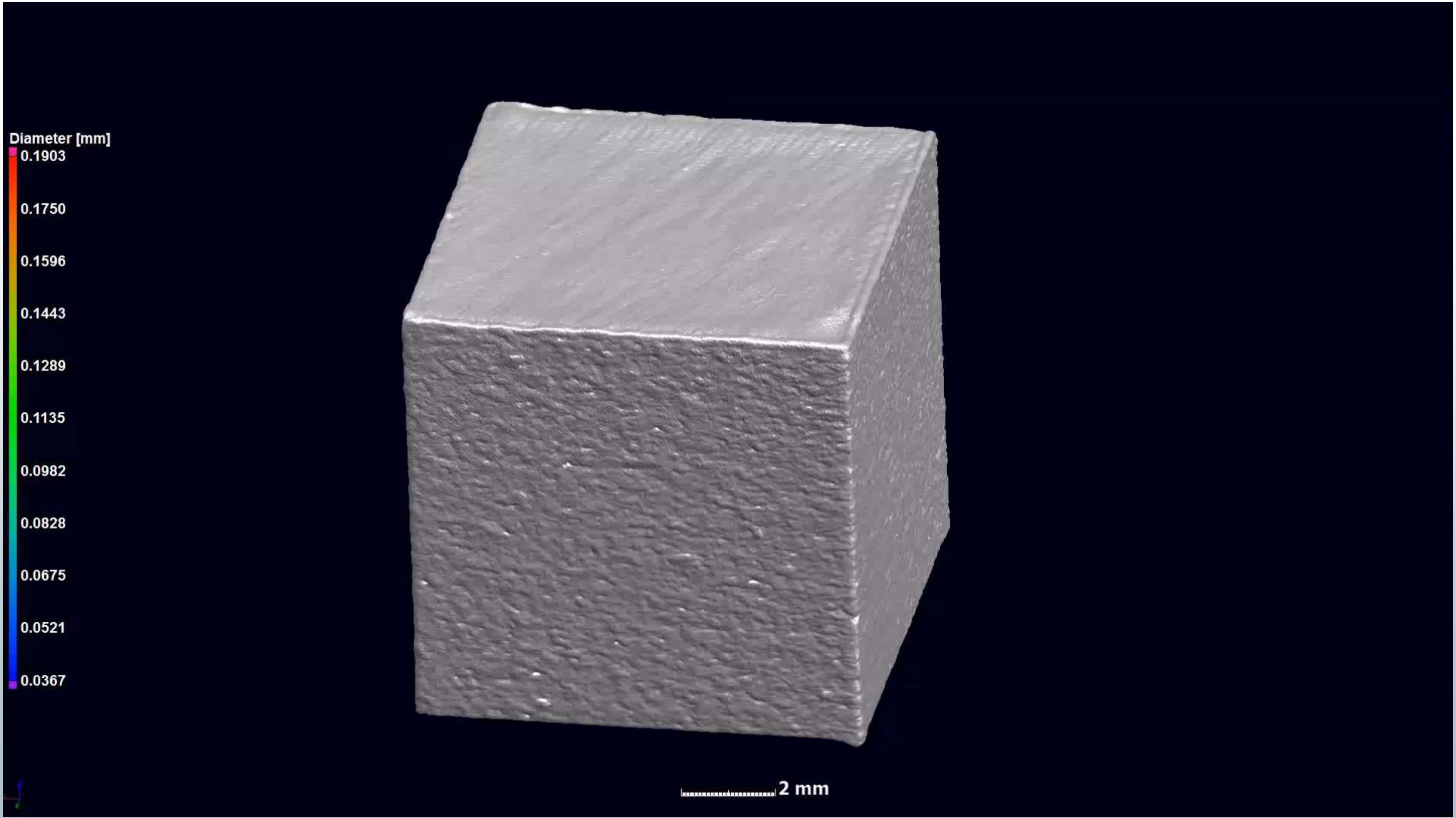
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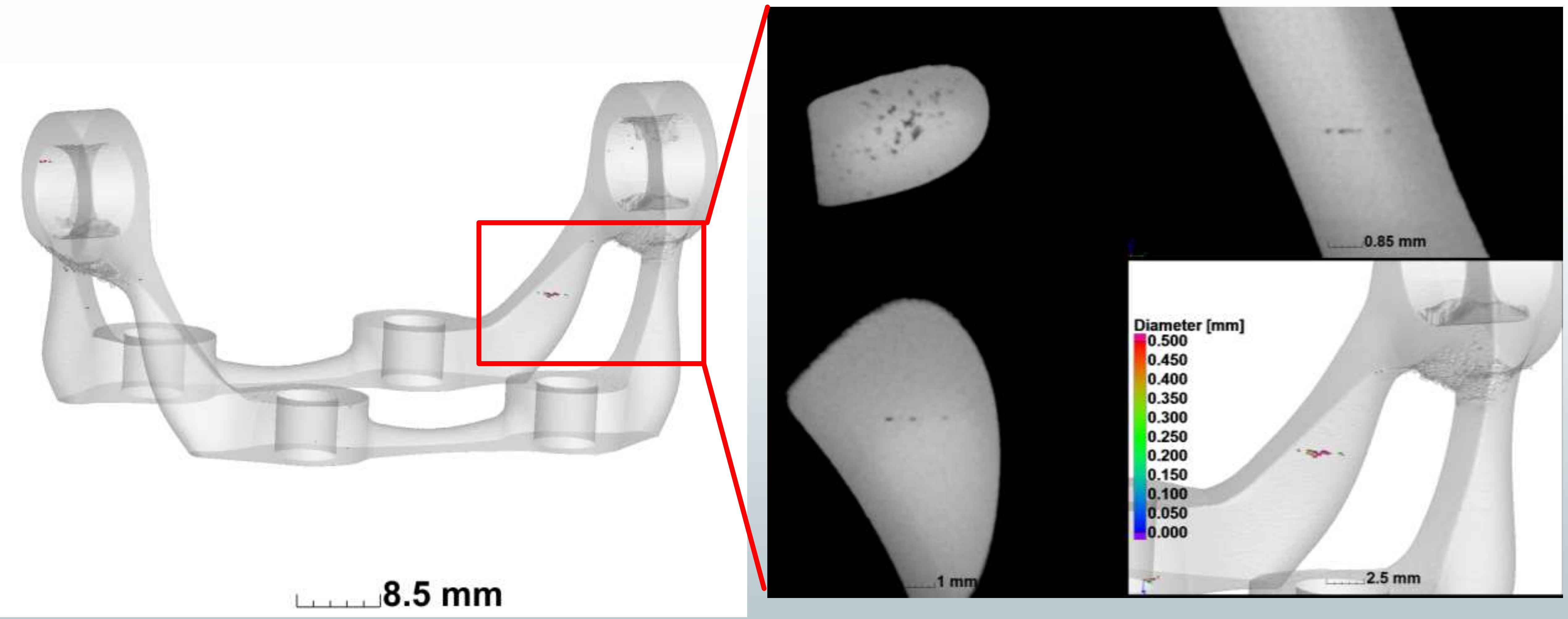
0.1750
0.1596
0.1443
0.1289
0.1135
0.0982
0.0828
0.0675
0.0521
0.0367
2 mm



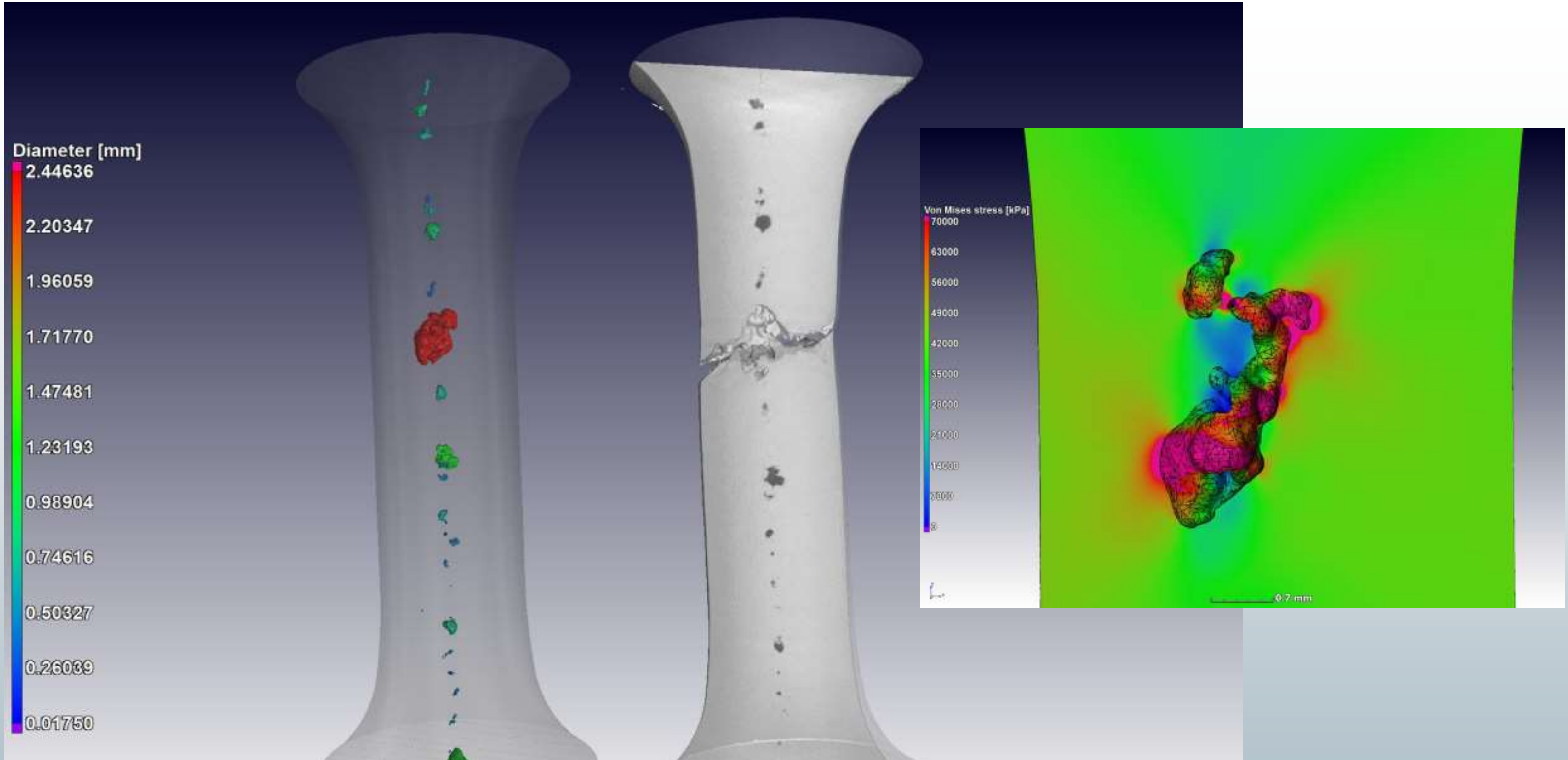
8.5 mm
0.85 mm
1 mm
Diameter [mm]
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
2.5 mm

What are the effects of build imperfections?

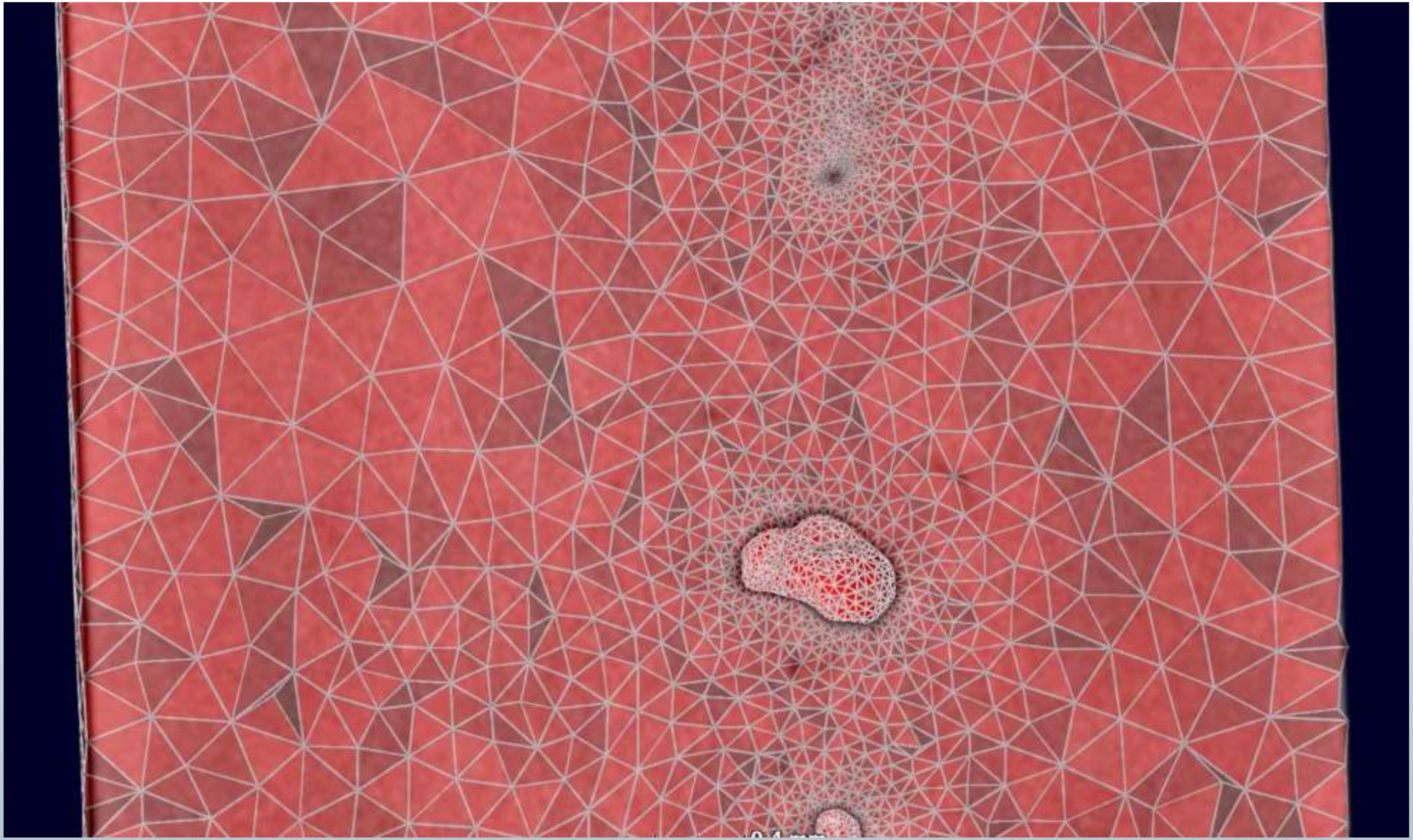
→ Manufacturing imperfections are not new at all, we can learn from other manufacturing processes

→ For analyzing porosity and its effect on mechanical properties, let’s look at casting porosity first

→ Casting pores are much bigger than LPBF pores so should be simple to understand



* Du Plessis, A., Yadroitsava, I., Le Roux, S.G., Yadroitsev, I., Fieres, J., Reinhart, C. and Rossouw, P., 2017. Prediction of mechanical performance of Ti6Al4V cast alloy based on microCT-based load simulation. *Journal of Alloys and Compounds*, *724*, pp.267-274. https://doi.org/10.1016/j.jallcom.2017.06.320



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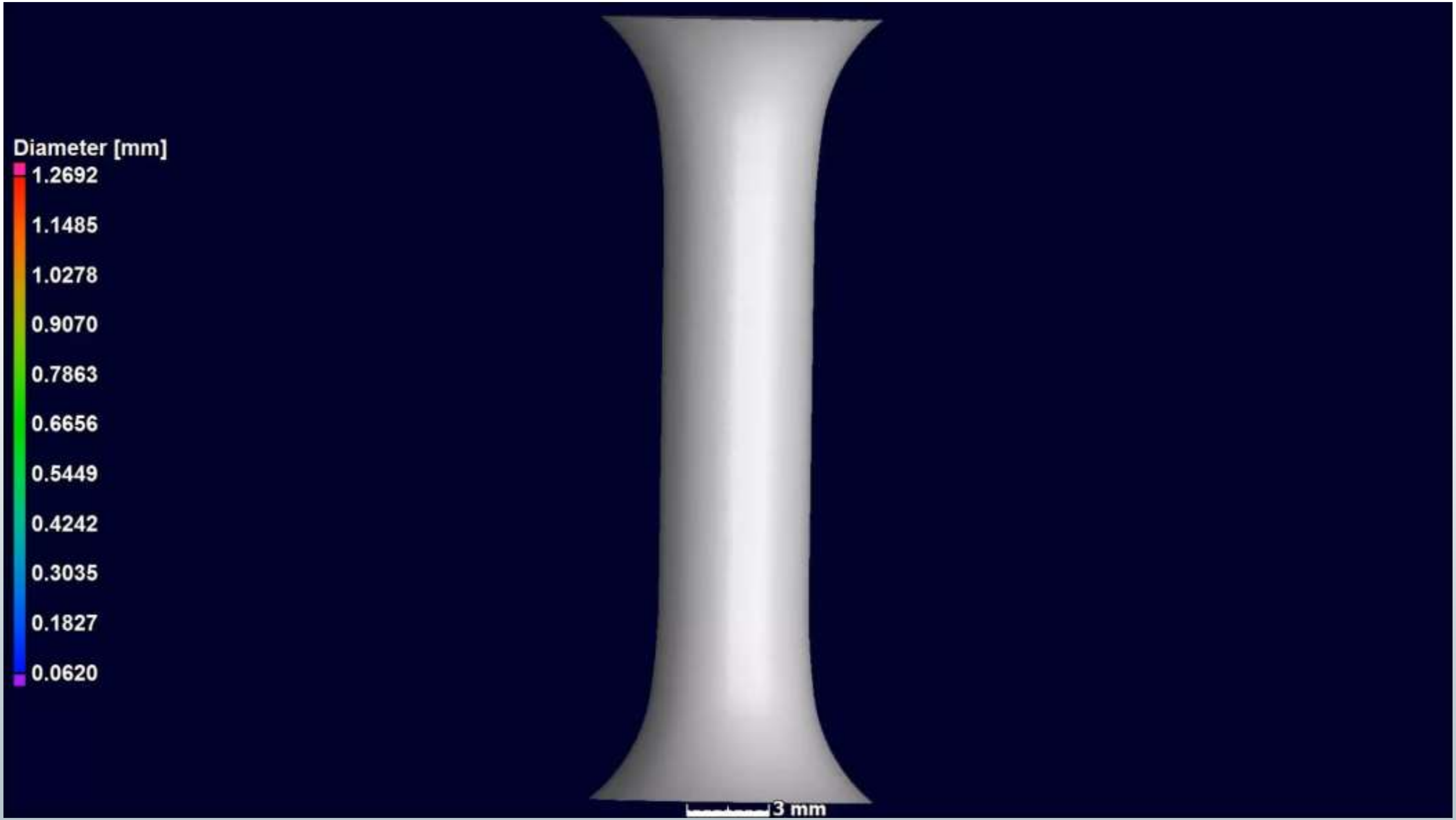

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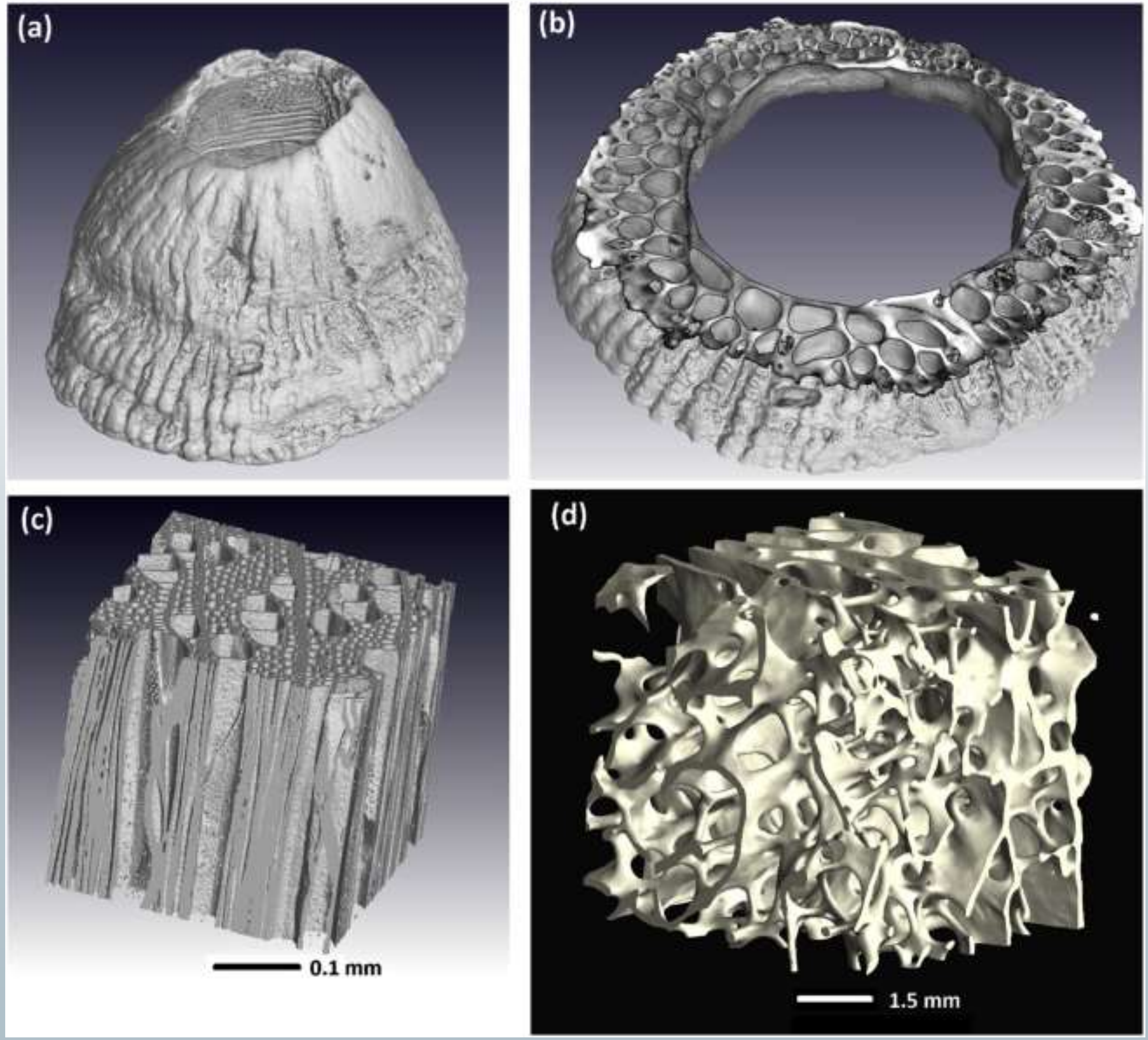
Lightweight parts: complex geometries

Cellular structures in nature

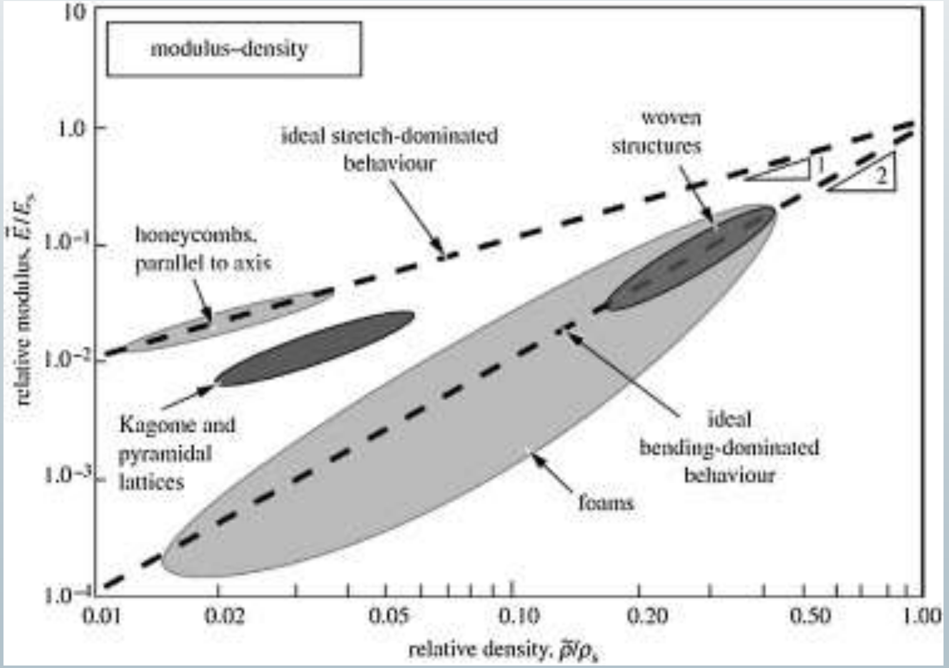


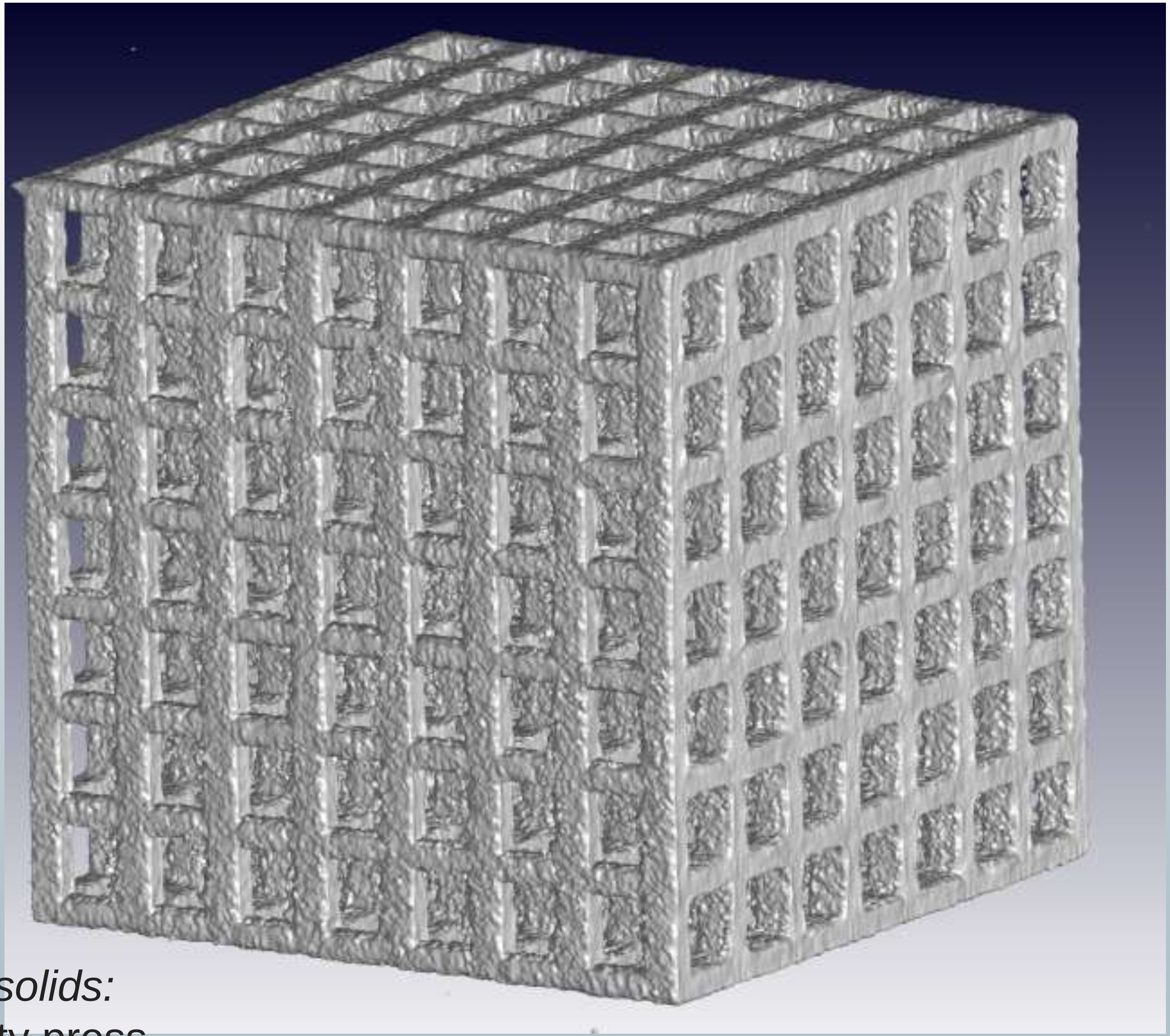
Lattice structures in additive manufacturing

1. This is about physical macroscale **lattice structures (not “supports” and not atomic lattice)**
2. Lattice structures have unique properties that can be exploited by the complexity of AM
    1. Lightweight: aerospace, automotive parts, sports gear, etc.
    2. Permeable: bone replacement implants, catalysts, water filtration, etc.
    3. Impact protection: headgear, custom protective designs
    4. Thermal insulation or control: custom or high performance radiators, etc.
    5. Acoustic and vibration insulation
    6. Tunable properties – stiffness, strength, etc. all controlled by design

Lattice structures: basics

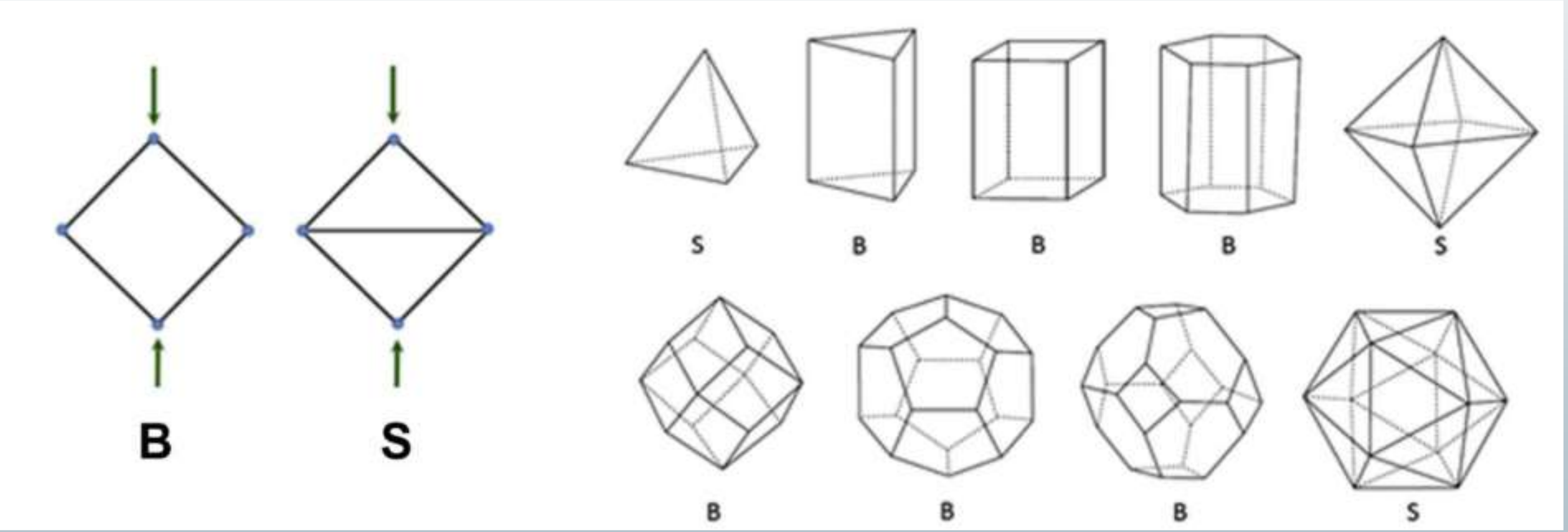
$$E = \alpha_2 \times E_{solid} \times \left[\frac{\rho}{\rho_{solid}} \right]^2$$



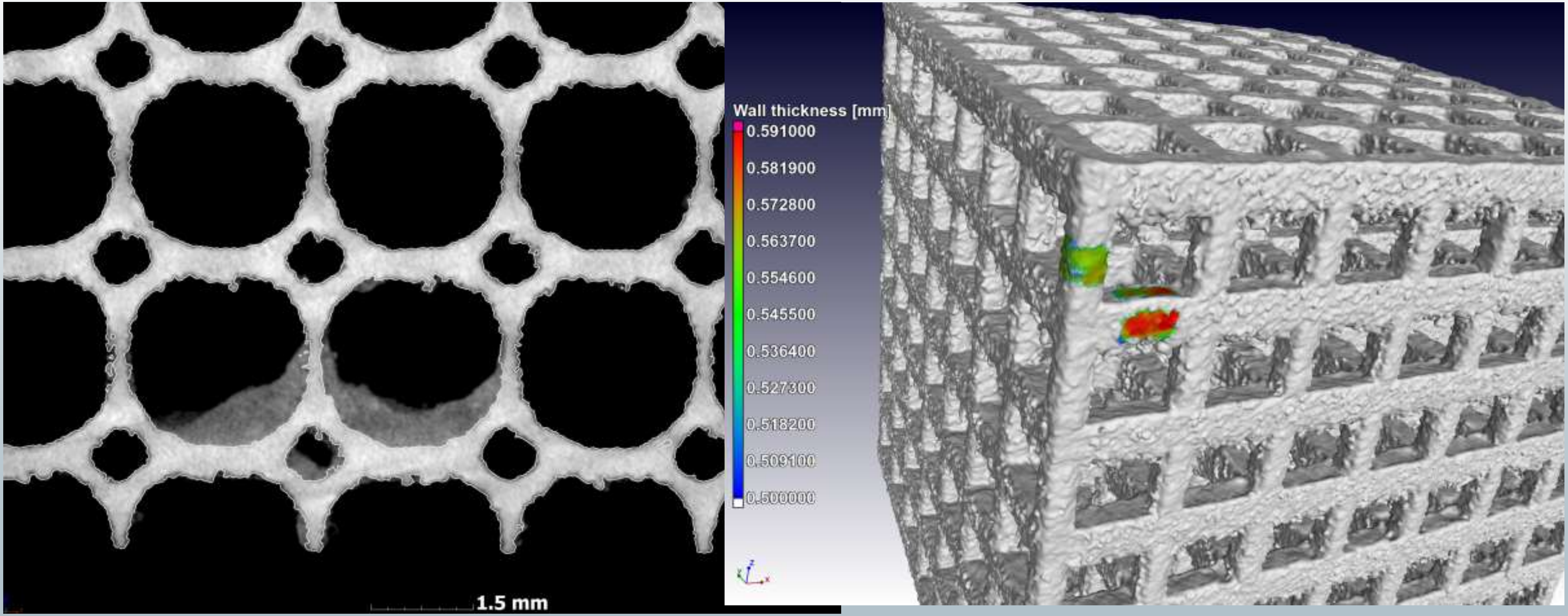


Gibson, L.J. and Ashby, M.F., 1999. *Cellular solids: structure and properties*. Cambridge university press.

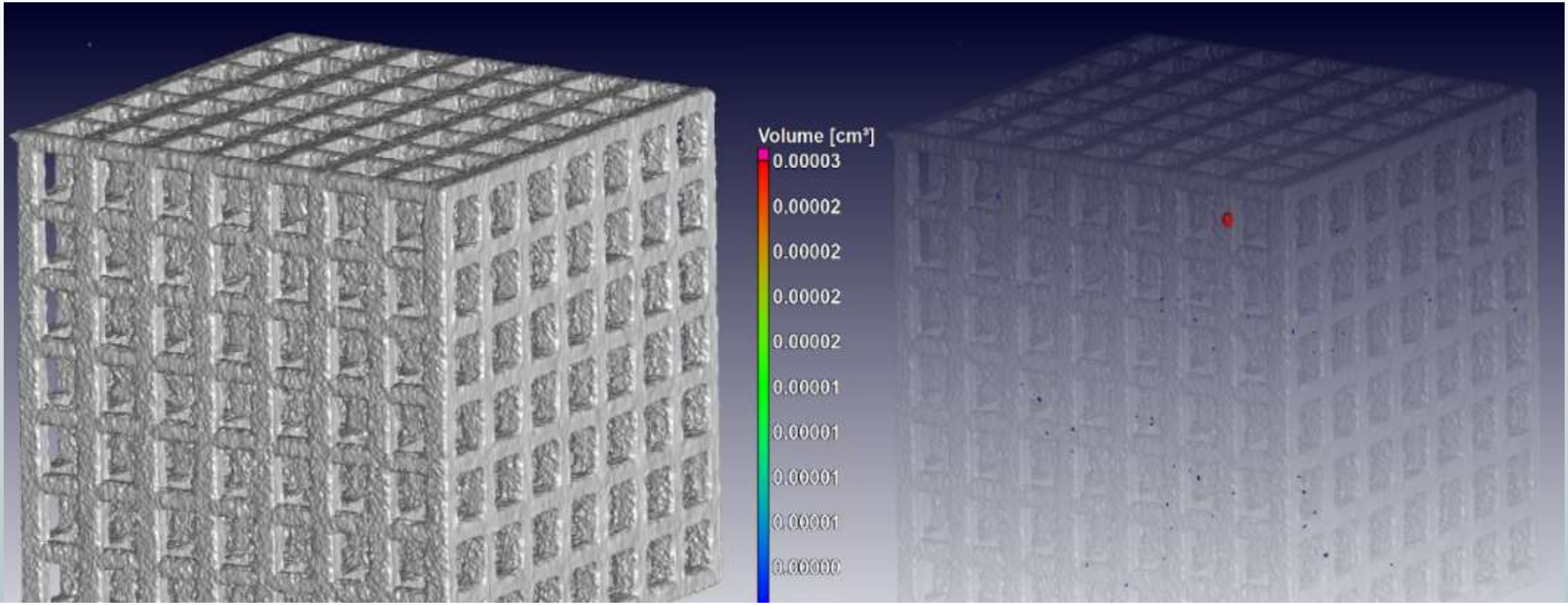
Lattice structures: basics



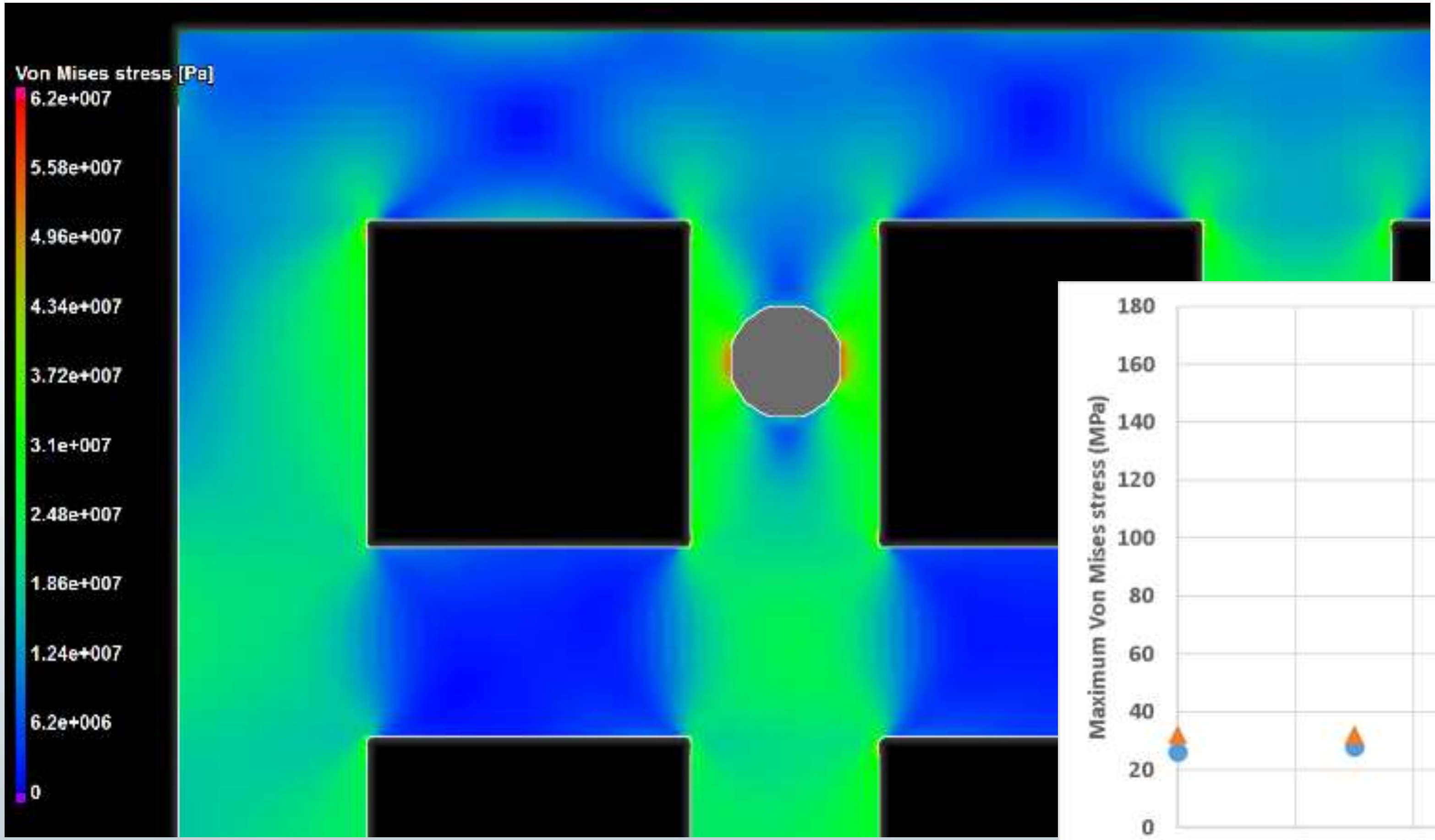
Role of CT in this?

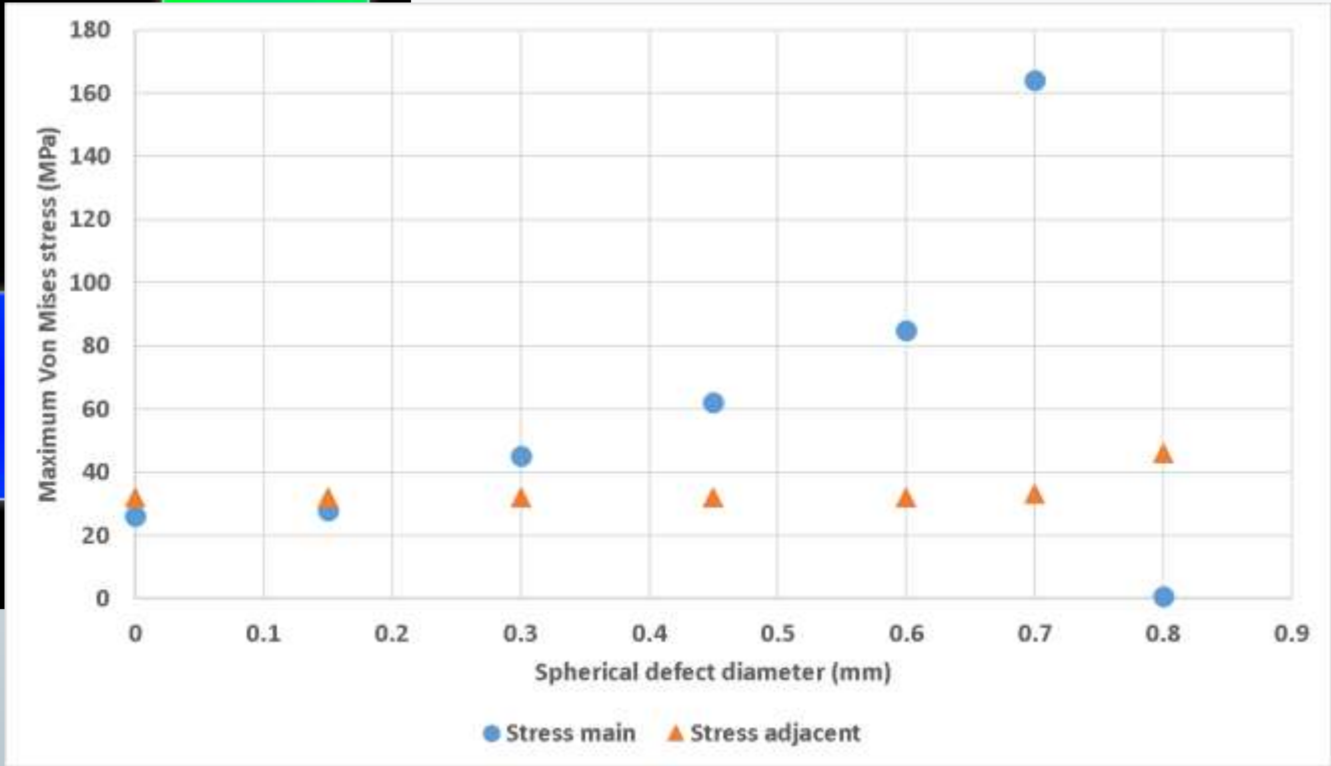


What about pores in struts?



- **Du Plessis, A., Kouprianoff, D.P., Yadroitsava, I. and Yadroitsev, I., 2018. Numerical and experimental investigation of artificial porosity in a lattice structure. Solid Freeform Fabrication 2018 – proceedings**
- https://sffsymposium.engr.utexas.edu/sites/default/files/2018/066%20NumericalandExperimentalStudyoftheEffectof.pdf





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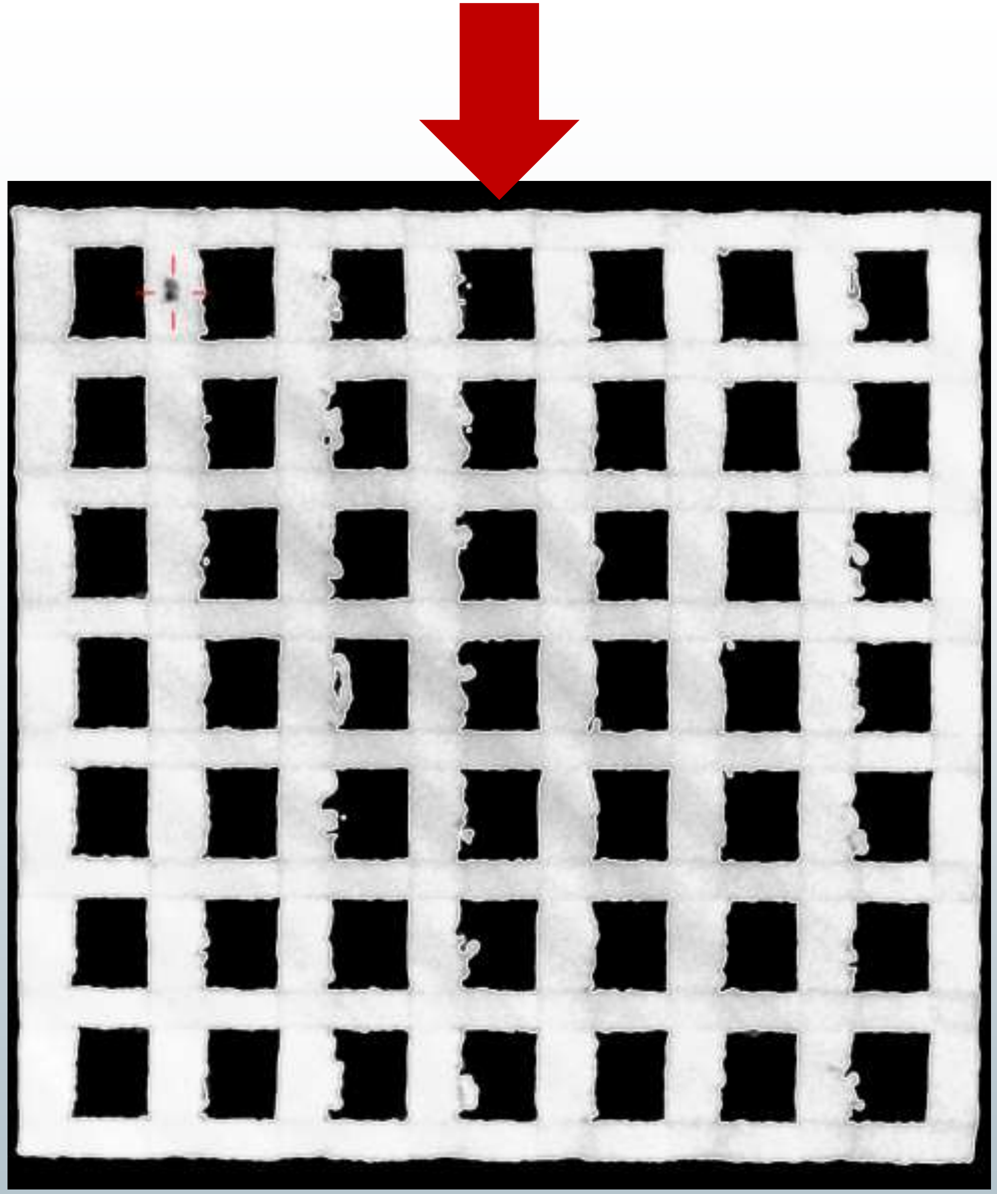

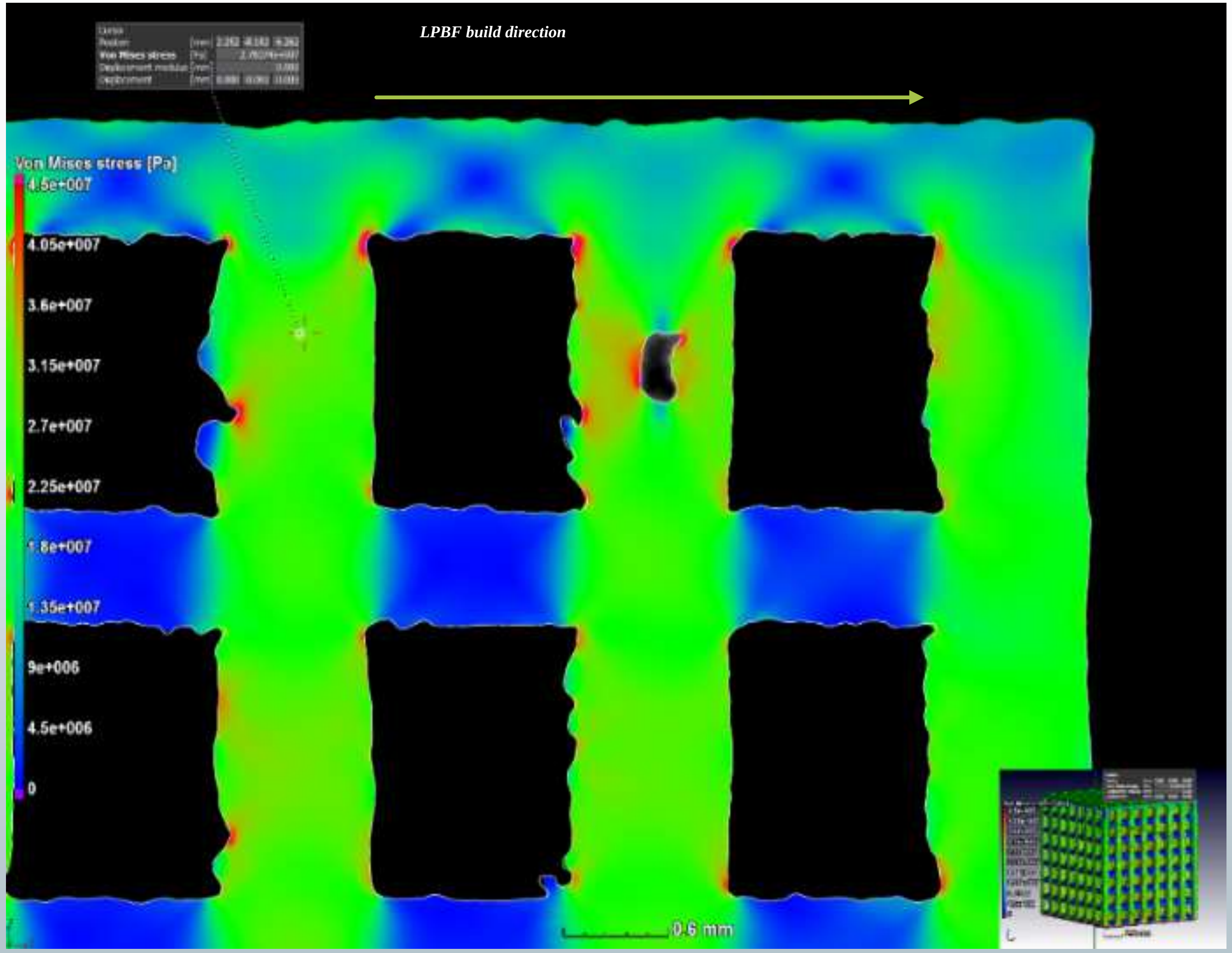

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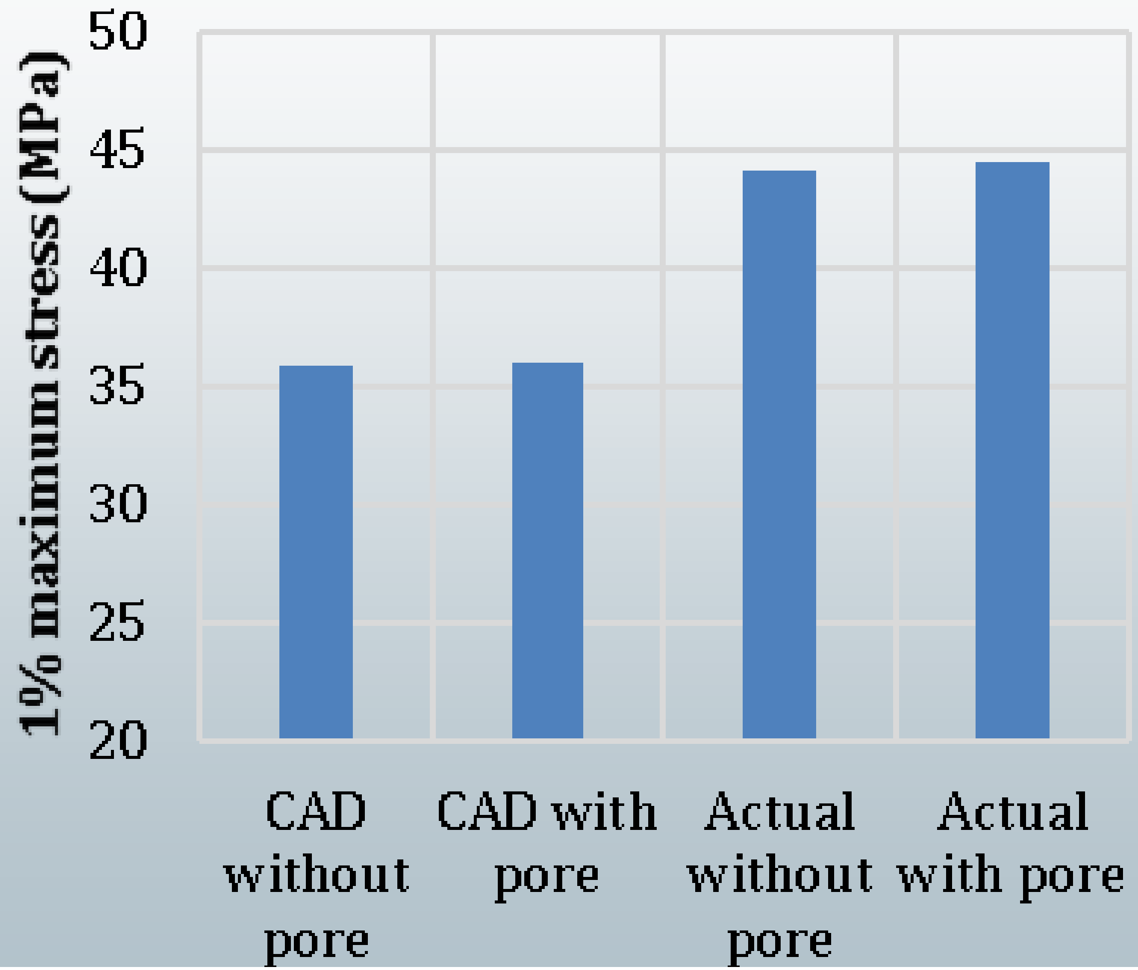
Compression of lattice with and without pore



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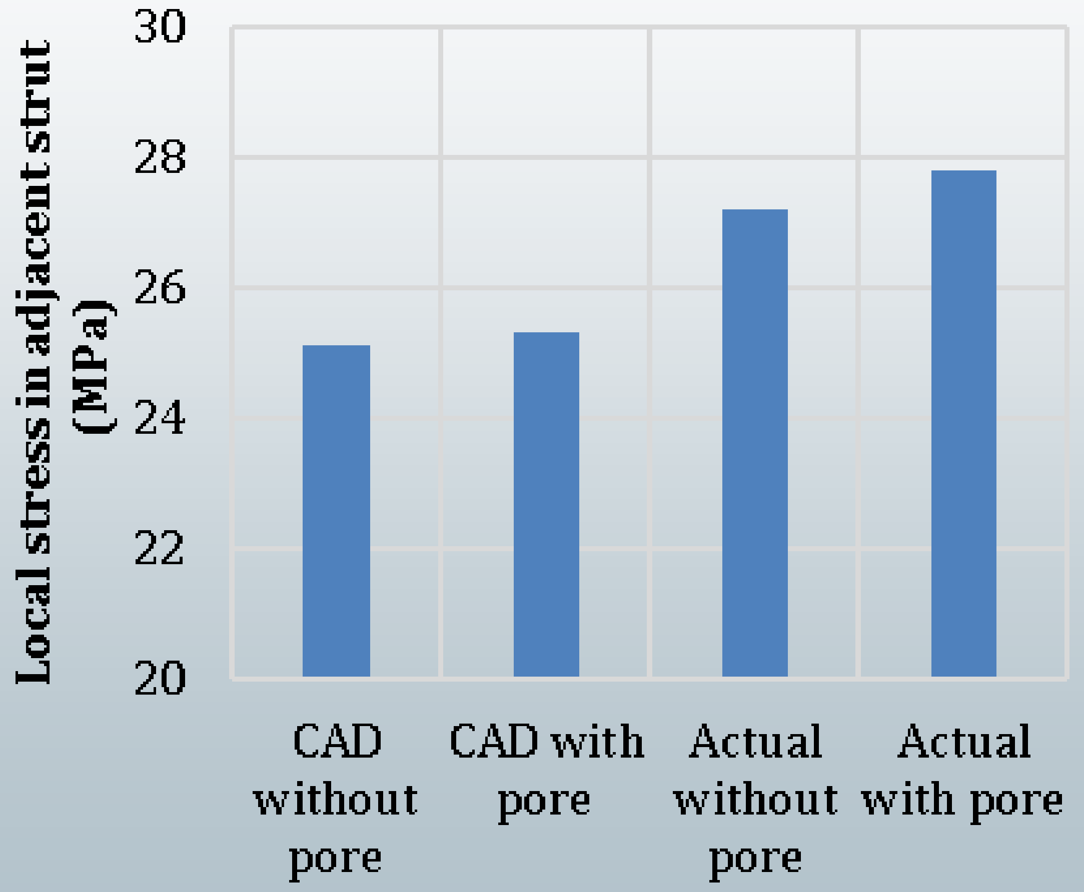

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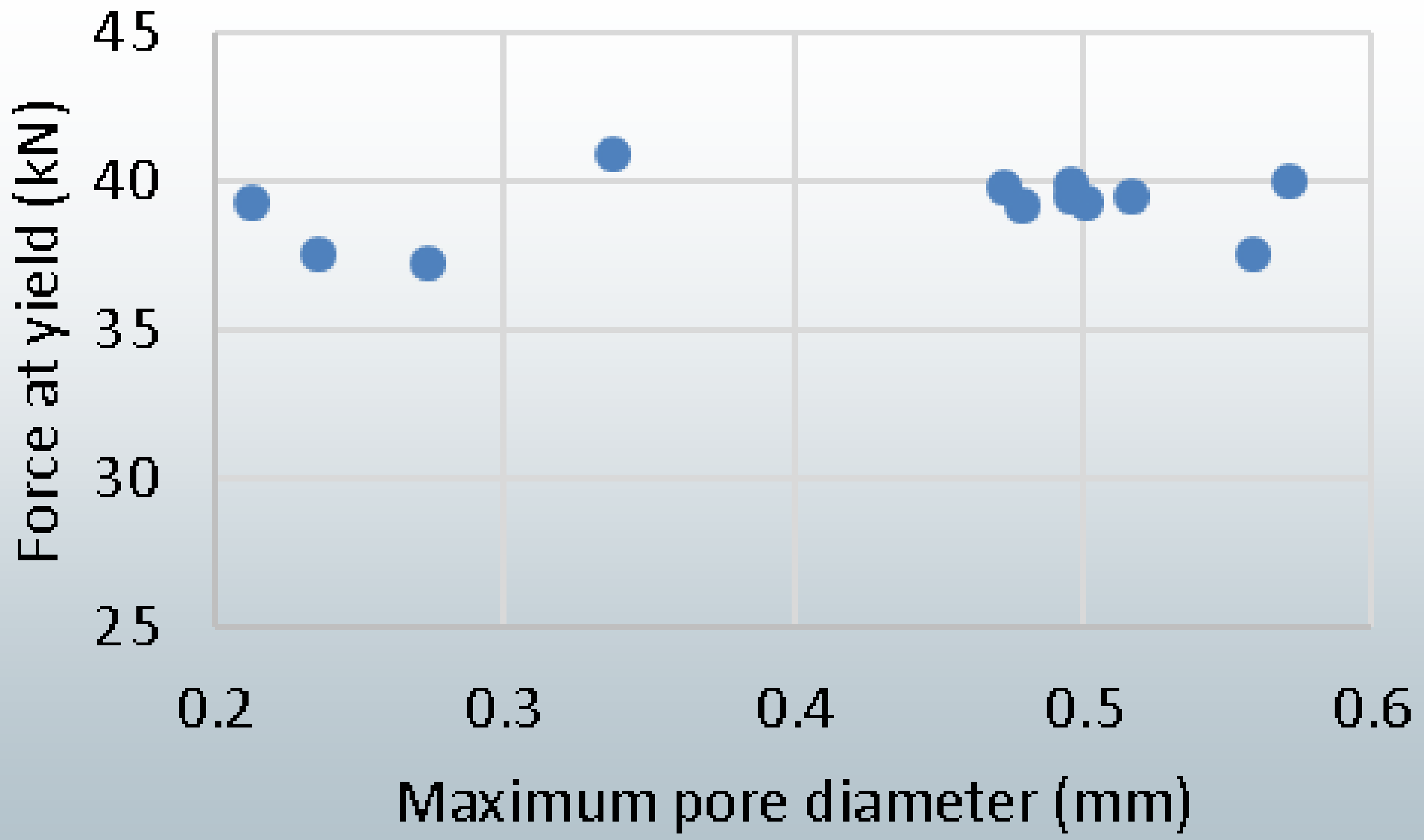

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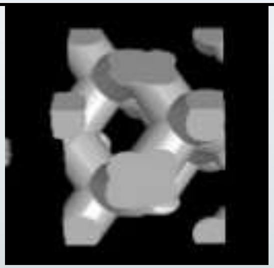
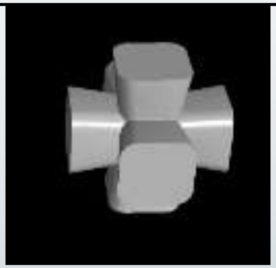
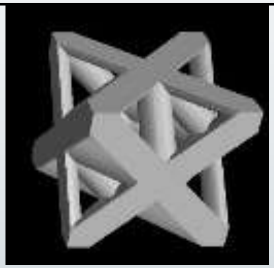
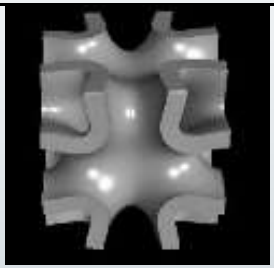
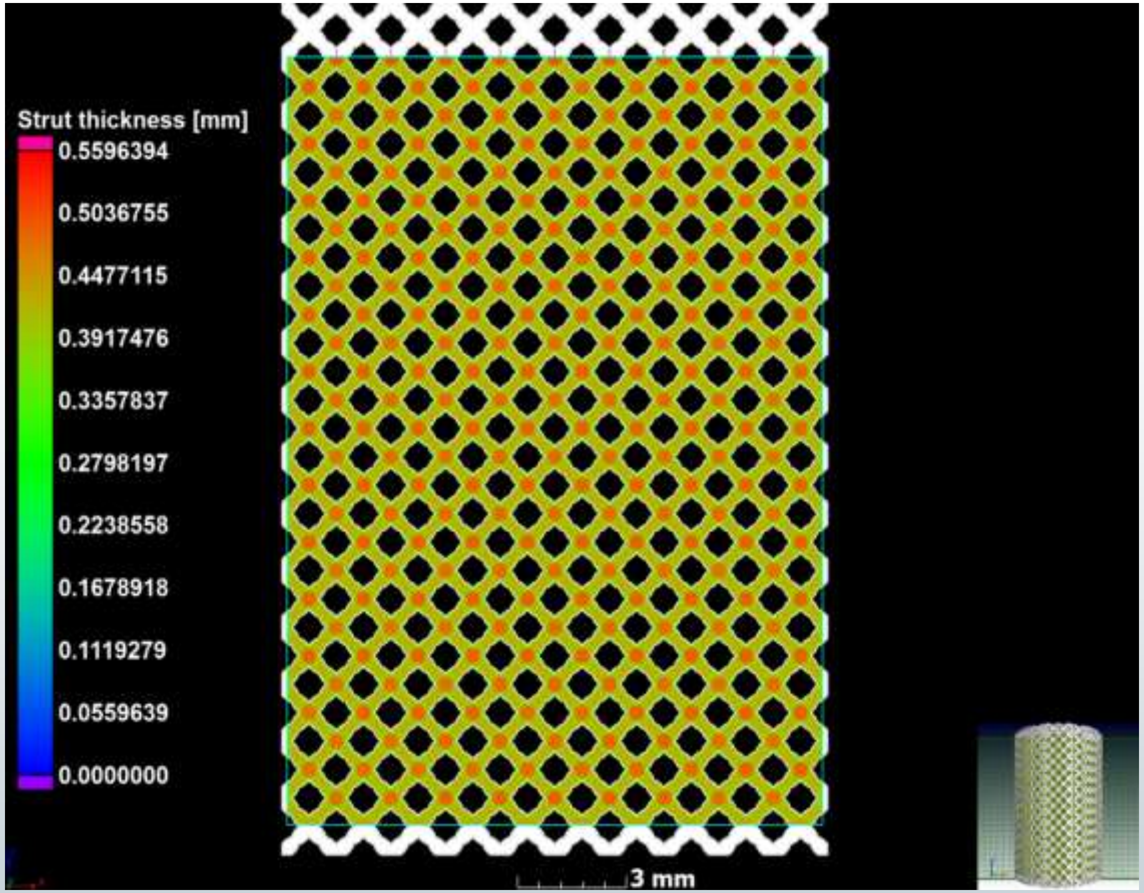
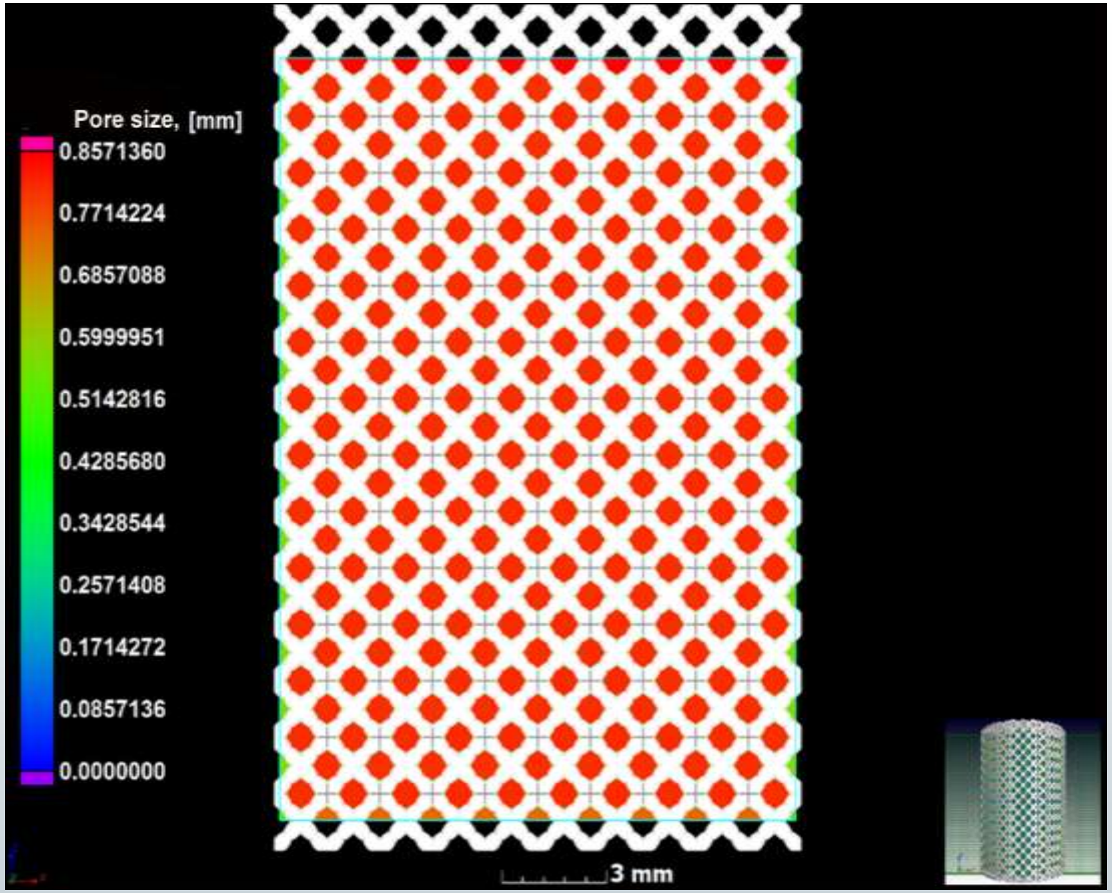
Table 1. Investigated designs for lattice structures

Strut-based design				Minimal surface design			
Rhombic dodecahedron	Diamond	G-struct	Octet	Diamond	Gyroid	I-WP	Primitive
							
R-sb	D-sb	G-sb	O-sb	D-ms	G-ms	I-ms	P-ms
Porosity, %							
63	61	63	62	62	63	65	62

- **Du Plessis, A., Yadroitsava, I., Yadroitsev, I., le Roux, S.G. and Blaine, D.C., 2018. Numerical comparison of lattice unit cell designs for medical implants by additive manufacturing. Virtual and Physical Prototyping, 13(4), pp.266-281.**
- **https://doi.org/10.1080/17452759.2018.1491713**





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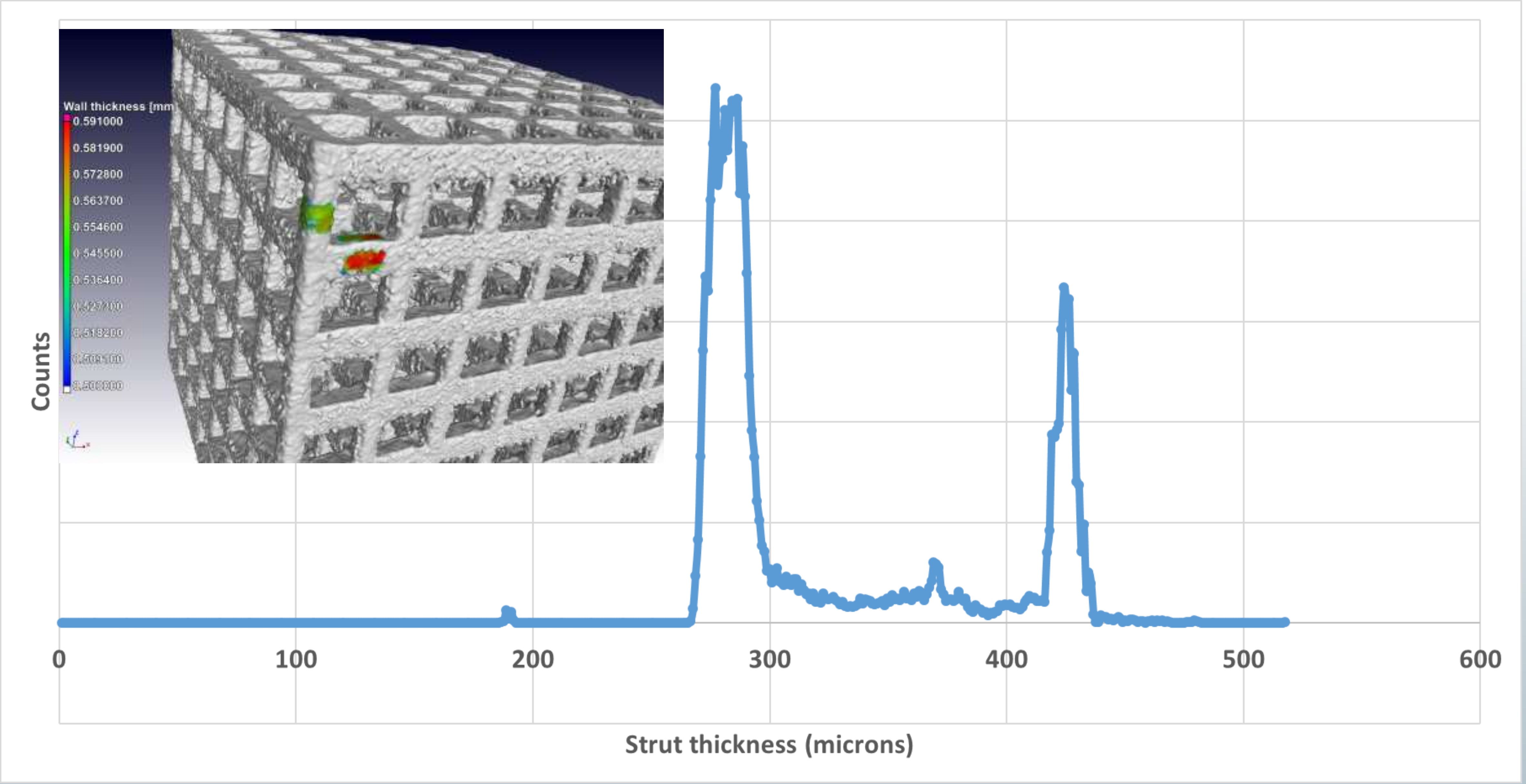

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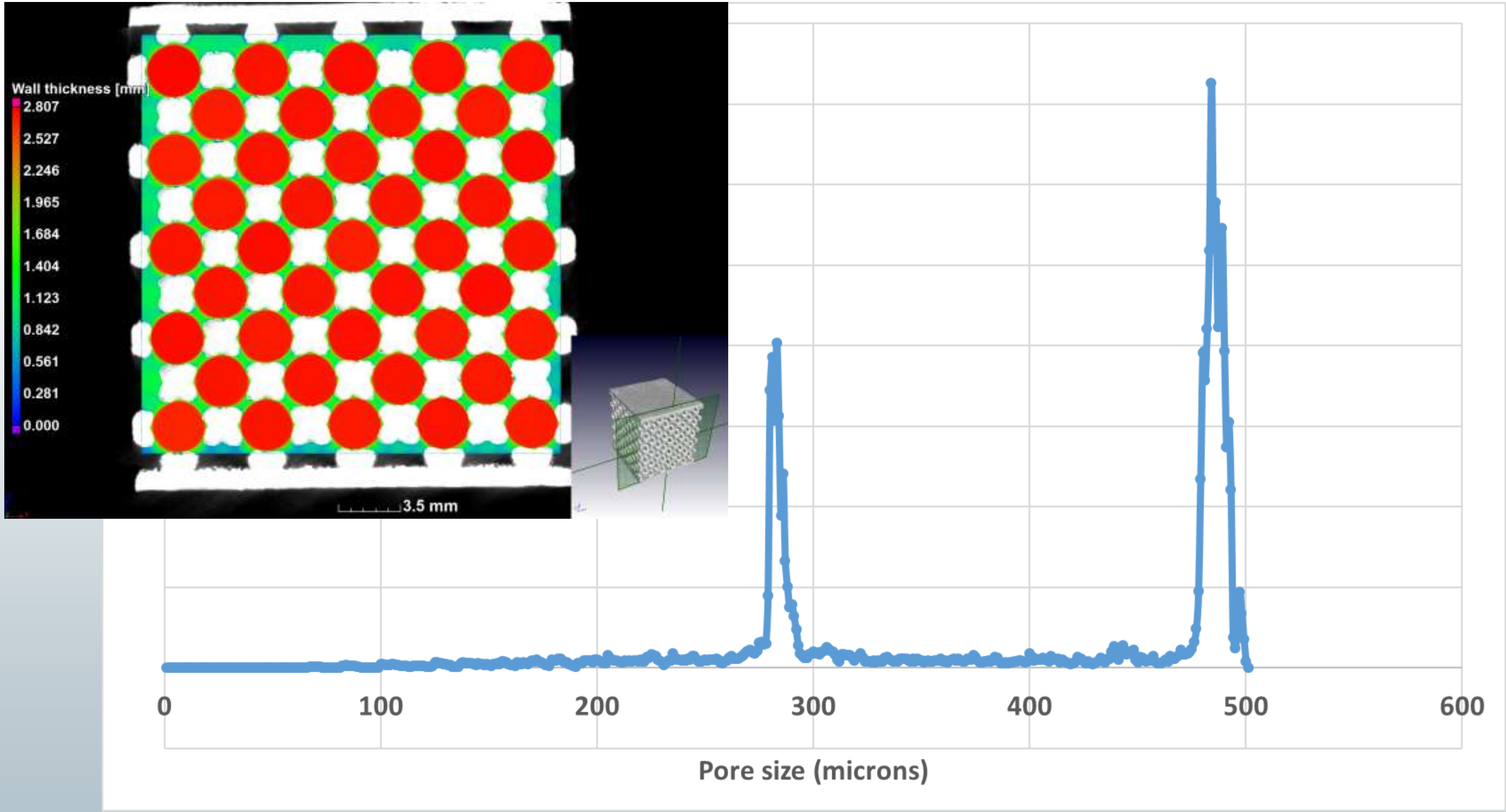

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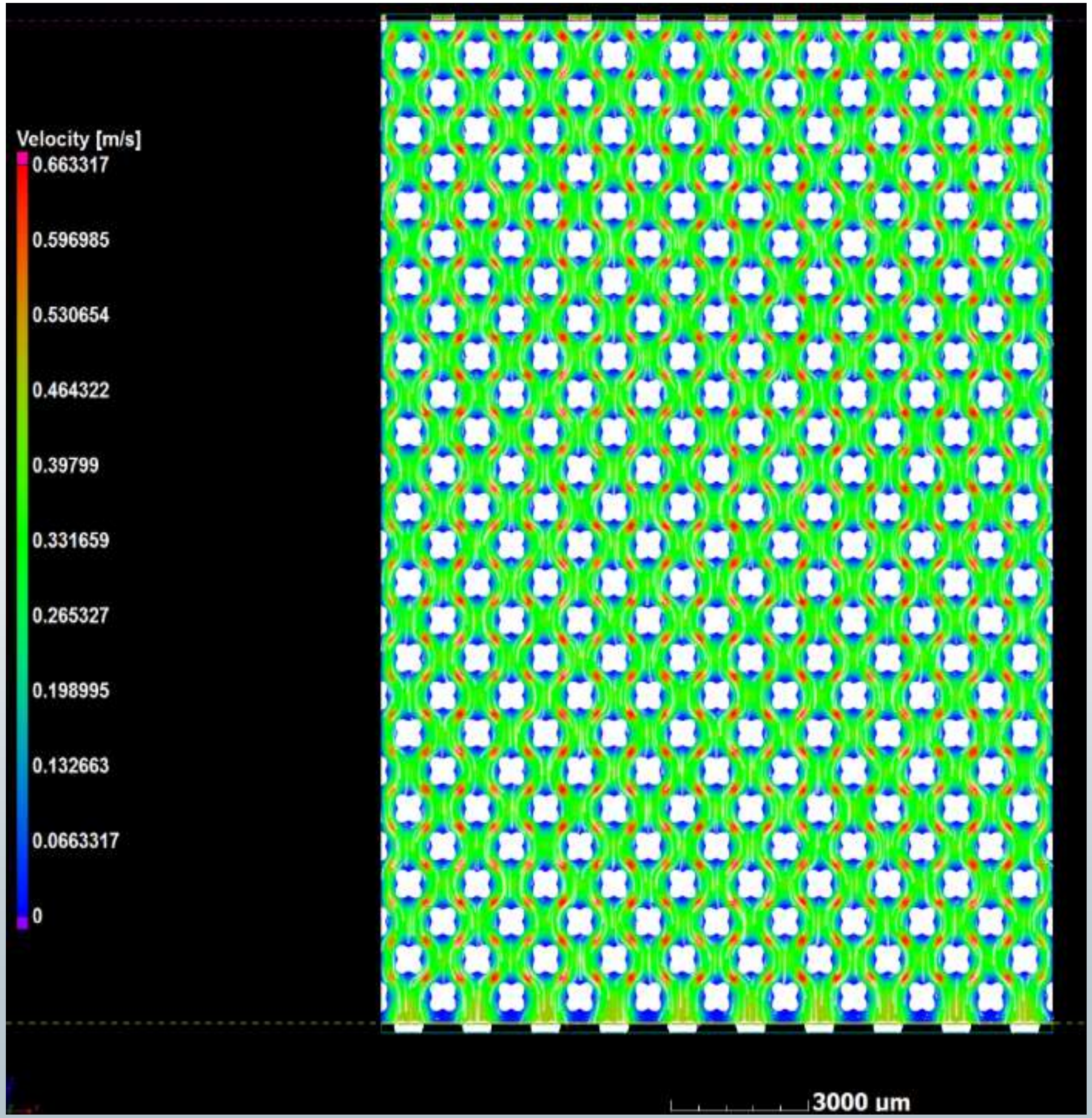

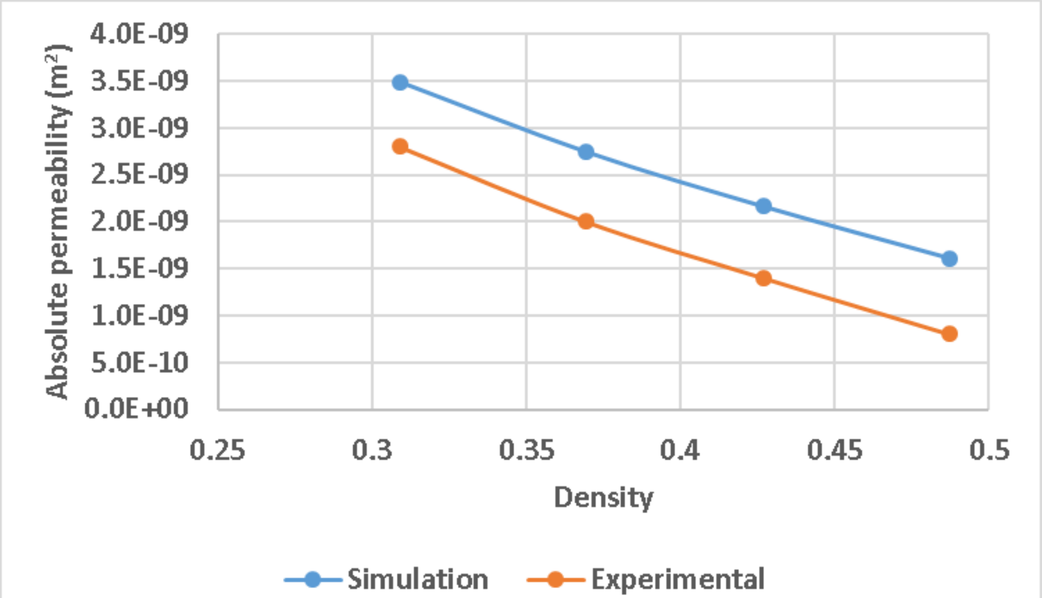

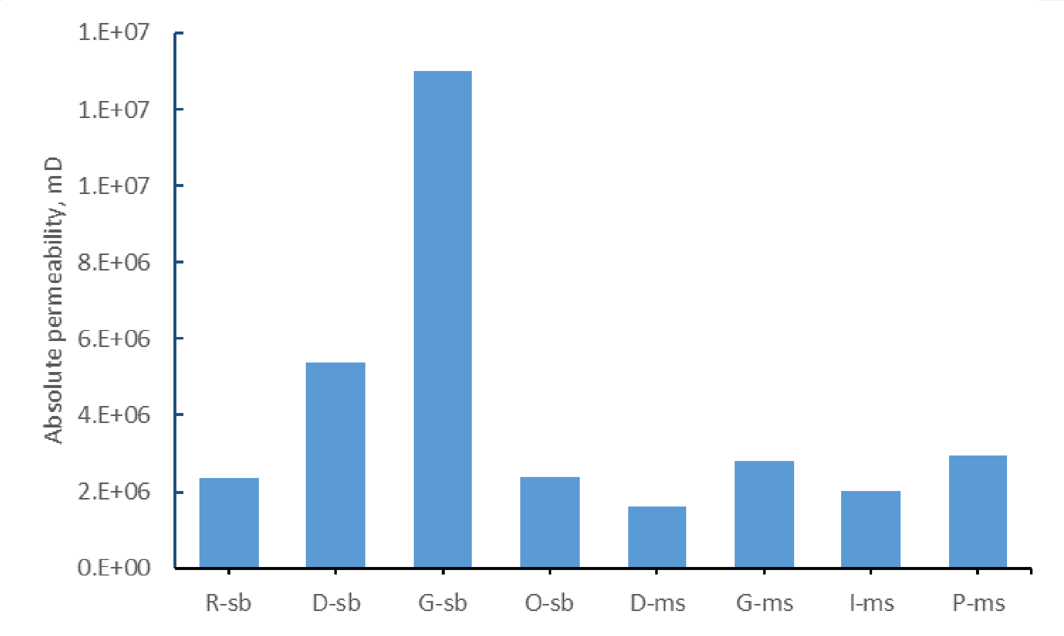

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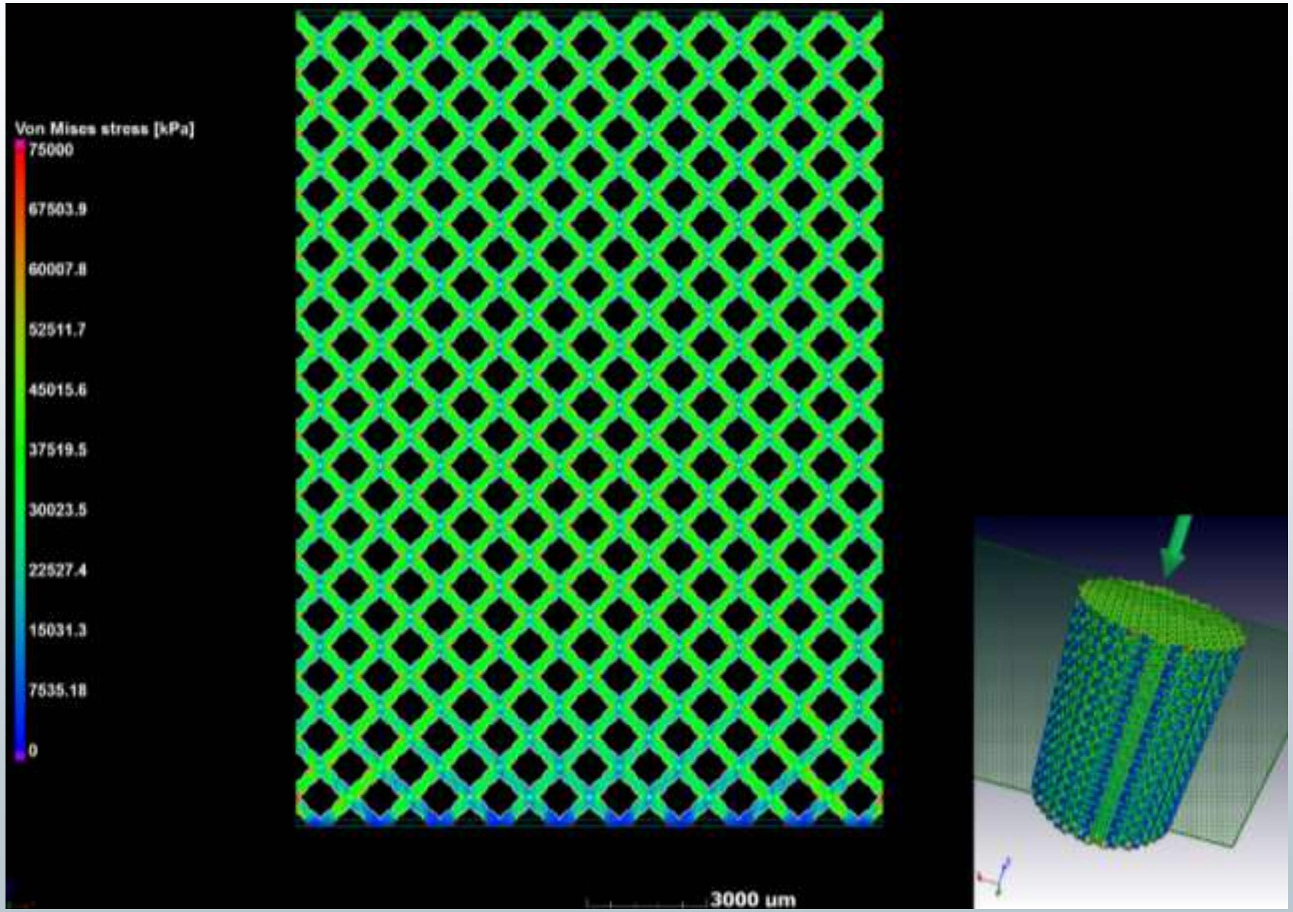

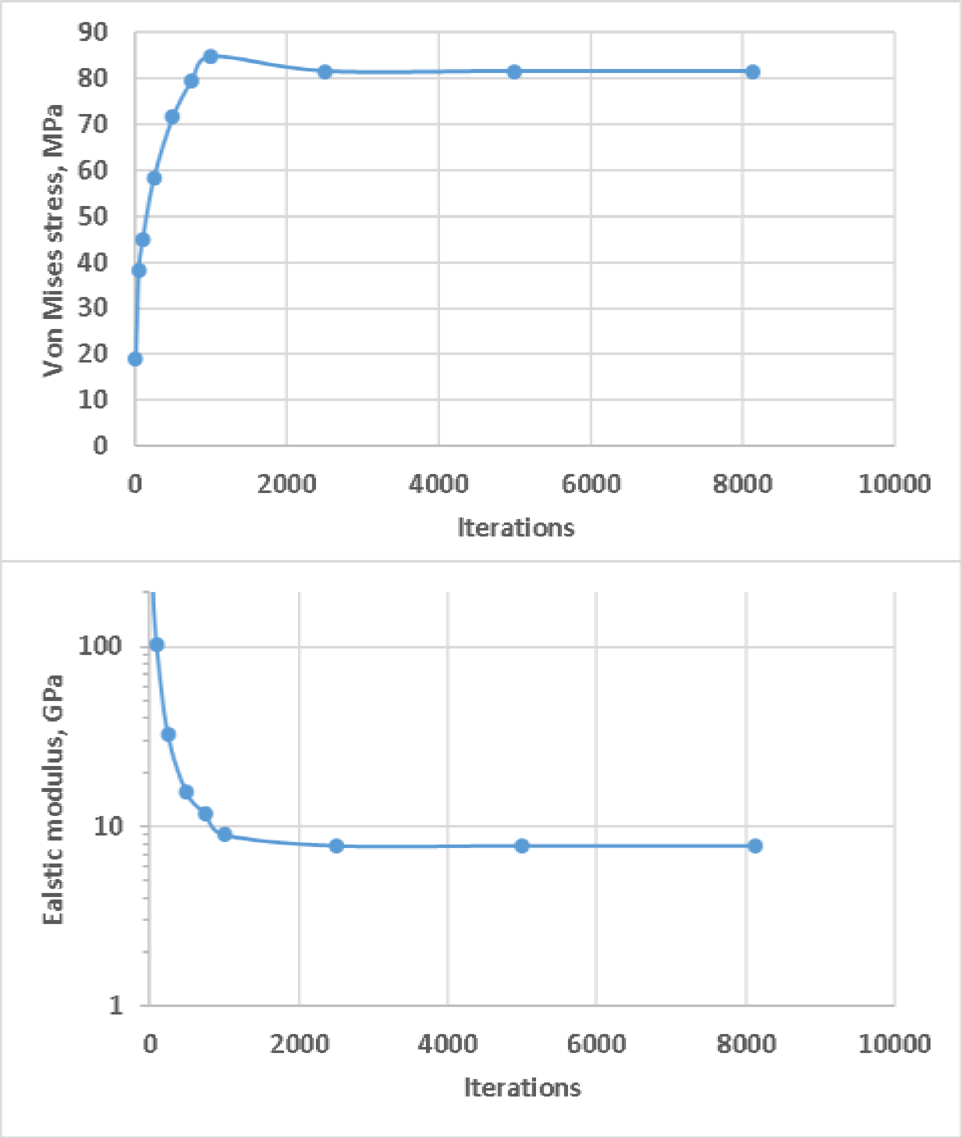

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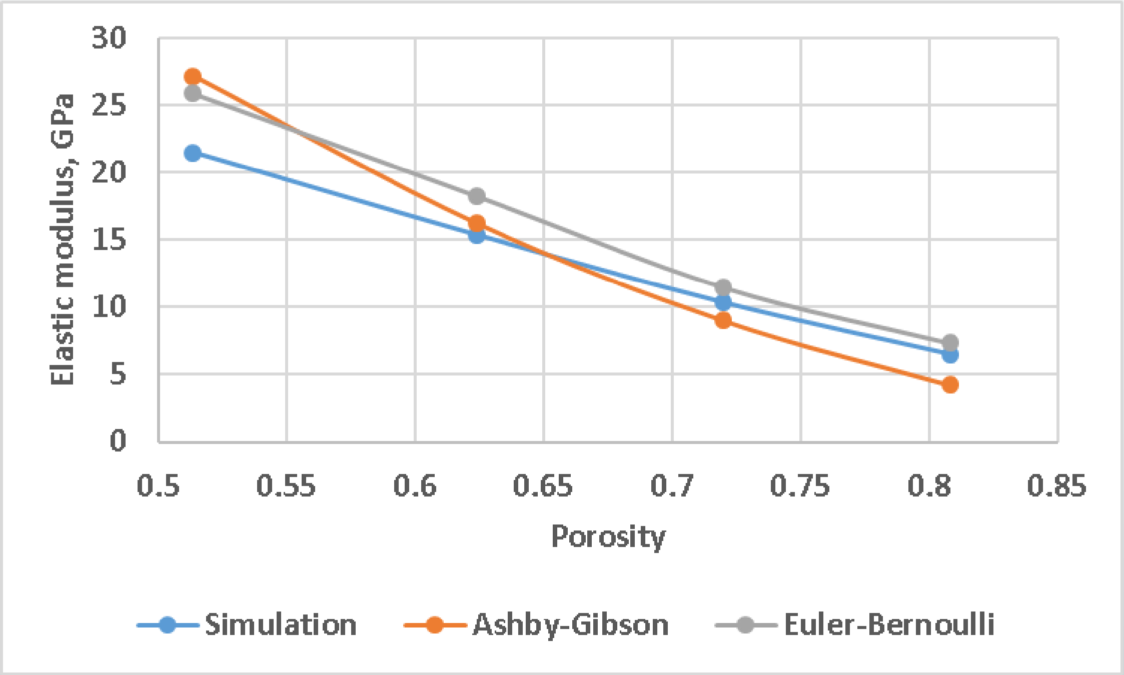

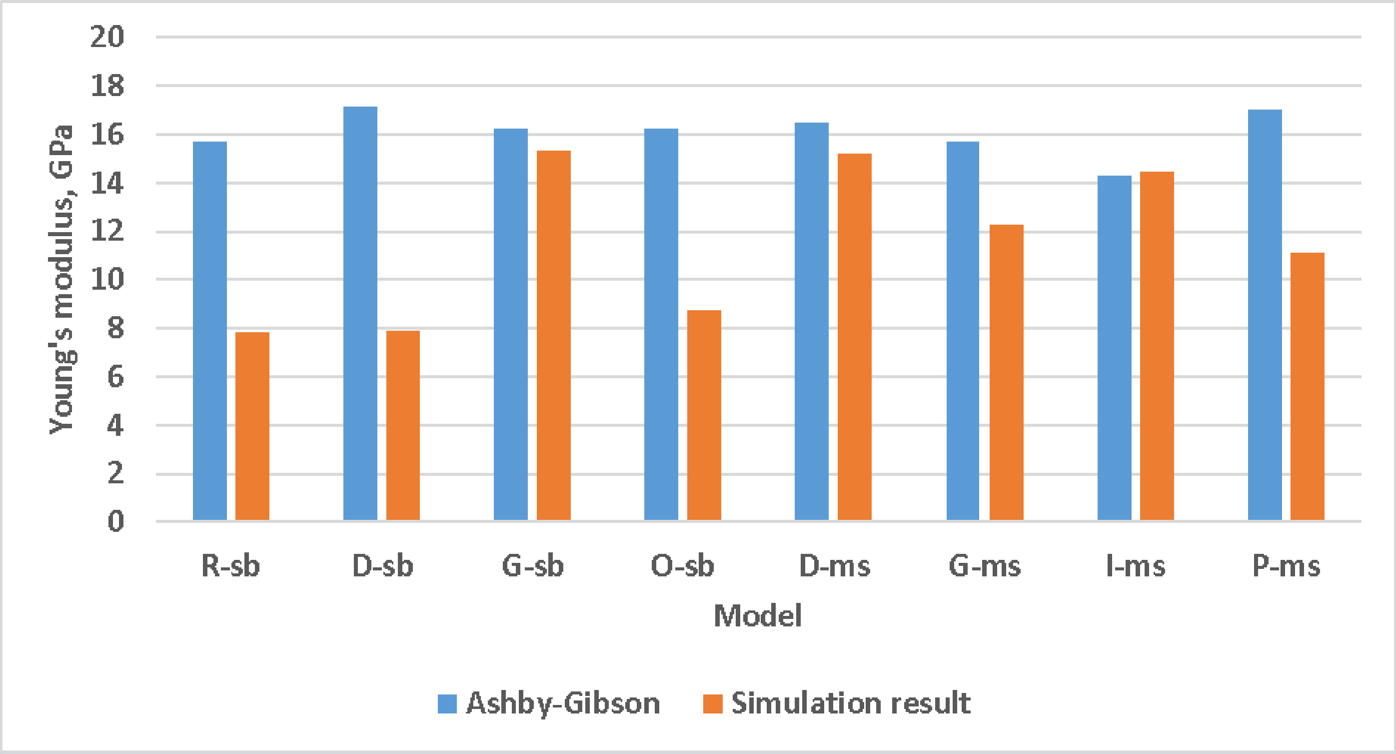

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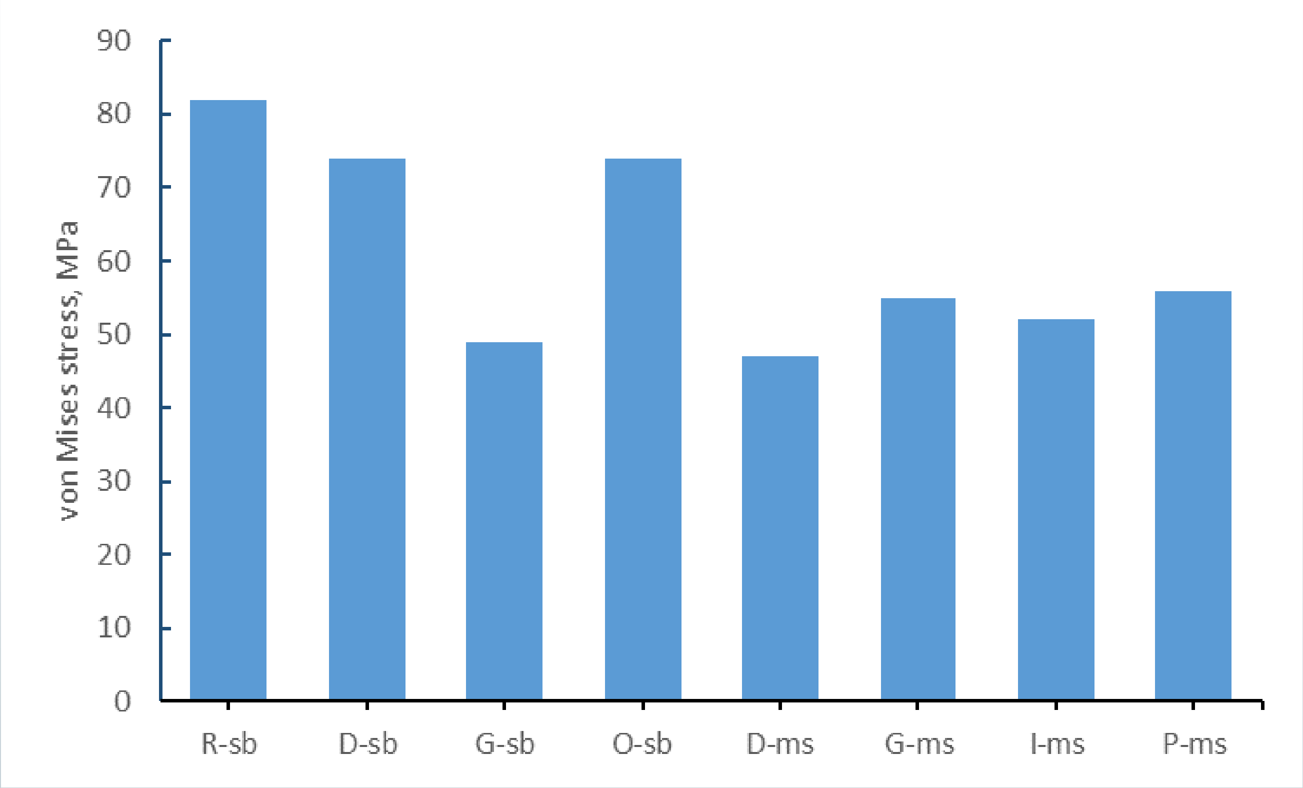

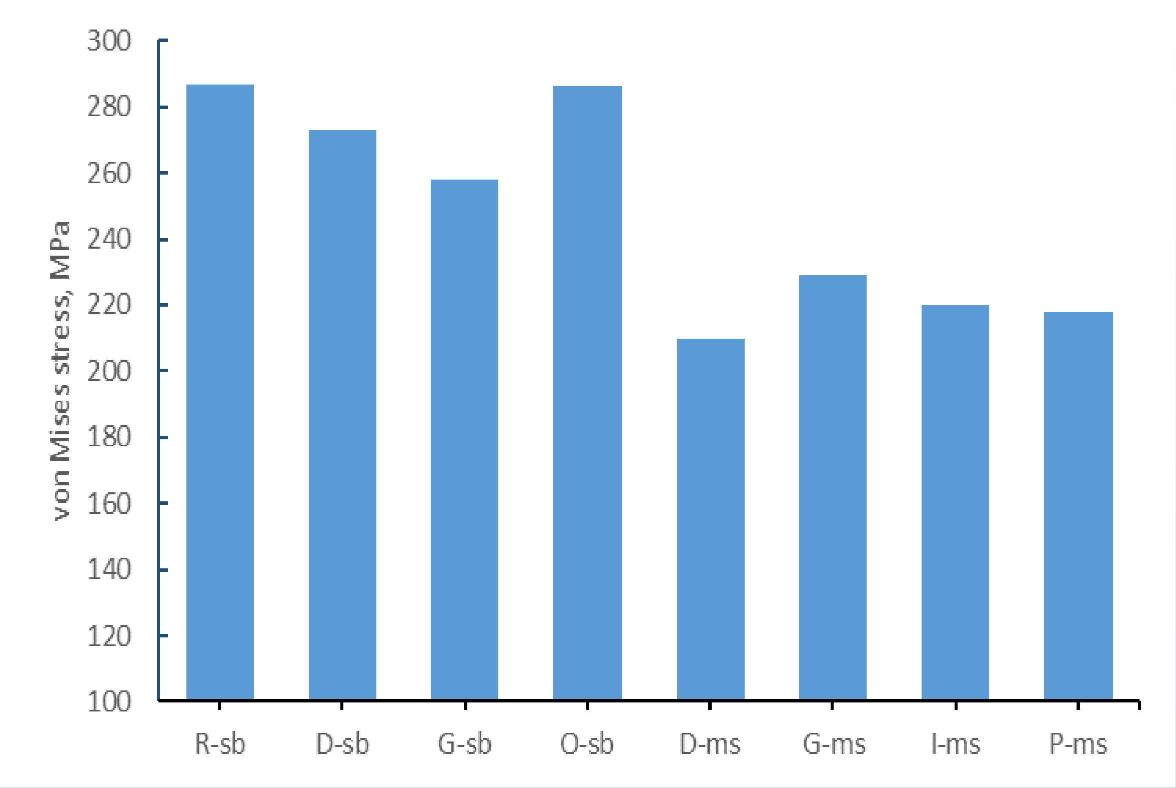

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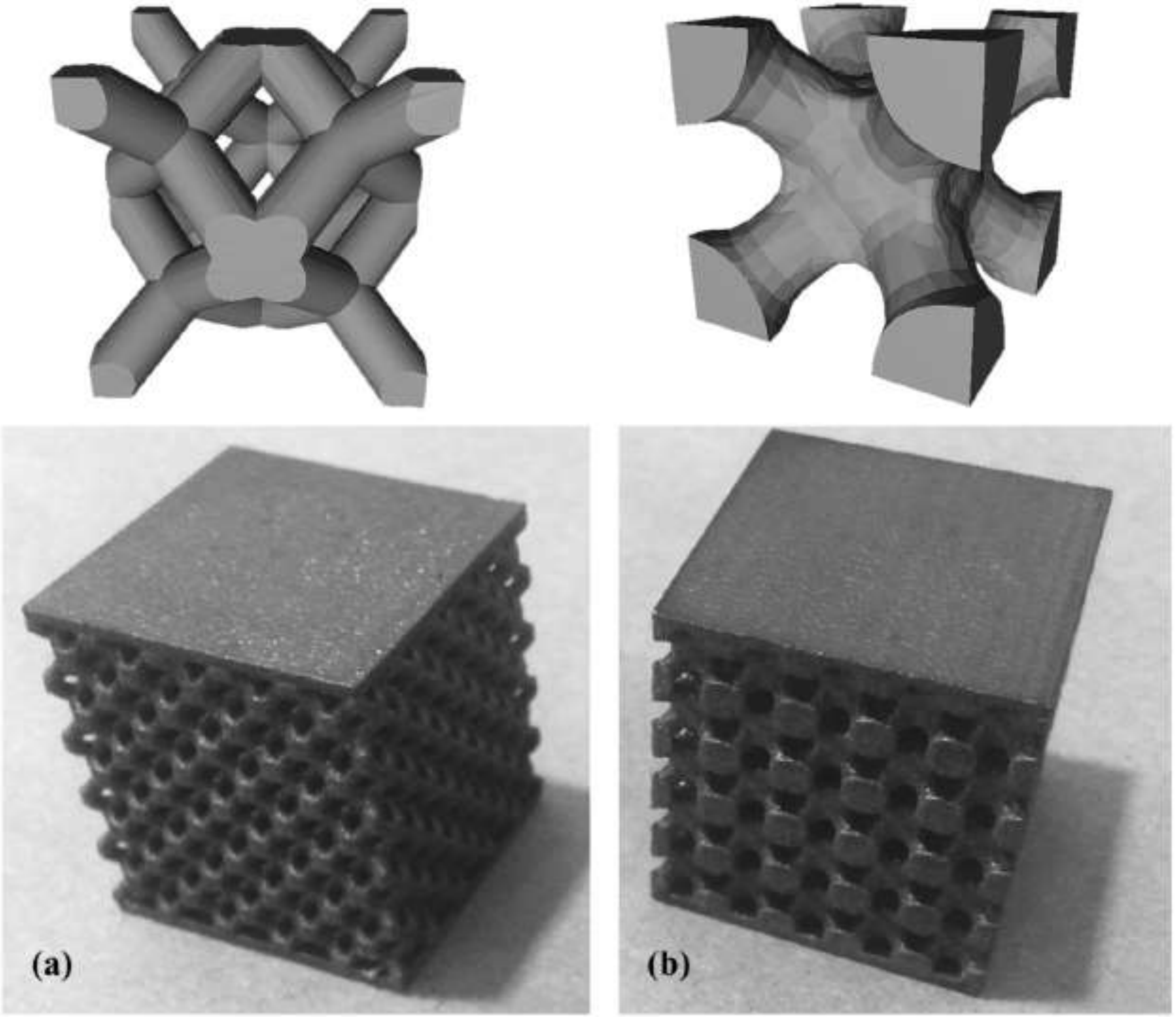
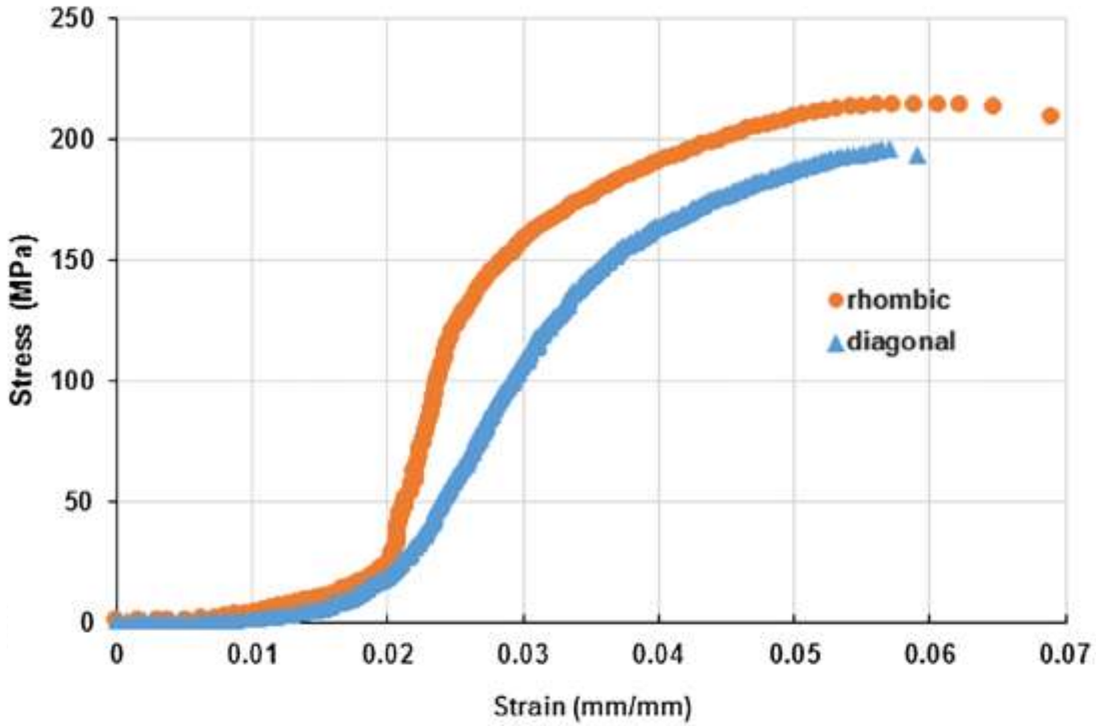
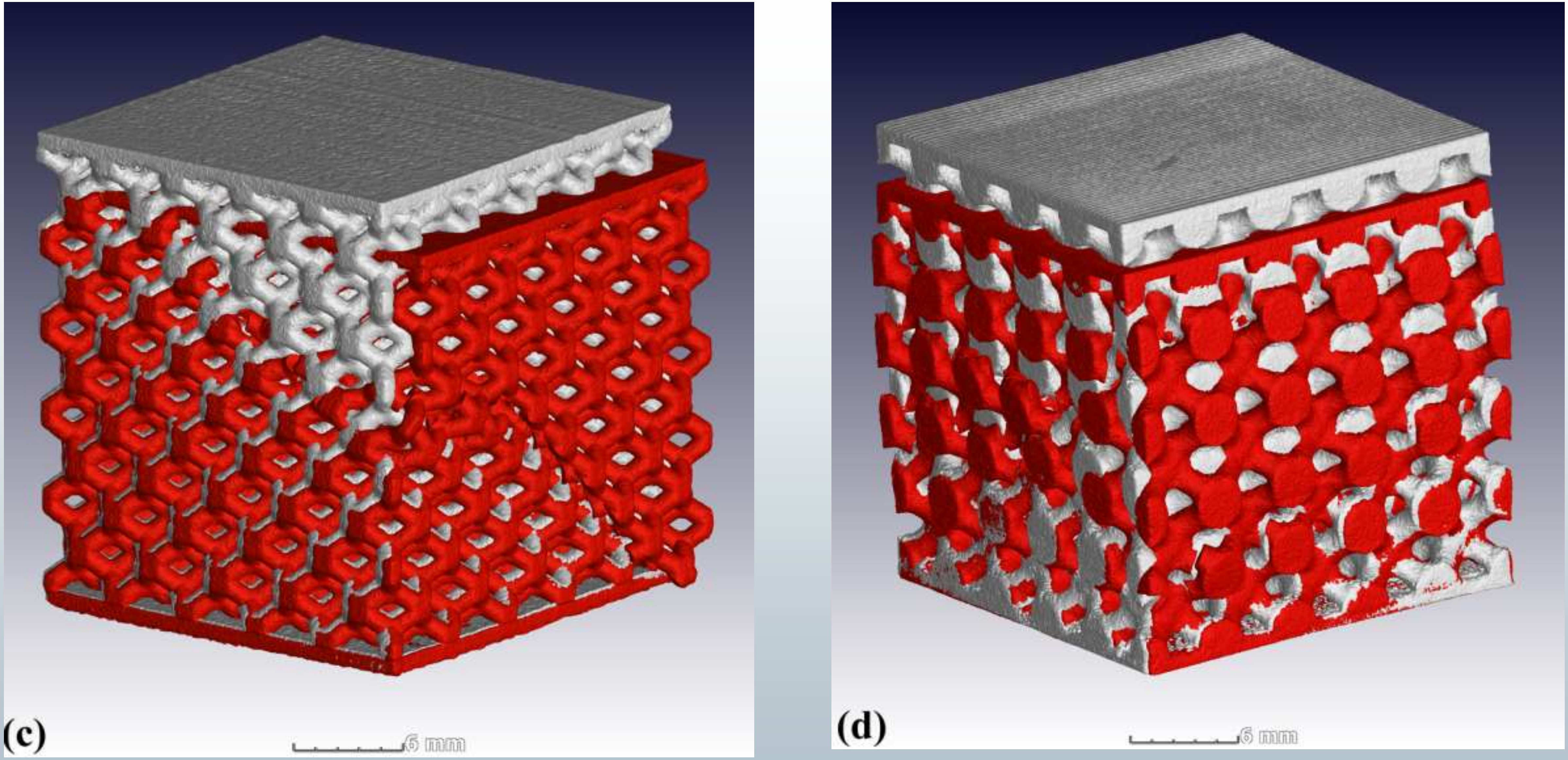


Fig. 1. CAD models of unit cells and LPBF tessellated lattice parts with rhombic (a) and diagonal designs (b).



- du Plessis, A., Yadroitsava, I. and Yadroitsev, I., 2018. Ti6Al4V lightweight lattice structures manufactured by laser powder bed fusion for load-bearing applications. *Optics & Laser Technology*, *108*, pp.521-528.
- https://doi.org/10.1016/j.optlastec.2018.07.050



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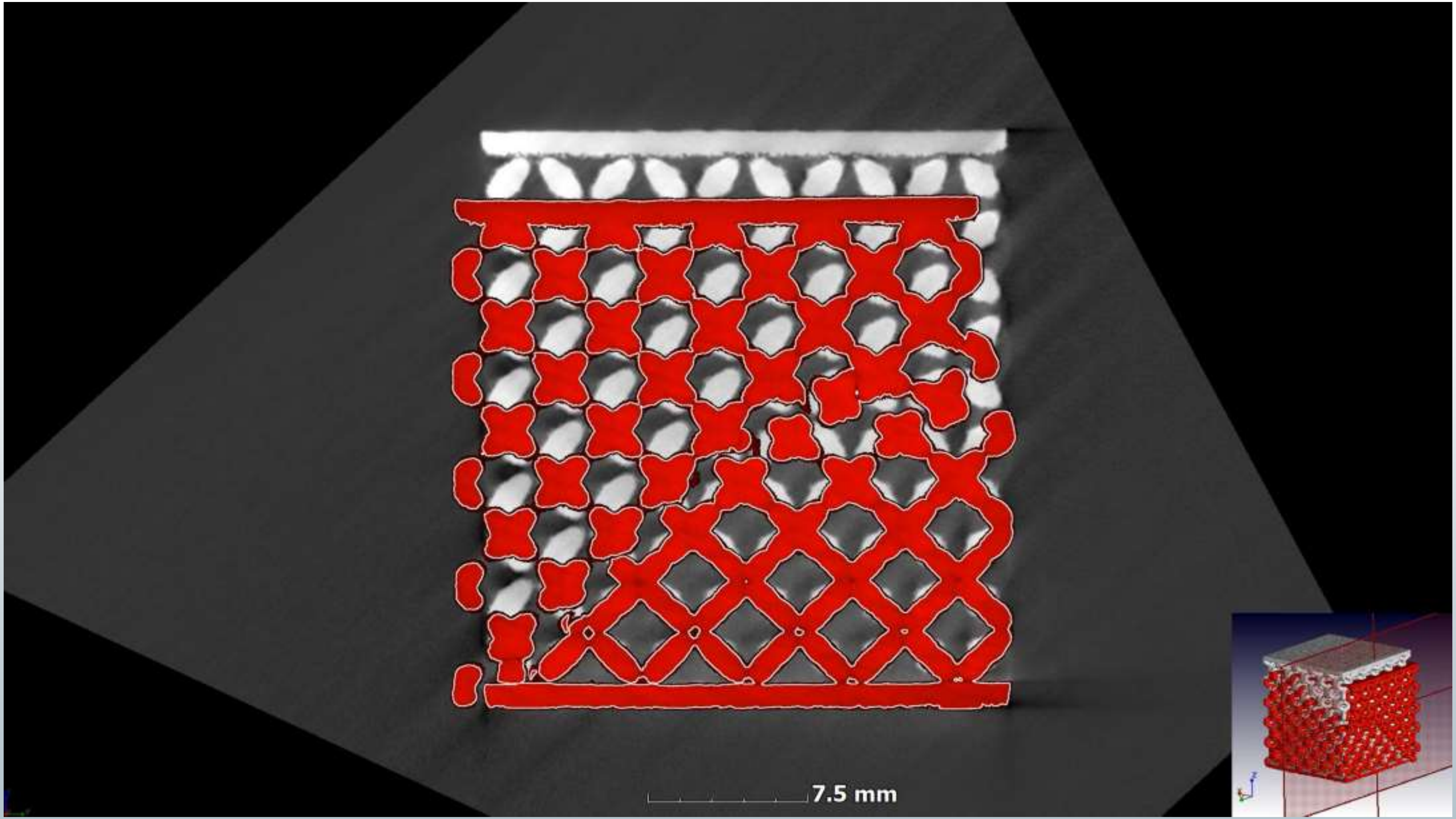

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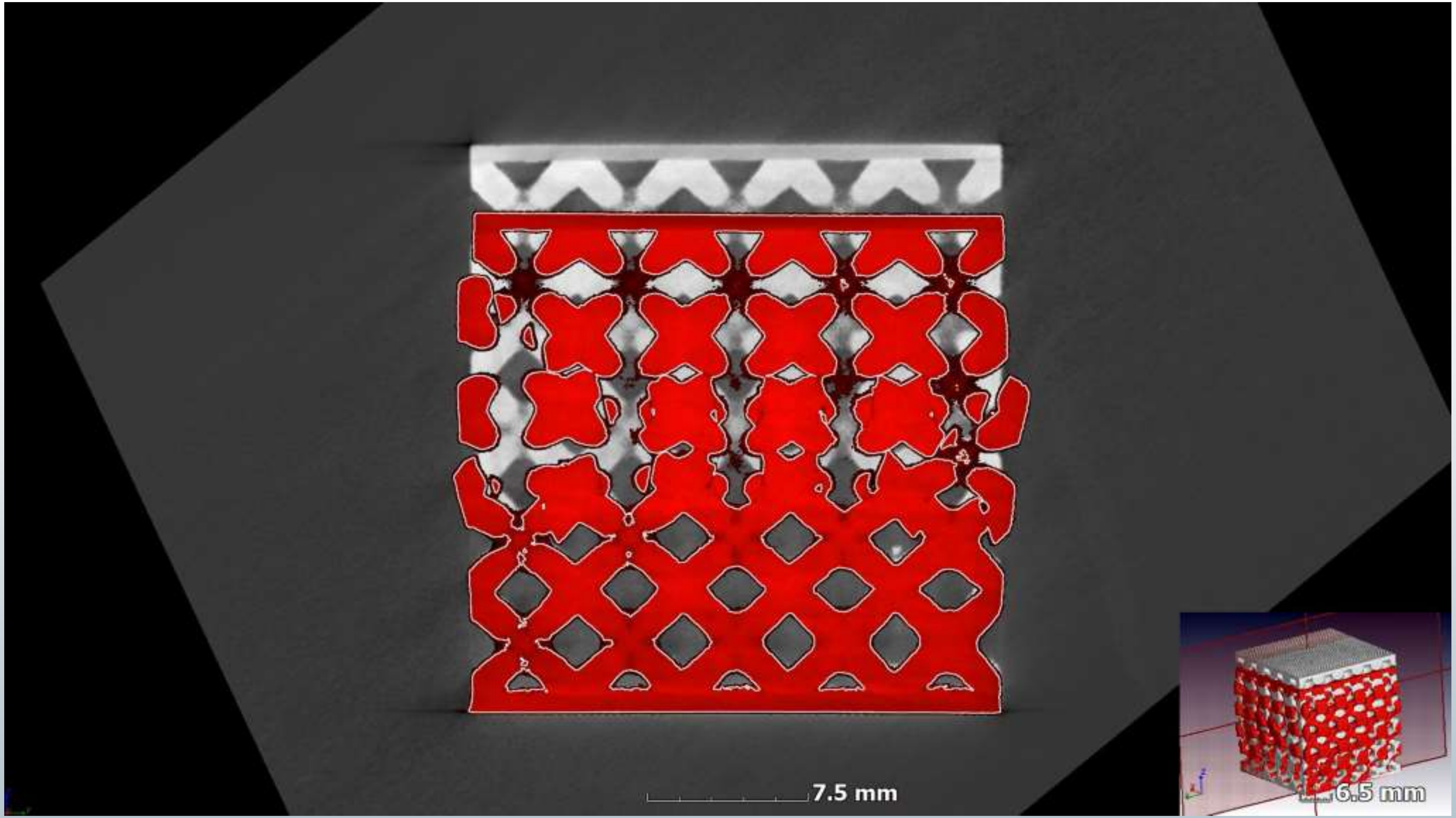

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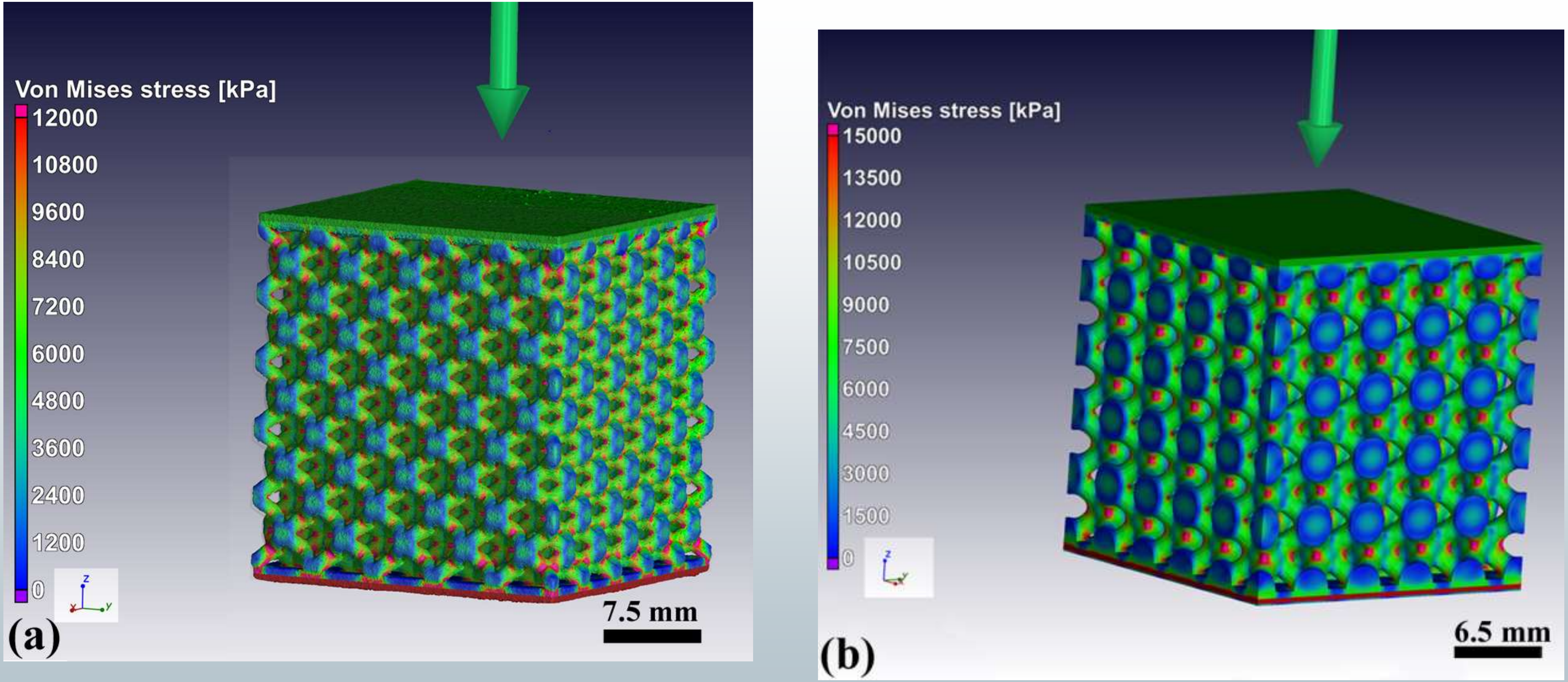

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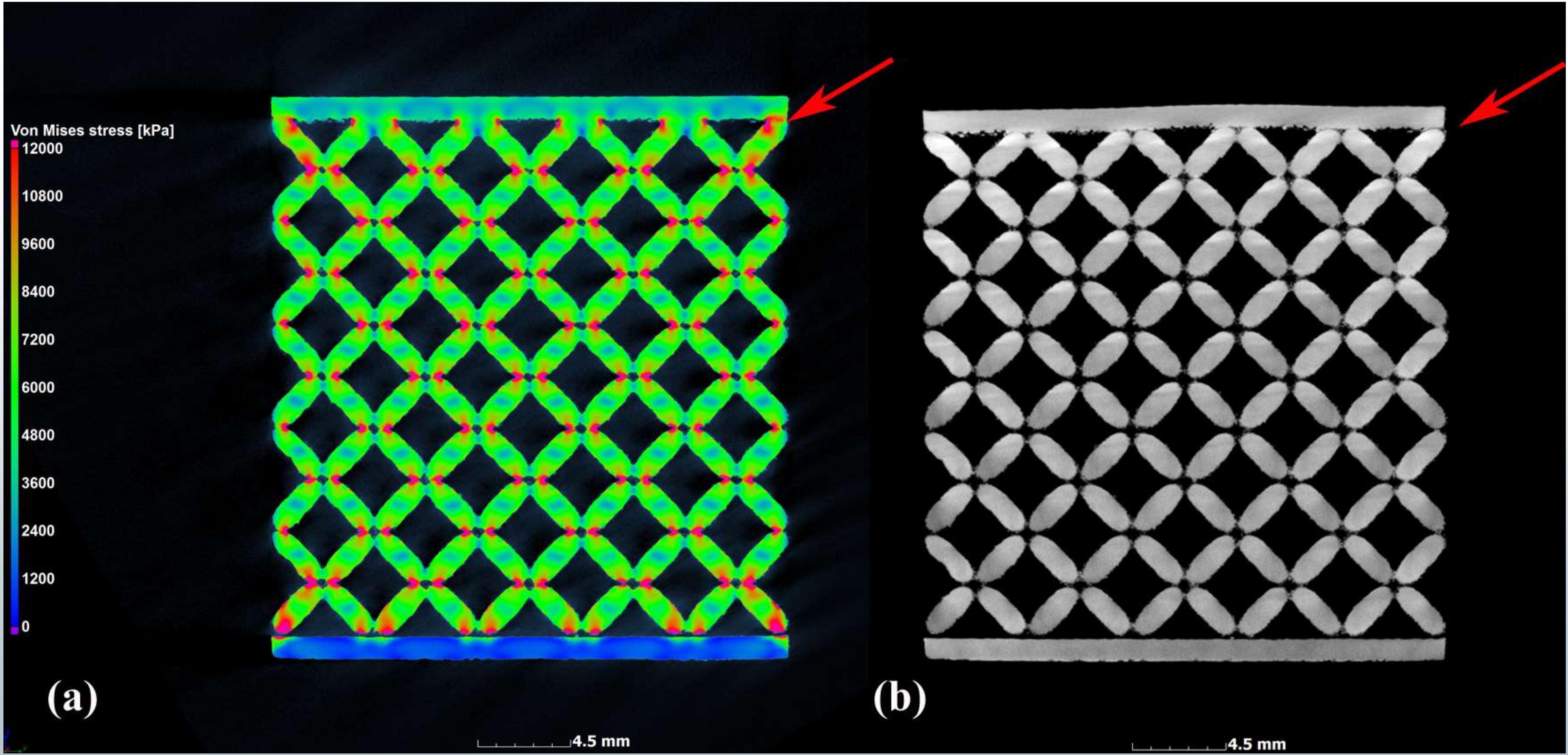

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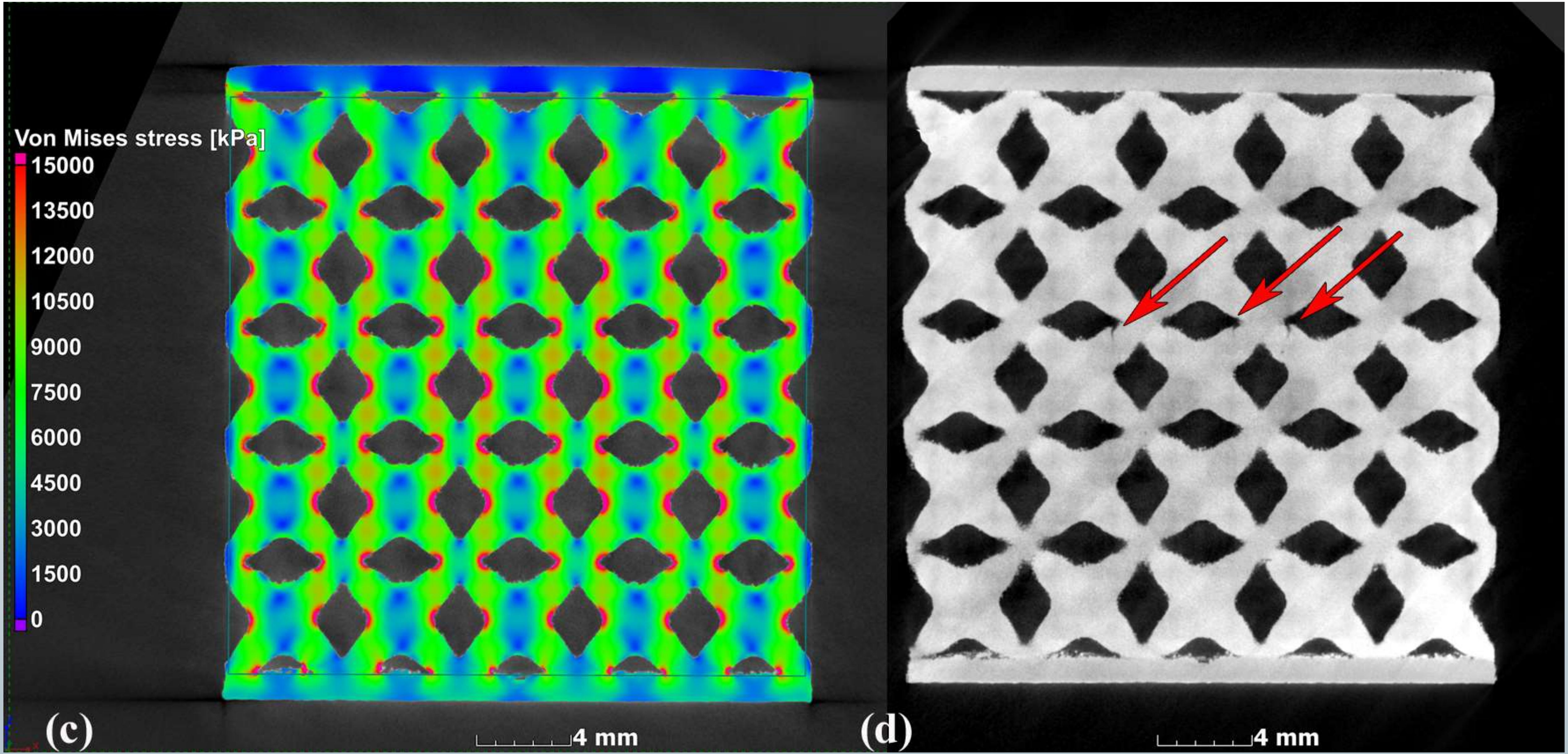

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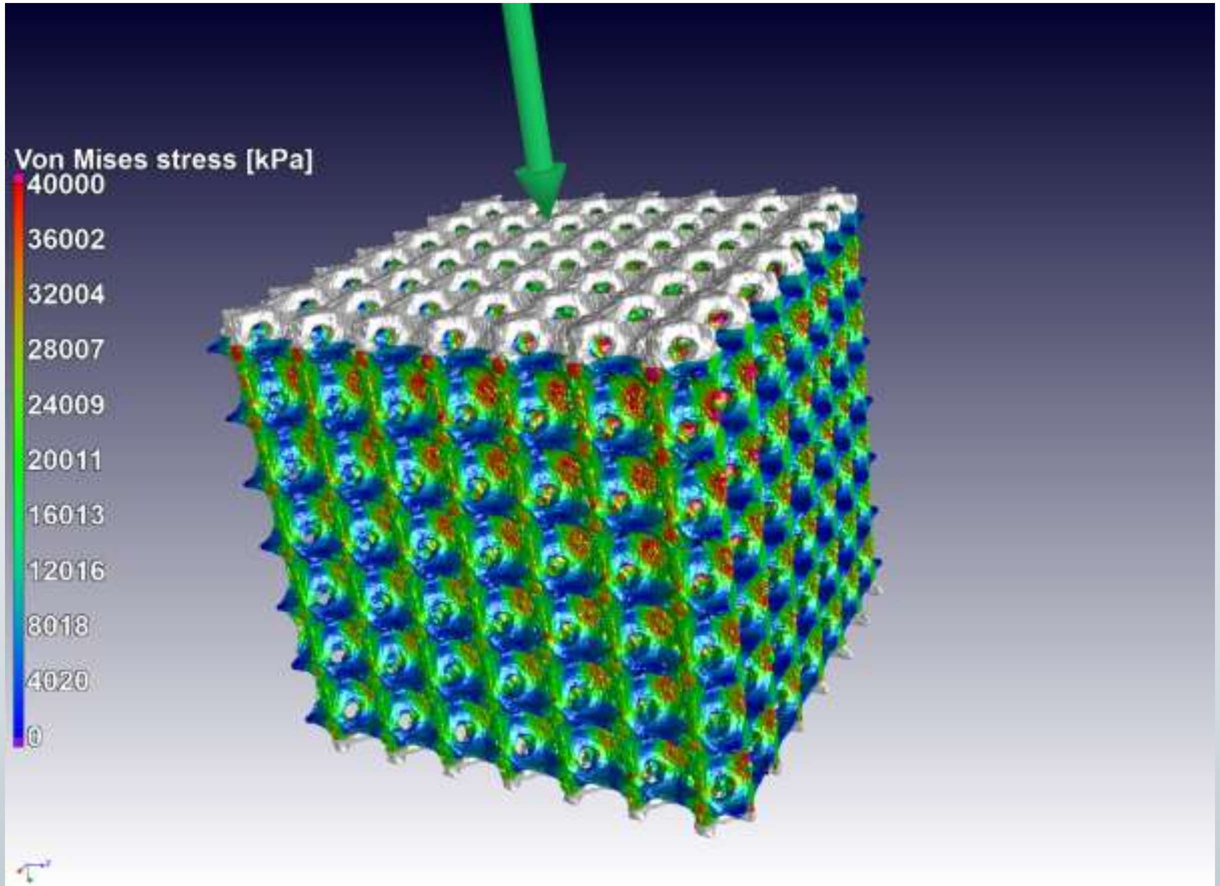
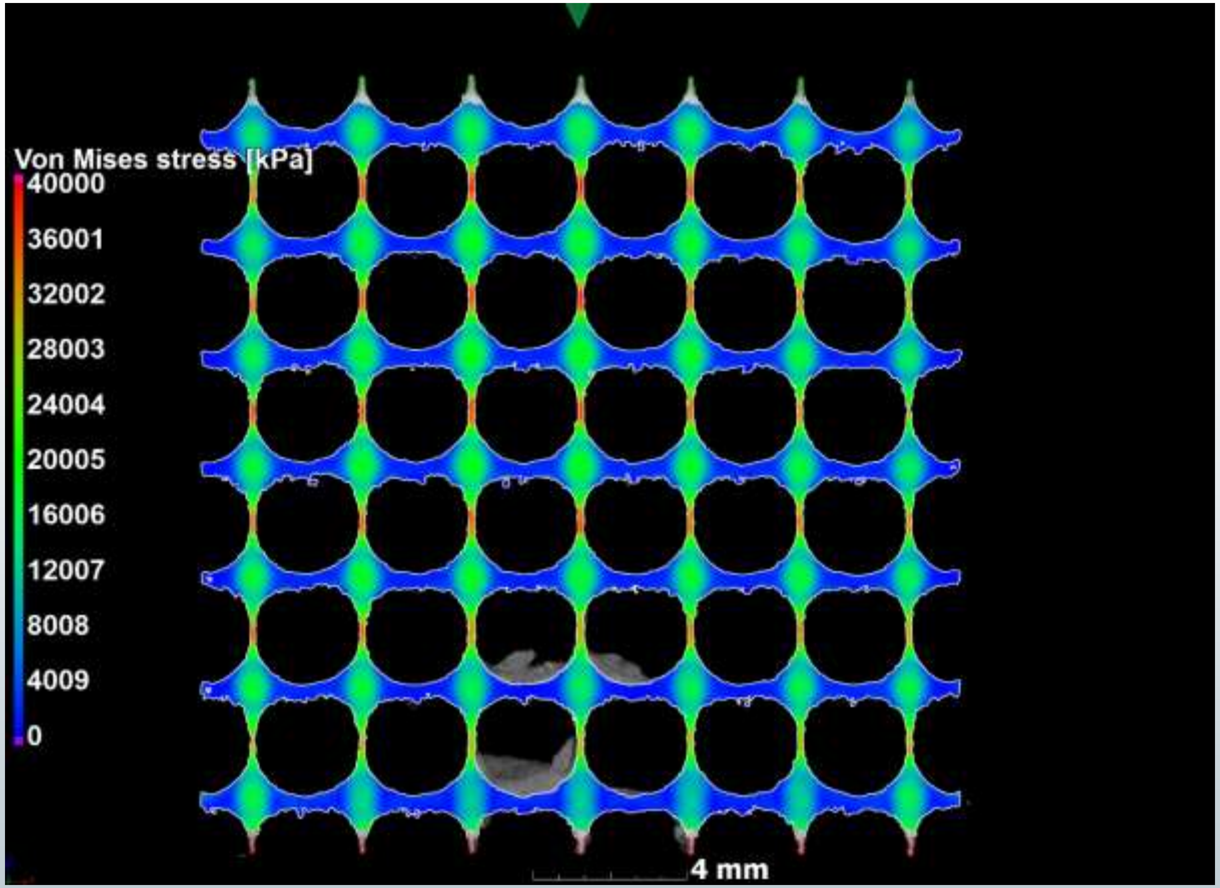
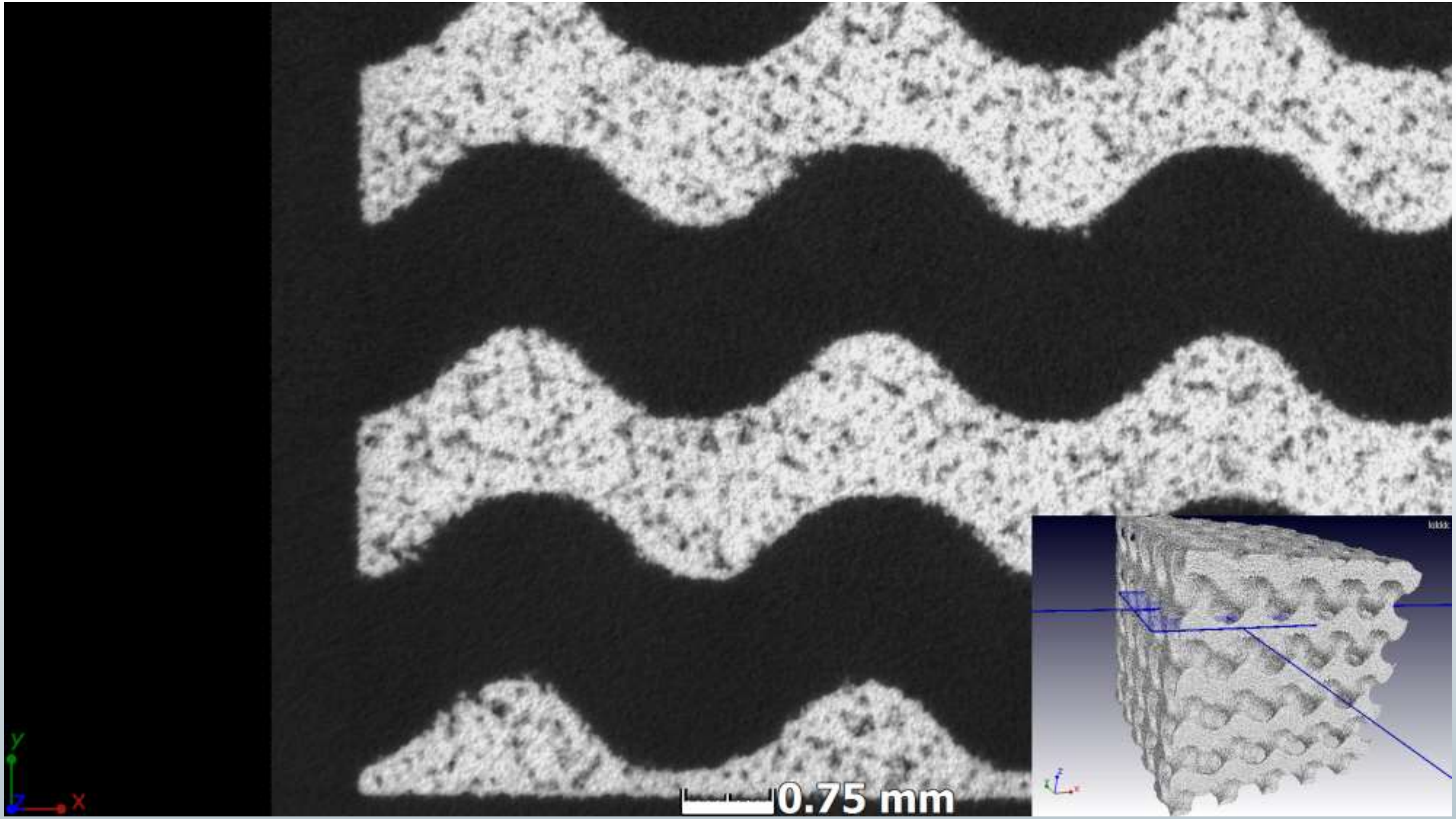
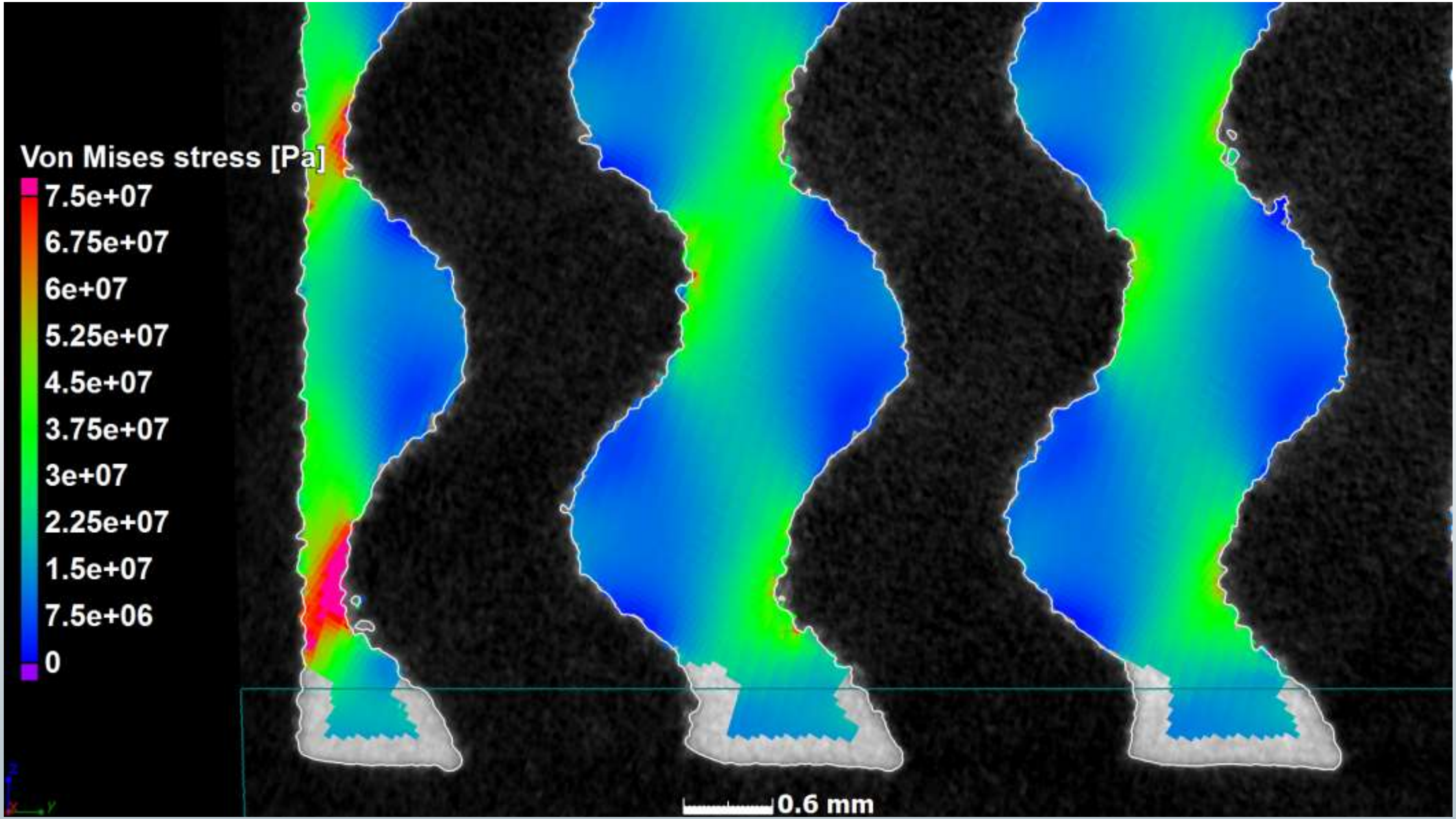




* AM. Vilardell, A. Takezawa, A. du Plessis, N.Takata, P.Krakhmalev, M.Kobashi, I.Yadroitsava, I.Yadroitsev. Topology optimization and characterization of Ti6Al4V ELI cellular lattice structures by laser powder bed fusion for biomedical applications, Materials Science and Engineering A, 2019. https://doi.org/10.1016/j.msea.2019.138330



* Work in progress: Ti6Al4V gyroids produced by L-PBF – simulation and mechanical properties



*** Work in progress: Ti6Al4V gyroids produced by L-PBF – simulation and mechanical properties**

CONCLUSIONS

- Image based simulations used for lattice structures
- Overview of different studies shows its utility
- I would like to discuss future potential in this field
- I am open to new collaborations

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THANKS FOR LISTENING!