A DISCUSSION ABOUT FINITE ELEMENT MODELING OF SLM PRODUCED STENTS

POLITECNICO MILANO 1863

LaBS www.labsmech.polimi.it

AddMe.Lab www.mecc.polimi.it

Alessandro Muzio[1], Francesca Berti[1], Valentina Finazzi[2], Ali Gokhan Demir[2], Barbara Previtali[2], Giancarlo Pennati[1] and Lorenza Petrini[3]

[1] LaBS, Chemistry, Materials and Chemical Engineering Department, Politecnico di Milano

[2] Department of Mechanical Engineering, Politecnico di Milano

[3] Department of Civil and Environmental Engineering, Politecnico di Milano

INTRODUCTION

SELECTIVE LASER MELTING

- Additive manufacturing technique employing **high power-density laser** to create **layer by layer 3D parts** through the **selective** melting of metal **powder particles**.
- ADVANTAGES: Customization, complex geometries, low cost, fast production time, high mechanical performance, CRITICALITIES: Complicated process, defect such as porosities, cracks, residual stresses and un-melted regions, low surface quality [1].

- Examples of biomedical parts produced by SLM [2,3]

SLM STENTS

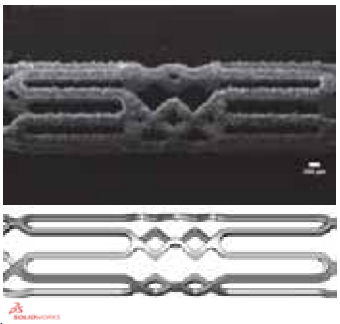
- SLM stents are influenced by the very low dimensions compared to macroscale applications: the necessity of **micro or nanoscale particles** difficult to handle safely, **size effect** altering microstructure and performances due to the **poor surface quality** are among the criticalities concerning the development of stents produced by SLM [4,5].
- Recently, experimental testing on process parameters, performances has been conducted leading to promising results. Different designs have also been developed and investigated, such as bifurcated stents [6]. Nevertheless, to the authors' knowledge, **there are no published studies on Finite Element modeling and simulation of SLM stents**.

AIM:

- To build a SLM produced stent model for functional FE Analysis.
- To figure out an effective computational approach for rapid comparison with experimental tests and validation.
- To define general guidelines for numerical simulations on SLM stents.

MODELING SLM PRODUCED STENTS

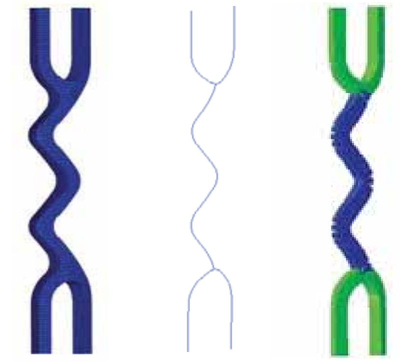
① CAD vs SLM



- The comparison of the initial CAD model and the final 3D part produced by SLM shows **significant differences** in strut thickness, surface roughness and overall irregularities and defects.
- In order to computationally investigate the SLM stent behaviour, taking into account the 'as built' device geometry is necessary to develop a model.
- X-ray **microtomography** scans can be useful, however **heavy and difficult to process data** are generated, which can prevent direct meshing procedure with tetrahedral or hexahedral elements.
- **Centerline** extraction from the μCT scans can be performed, allowing for a **beam element** model to be created and assessed.

② PRELIMINARY MODEL INVESTIGATION

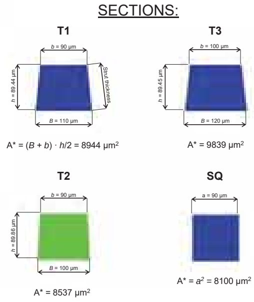
- In order to verify the accuracy of a beam model, a **comparison** between beam and 3D hexahedral element was performed. Initial CAD geometry was employed, presenting **trapezoidal-shaped struts** with **variable cross-sectional Area** along the stent geometry.



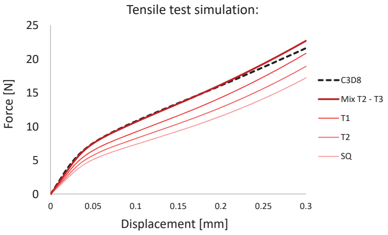
- 3D solid mesh - Centerline from CAD - Beam mesh Mix T2 - T3

- Solid mesh was built with 5x5 C3D8 elements, whereas for the beam elements different section shapes were considered (trapezoidal T, squared SQ). Along the geometry, beam sections were **uniformly** distributed (T1, T2, SQ) except for one **mixed** configuration (Mix T2 - T3), where 2 different beam cross-sections were assigned to different regions of the centerline.

SECTIONS:

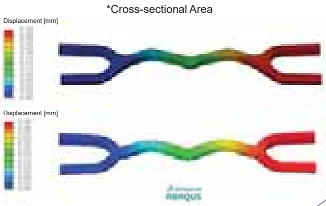


Tensile test simulation:



	3D	Beam
Strut thickness	90 μm	90 μm
Element type	C3D8	B31
Average element size	18μm x 18μm x 18μm	45μm (x A*)
Total number of elements	30350	485
Average runtime	40'	1' - 2'

*Cross-sectional Area

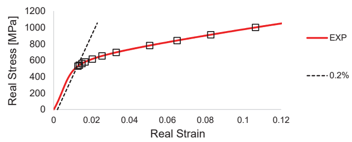


Conclusion: given the variable cross-sectional Area of the 3D geometry, beam cross-section must be assigned **accordingly with this variability**. Mixing different beam cross-sections along the centerline leads to better comparison with hexahedral element.

③ REAL STENT SIMULATION

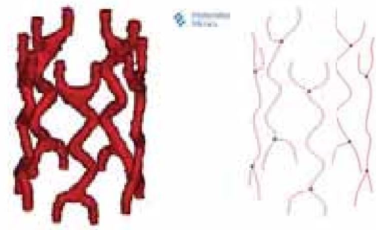
- MATERIAL MODEL: **Experimental data** from tensile tests on specimens manufactured with the same SLM parameters employed for stents.

Mechanical parameters	
E [GPa]	50.18
Poisson	0.45
σ_{yield} [MPa]	529.11
ε_{yield} [%]	1.28



- GEOMETRY:

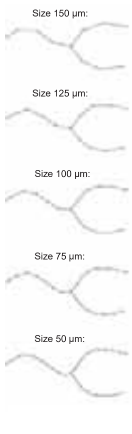
Tomographic scans → 3D meshing problems due to high geometrical irregularity → Centerline extraction → Beam Modeling



- μCT stent reconstruction - Centerline

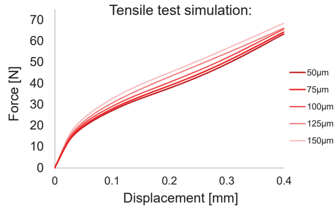
- MESH SENSITIVITY STUDY:

5 different beam element sizes were confronted to find mesh convergency.



Mean error relative to size 50 μm [%]	
Size 150 μm	17.33
Size 125 μm	11.6
Size 100 μm	6.53
Size 75 μm	2.68

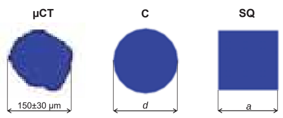
Tensile test simulation:



Conclusion: element size of 75 μm was found to be convergent.

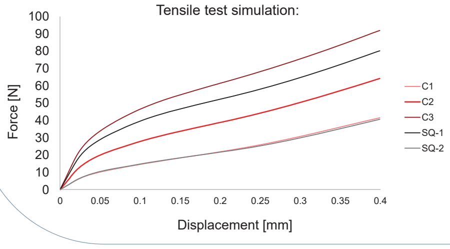
- BEAM SECTION SENSITIVITY:

Given the high random **geometrical variability of SLM processed devices**, beam cross-section geometry was analysed, in order to verify the sensitivity of the model to the cross-section selection. The variability range was derived from measurements on the μCT geometry, both squared and circular geometries were considered:



SQ-1, a = 150 μm
SQ-2, a = 150/√2 μm
C1, d = 120 μm
C2, d = 150 μm
C3, d = 180 μm

Tensile test simulation:



Conclusion: different shape and dimension of the beam lead to different results. In order to choose the suitable values for these parameters, **experimental validation** and **correct μCT measurements** of the section variability are required.

FINAL CONSIDERATIONS

Finite element modeling of stent manufactured by SLM was accomplished through beam element technique, from which the following **rules and guidelines** can be deduced:

- **Centerline** extraction from **μCT scans** is mandatory in order to approximate and discretize the real SLM stent geometry.
- Different **beam cross-section** can alter analysis results, and therefore must be selected accordingly to μCT scanning.
- Strut cross-sections of as-built SLM stents appear to be **larger** than CAD models and **circular-like**, despite the original CAD trapezoidal geometry. Realistic modeling must consider this discrepancies.
- Mesh convergency was demonstrated when element size equals **half the diameter** of a beam circular cross-section: for d = 150 μm, the optimal element size was found to be 75 μm.

Further research should investigated into experimental validation of FE results and model improvement.

Contact addresses:
alessandro.muzio@mail.polimi.it
francesca.berti@polimi.it
valentina.finazzi@polimi.it

References: [1] W. J. Sames, F. A. List, S. Pannala, R. R. Dehoff, and S. S. Babu, "The metallurgy and processing science of metal additive manufacturing," Int. Mater. Rev., 2016.
[2] Fraunhofer Institute for Laser Technology ILT, www.ilt.fraunhofer.de
[3] L. C. Zhang and H. Attar, "Selective Laser Melting of Titanium Alloys and Titanium Matrix Composites for Biomedical Applications: A Review," Adv. Eng. Mater., 2015.
[4] B. Nagarajan, Z. Hu, X. Song, W. Zhai, and J. Wei, "Development of Micro Selective Laser Melting: The State of the Art and Future Perspectives," Engineering, 2019.
[5] A. G. Demir and B. Previtali, "Additive manufacturing of cardiovascular CoCr stents by selective laser melting," Mater. Des., vol. 119, pp. 338–350, Apr. 2017.
[6] V. Finazzi et al., "Design Rules for Producing Cardiovascular Stents by Selective Laser Melting: Geometrical Constraints and Opportunities," Procedia Struct. Integr., vol. 15, pp. 16–23, 2019.