TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA
Dipartimento di Ingegneria Industriale

IAGE Italy
INTERNATIONAL ASSOCIATION FOR GREEN ENERGY

Materiali porosi per la transizione energetica

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Webinar CNI 19/05/2025

Agenda

- Introduction and Objectives
- Some research results
- Publications
- Future Developments

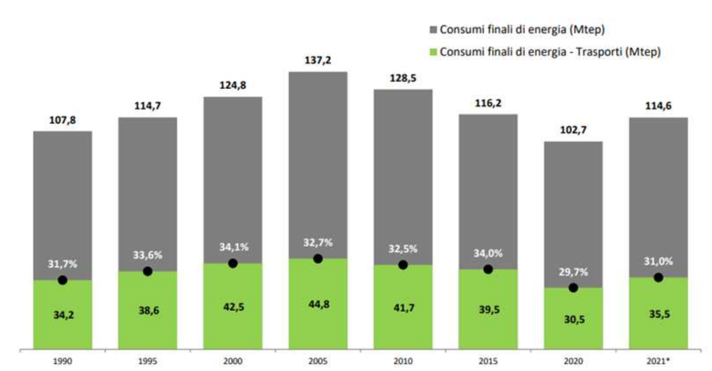
Introduction

- In 2021, national energy consumption in the **transportation sector** accounted for **31%** of the country's **total energy consumption**, of which **88.6%** was related to **road transport**.

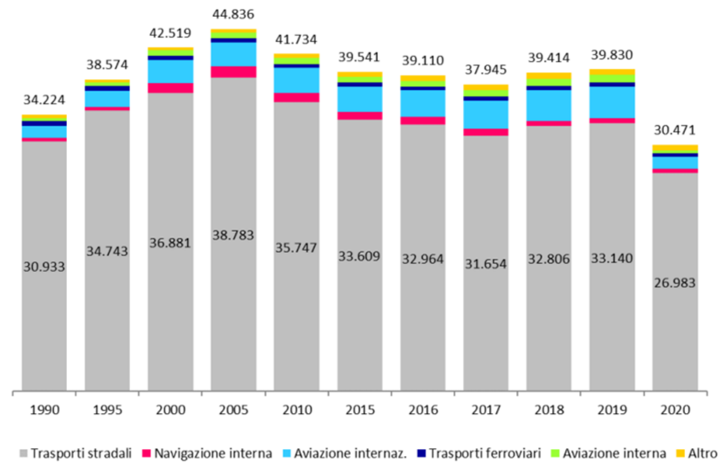
direttiva 2014/94/EU
direttiva 2018/2001

- **European Green Deal**
  - A 55% reduction in greenhouse gas emissions compared to 1990. → **2030**
  - Carbon-neutrality → **2050**

- The automotive industry is undergoing a significant transition towards sustainable mobility, focusing on electric vehicles (EVs) as an alternative to traditional internal combustion engine vehicles.



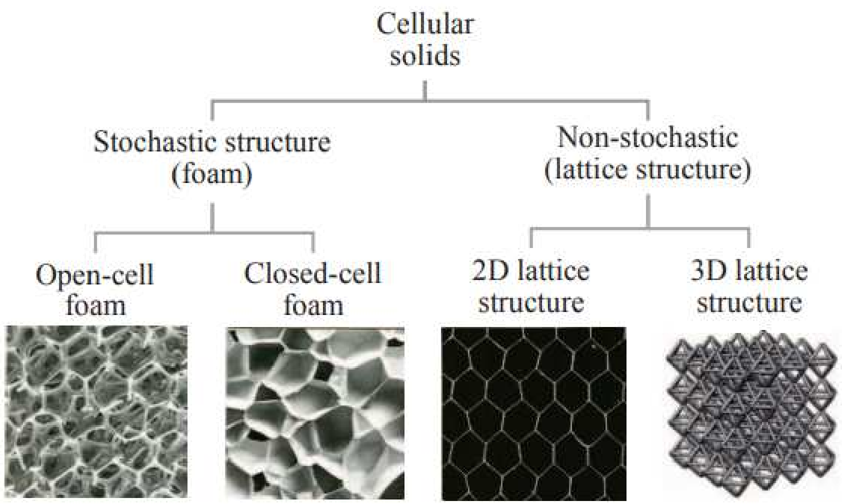
Fonte: elaborazioni GSE su dati Eurostat
(*) stime preliminari basate su dati Mite, Snam, Terna, GSE



Fonte: elaborazioni GSE su dati Eurostat

Introduction

Cellular solids



Design of Lattice Structure for Additive Manufacturing

Cellular structures offer a combination of lightness and mechanical strength due to their interconnected cell geometry.

- High energy absorption in the event of impacts or accidents.
- Reduction of the overall vehicle weight without compromising structural integrity and passenger safety.

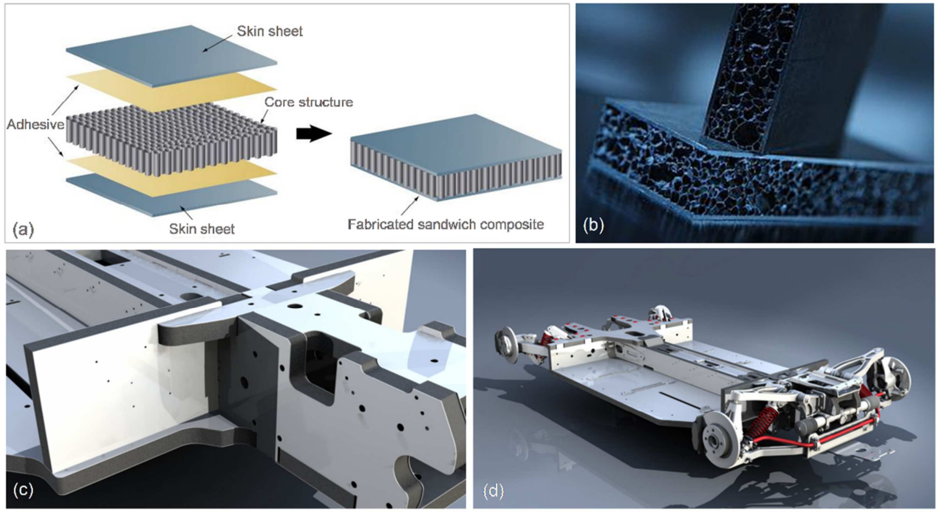
Reducing the electrical energy consumption required to move the vehicle, allowing for greater range on a single battery charge.

Introduction

Application of Cellular solids

The applications of cellular structures in vehicles are diverse and cover various areas, including:

- **<u>Batteries</u>**: the increased surface area improves thermal exchange and management.
- **<u>Lightweight structural components</u>**: used as frames, panels, and beams. This helps to reduce the overall weight of the vehicle, thereby improving energy efficiency and range while maintaining mechanical properties.
- **<u>Dampers</u>**: to enhance driving comfort, vibration absorption, and vehicle stability.
- **<u>Acoustic insulation</u>**: improving soundproofing inside electric vehicles, thus reducing engine noise and enhancing the driving experience.
- **<u>Hydrogen storage:</u>** metal and carbon foams to increase surface area-to-volume ratio, facilitating hydrogen absorption and diffusion and providing mechanical support for hydrogen storage.



A comprehensive review of advanced light-weight materials for automotive applications. Procedia Manufacturing

Objectives

Main research objectives are:

- To analyze the characteristics of cellular structures and their potential impact on Evs;
- To develop design and optimization methods for cellular structures in electric vehicles;
- To produce different types of cellular materials;
- To analyze the mechanical performance, thermal exchange, and energy absorption of cellular structures in Evs.

Agenda

- Introduction and Objectives
- **Some research results…**
- Publications
- Future Developments

Some research results

Cellular solid

Stochastic structures (Foam)

Open-cell foam

Production of metal foams with *casting in salt grains*

Closed-cell foam

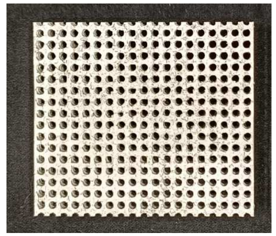
Production of metal foams by *melting of compacted powders*

Non-stochastic (Lattice structure)

2D lattice structure

3D lattice structure

Production of 3D lattice structures using the *lost PLA method*



Research results: *Open-cell foams*

Casting in salt grains method

Plaster mold

Burnout

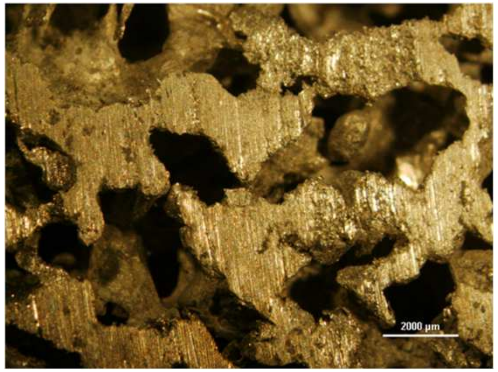
Gravity casting

Foam

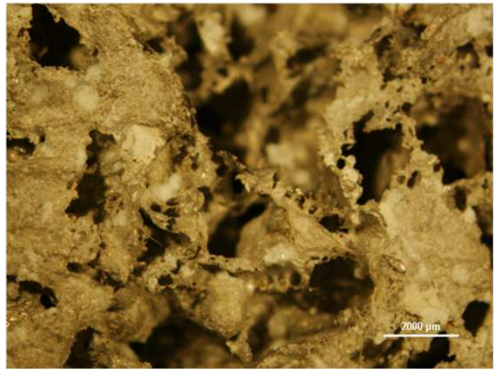
Final structure

Microscopic view 10x

Top view



Longitudinal section



Research results: Closed-cell foams

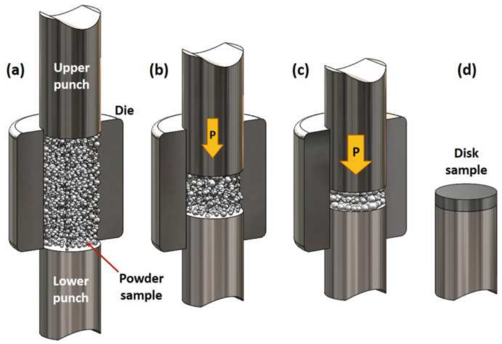
Melting of compacted powders method

1. Mixing of 3 metal powders:
   - Base metal/alloy: **Aluminum**
   - Foaming agent: **TiH_2**
   - Stabilizing agent: **SiC**

Compositions

- 0,1 % TiH2 – 2,8 % SiC
- 0,2 % TiH2 – 2,8 % SiC
- 0,4 % TiH2 – 2,8 % SiC
- 0,1 % TiH2 – 6,0 % SiC
- 0,2 % TiH2 – 6,0 % SiC
- 0,4 % TiH2 – 6,0 % SiC

2. Compaction of metal powders



3. Foaming

4. Cooling

Research results: Closed-cell foams

Compression Tests

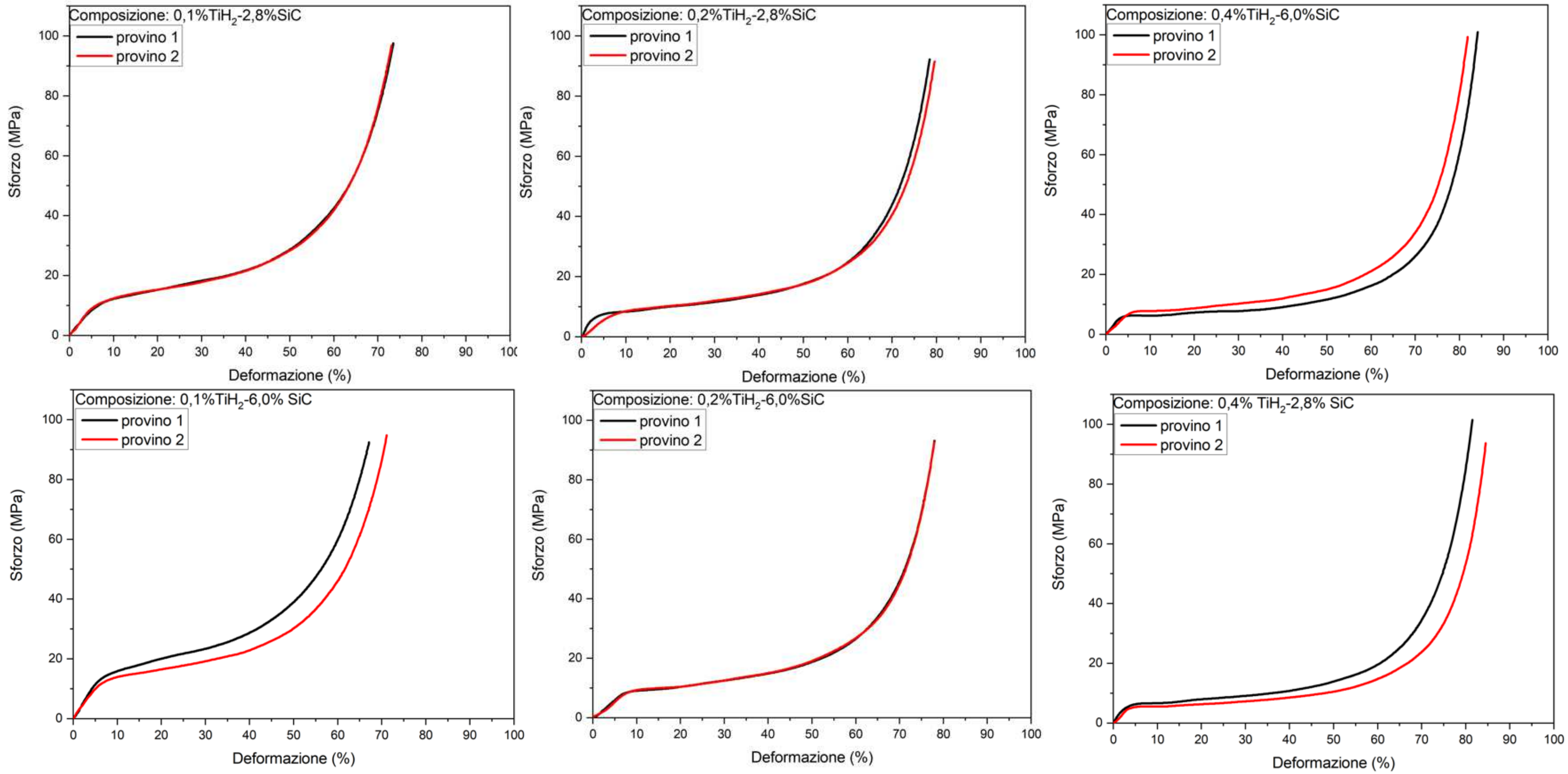
Research results: Closed-cell foams

Compression Tests

0,1 % TiH2 **0,2 % TiH2** **0,4 % TiH2**

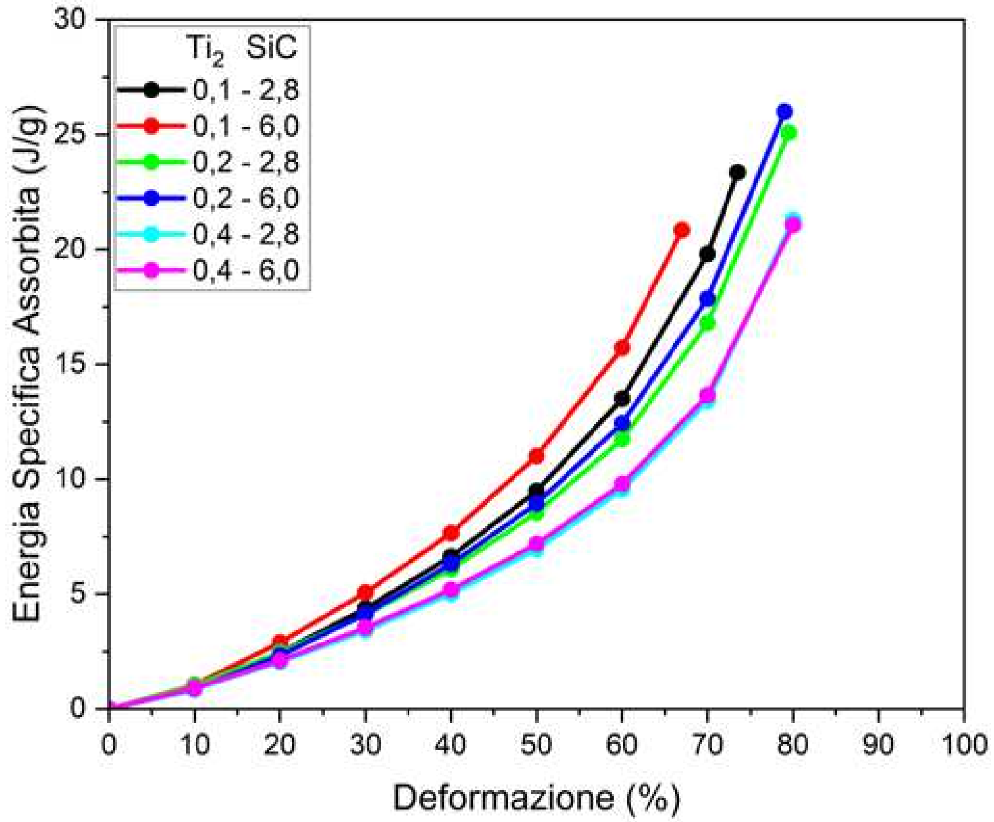
2,8 % SiC

6,0 % SiC



Research results: Closed-cell foams

Compression Test: SPECIFIC ENERGY ABSORPTION



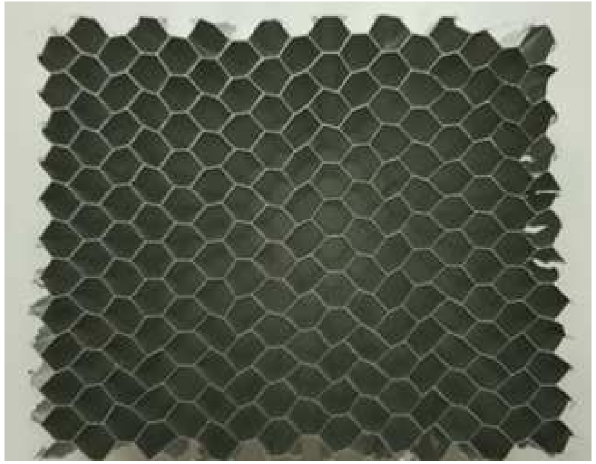
$$E_{Spec} = \frac{1}{\rho}\int_0^{\bar{\varepsilon}} \sigma d\varepsilon$$

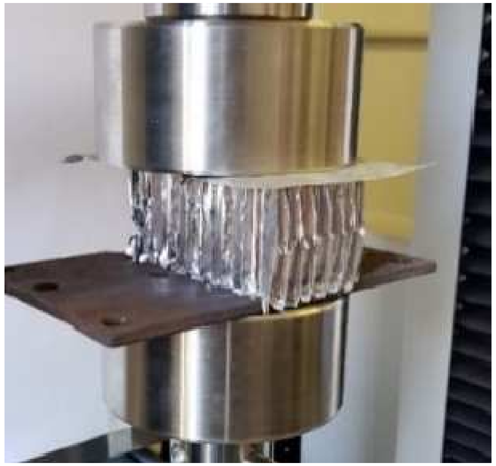
0,1 % TiH_2	**12 %** 0,2 % TiH_2		$\varepsilon = 50\%$
	38 % 0,4 % TiH_2		
0,1 % TiH_2	**26 %** 0,2 % TiH_2		$\varepsilon = 60\%$
	60 % 0,4 % TiH_2		

Strain (%)	Foam 0,1% TiH_2–6,0 % SiC
10	1,0
20	2,9
30	5,1
40	7,6
50	11,0
60	15,7
70	20,8

Research results: 2D lattice

HONEYCOMB: Compression static test





Research results: 2D lattice

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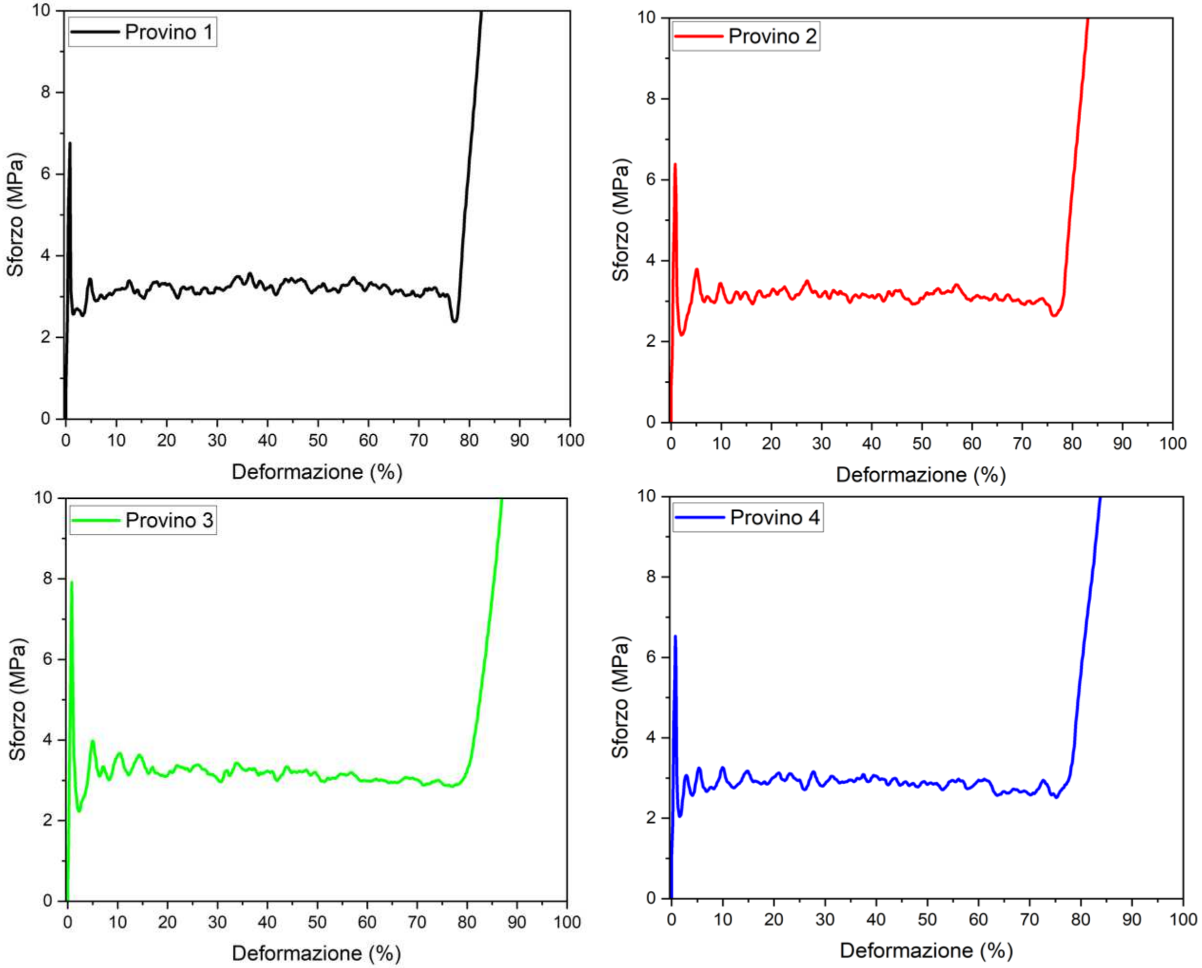

Research results: 2D lattice

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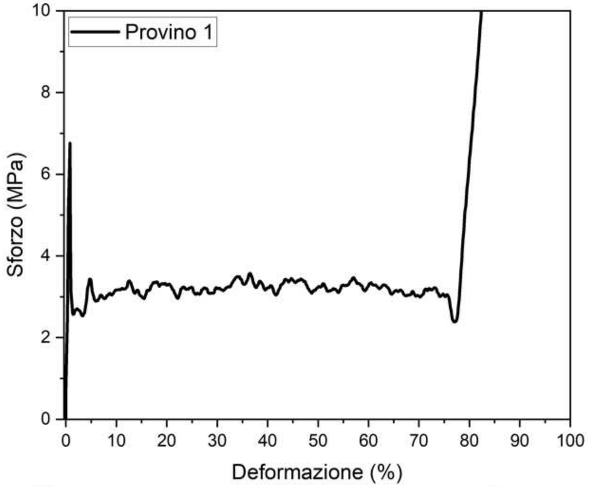
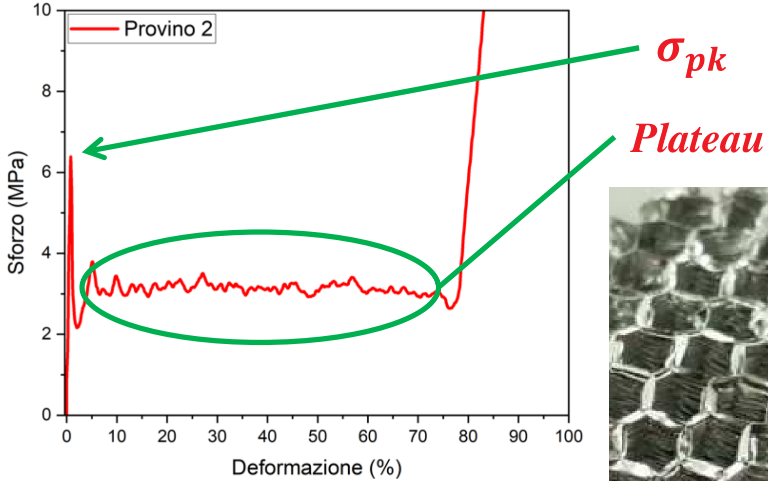
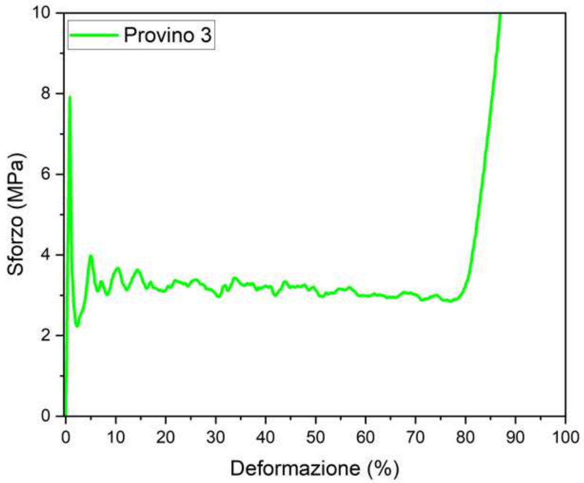
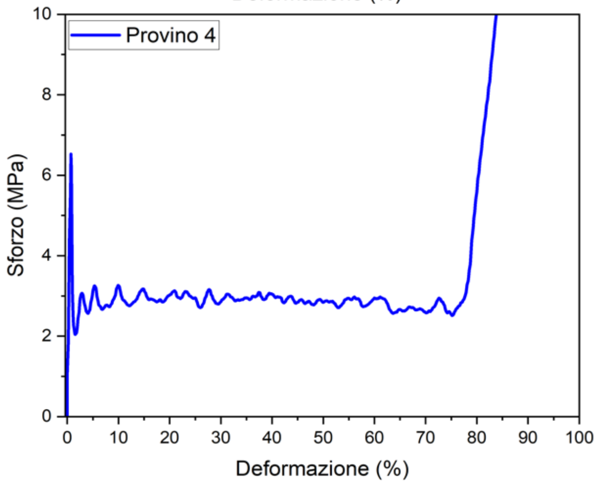


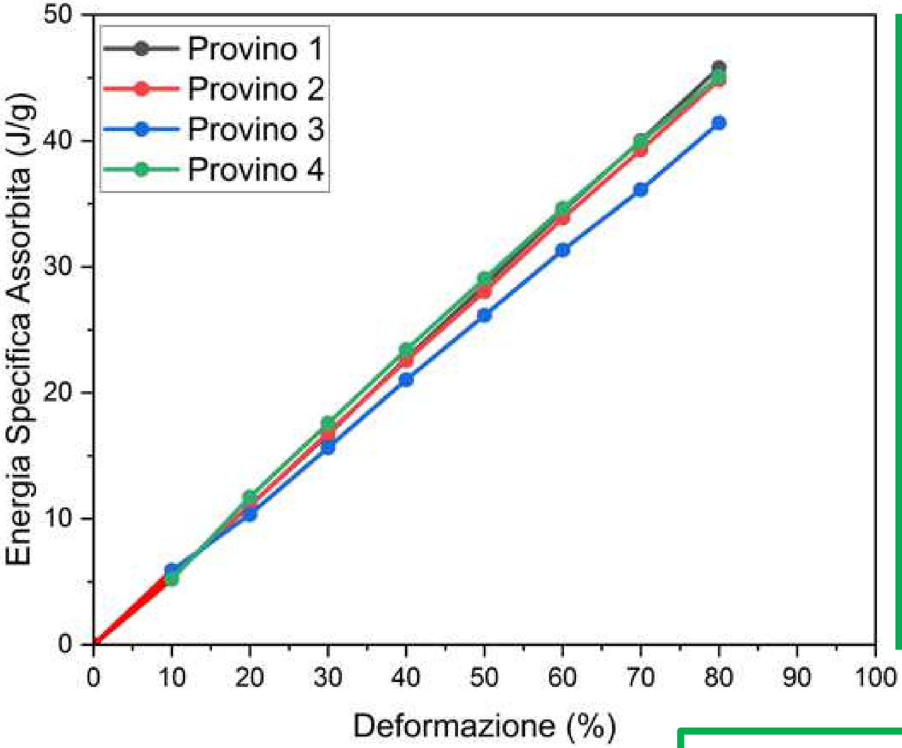






Research results: 2D lattice

HONEYCOMB: Compression static test, SPECIFIC ENERGY ABSORPTION

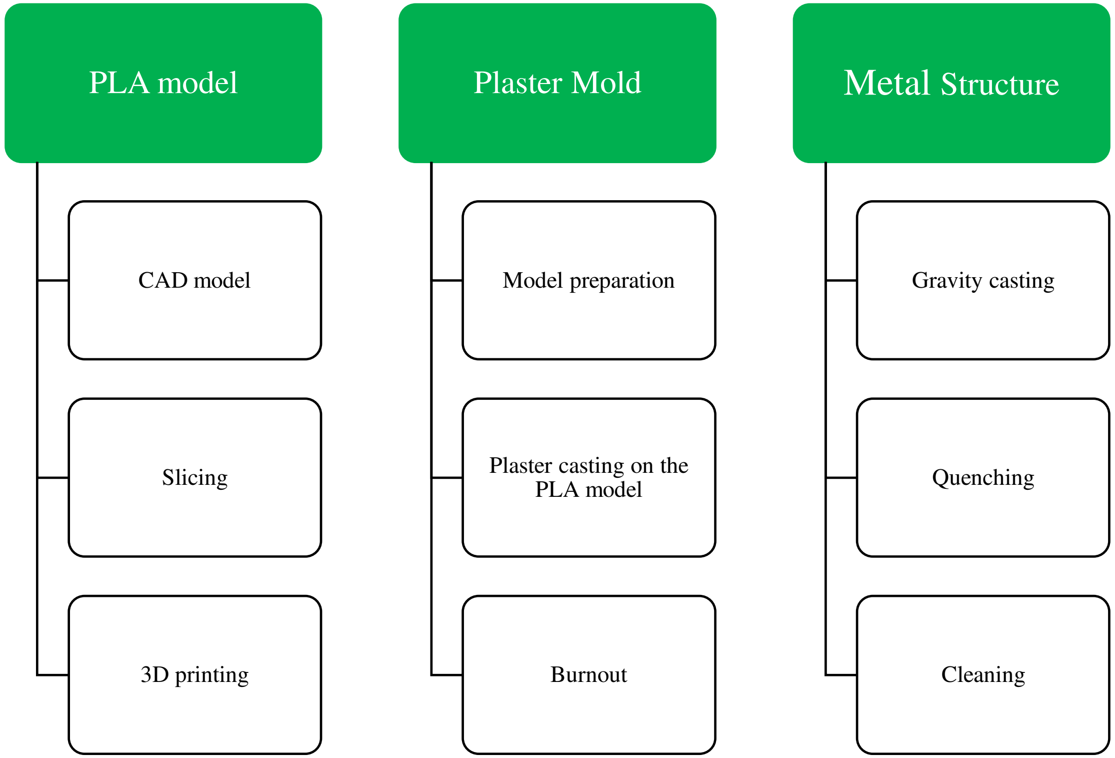


Strain (%)	Honeycomb Sample 1
10	5,4
20	11,0
30	16,7
40	22,7
50	28,5
60	34,5
70	40,0

$$E_{Spec} = \frac{1}{\rho}\int_0^{\bar{\varepsilon}} \sigma d\varepsilon$$

Research results : 3D lattice

Lost PLA method



Research results: 3D lattice

Lost PLA method

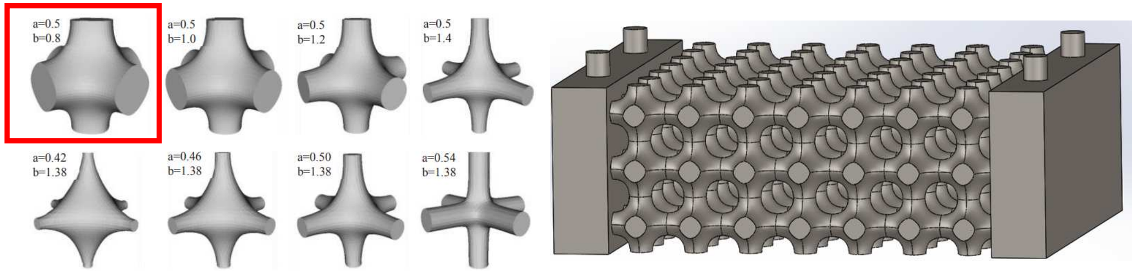
- PLA model
  - CAD model
  - Slicing
  - 3D printing

- Plaster casting on the PLA model
- Burnout

- Quenching
- Cleaning

CAD Model

$$\textit{Reference parametric function}: F(x,y,z) = \cos(2\pi x) + \cos(2\pi y) + \cos(2\pi z)$$
$$+\boldsymbol{a}\cdot\big(\cos(2\pi x)\cdot\cos(2\pi y)\big) + \cos(2\pi y)\cdot\cos(2\pi z) + \cos(2\pi z)\cdot\cos(2\pi x) + \boldsymbol{b} = 0$$



Research results: 3D lattice

Lost PLA method

PLA model

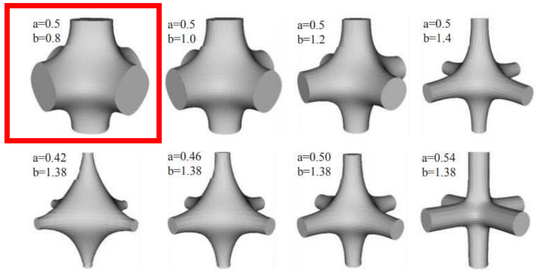
CAD model

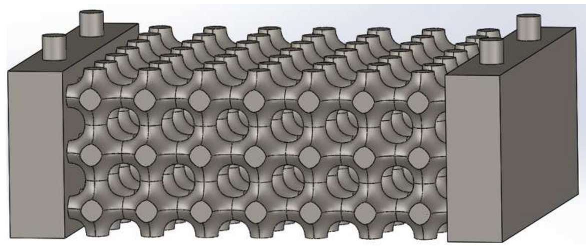
Slicing

3D printing

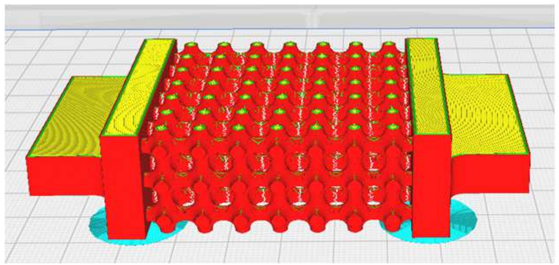
CAD Model

Reference parametric function : $F(x,y,z) = \cos(2\pi x) + \cos(2\pi y) + \cos(2\pi z) + \boldsymbol{a} \cdot (\cos(2\pi x) \cdot \cos(2\pi y)) + \cos(2\pi y) \cdot \cos(2\pi z) + \cos(2\pi z) \cdot \cos(2\pi x) + \boldsymbol{b} = 0$





Slicing



Research results : 3D lattice

Lost PLA method

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CAD Model

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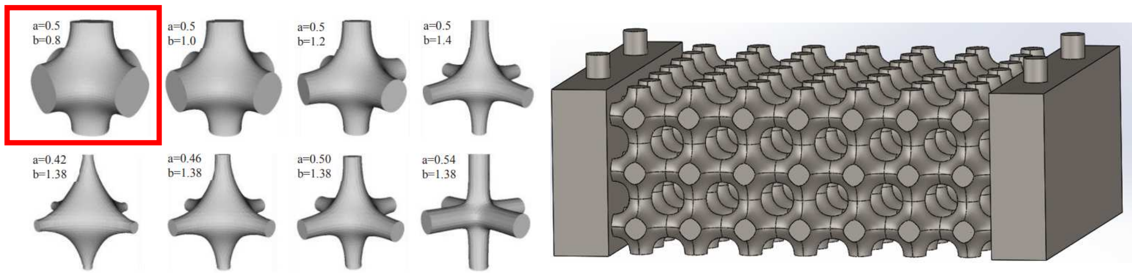
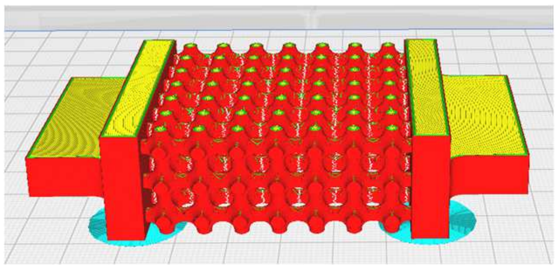
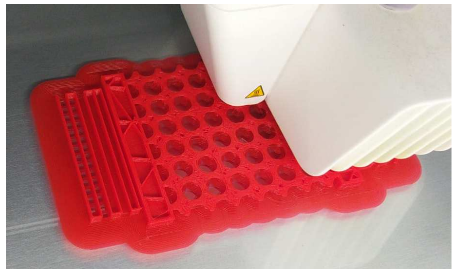


Slicing



3D printing



Research results: 3D lattice

Lost PLA method

Model Preparation

Slicing

3D printing

Plaster Mold

- Model preparation
- Plaster casting on the PLA model
- Burnout

Metal Structure

- Gravity casting
- Quenching
- Cleaning

Research results : 3D lattice

Lost PLA method

<u>Model Preparation</u>

Slicing

3D printing

Plaster Mold

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Metal Structure

<u>Plaster casting on the PLA model</u>

Research results: 3D lattice

Lost PLA method

Model Preparation

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Plaster casting on the PLA model

Research results: 3D lattice

Lost PLA method

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Research results: 3D lattice

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Metal Structure

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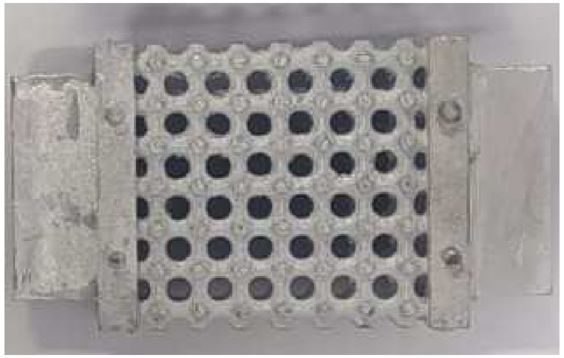
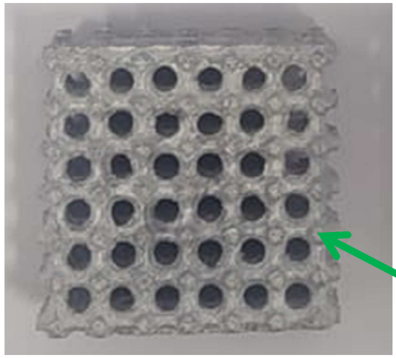
Cleaning





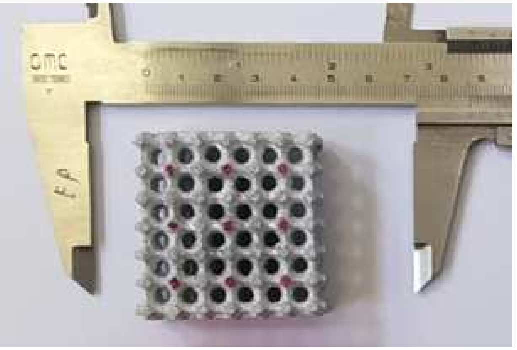
***Al* alloy EN AW - 6082**

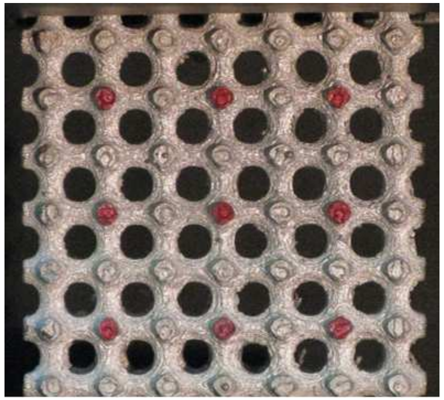
Research results: 3D lattice

Mechanical characterization

- Compression test
- Finite Element Analysis (FEA)
- Discrete Fourier Transform (DFT)
- Digital Image Correlation (DIC)

<u>*Compression test*</u>



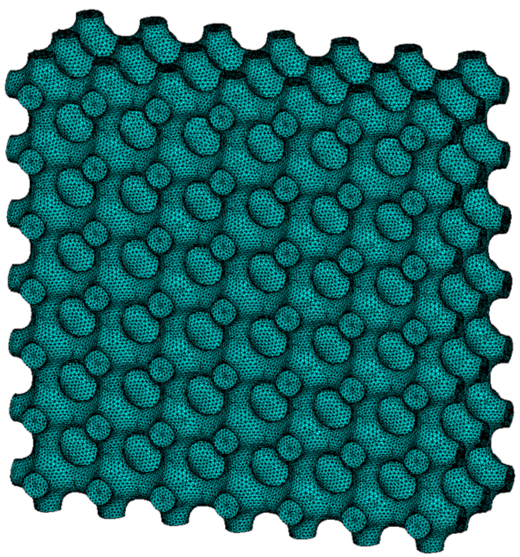


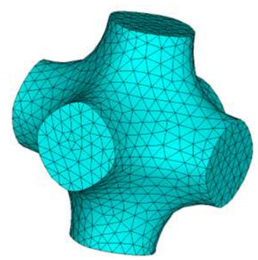
Research results: 3D lattice

Mechanical characterization: Finite Element Analysis (FEA)

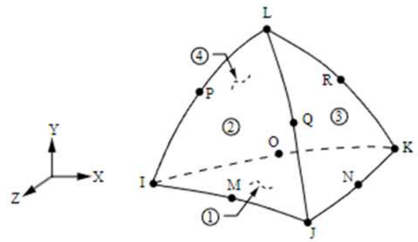
Mesh

Isometric view





Element type

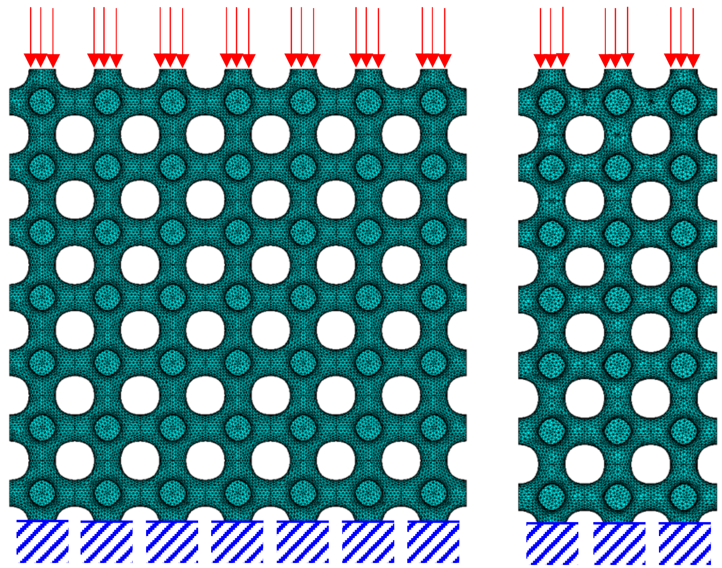


SOLID 187 (10 nodes - quadratic SF)

Loads and constraints

Front view *Side view*

Vertical Displacements applied

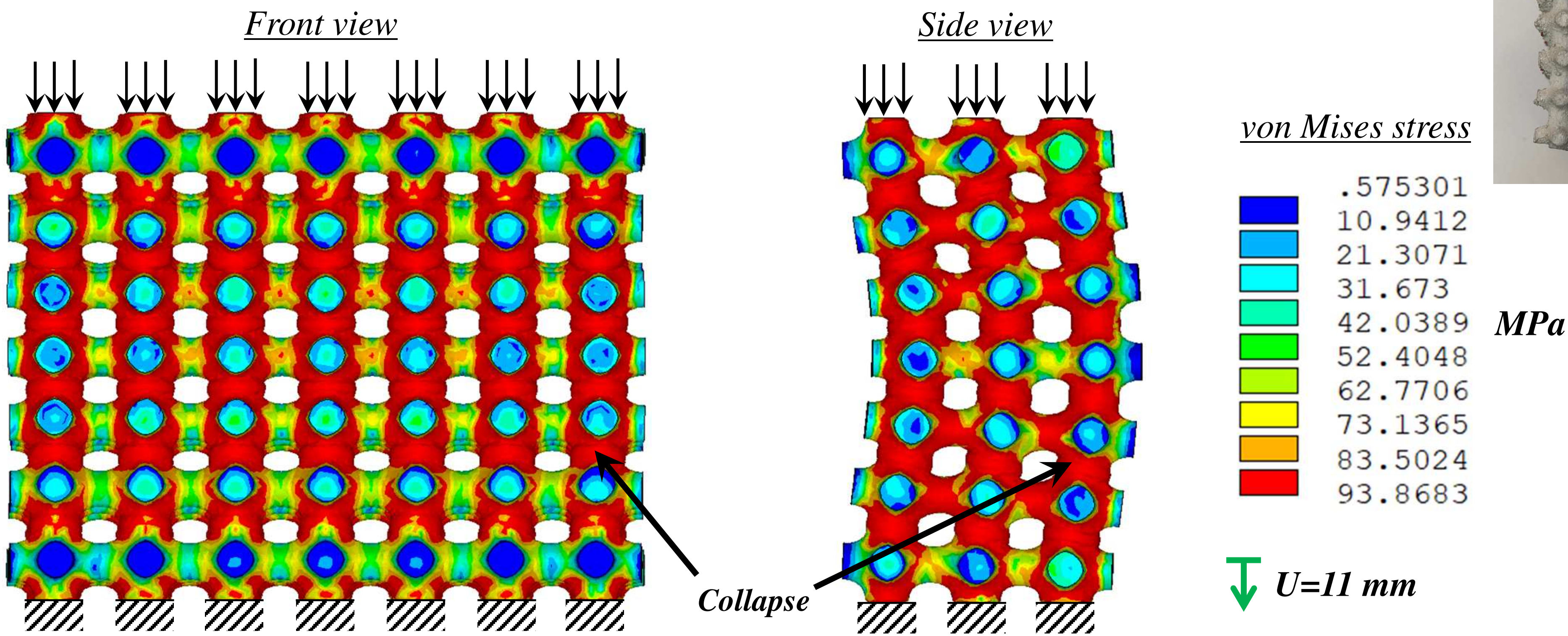


Clamped constraints

Research results: 3D lattice

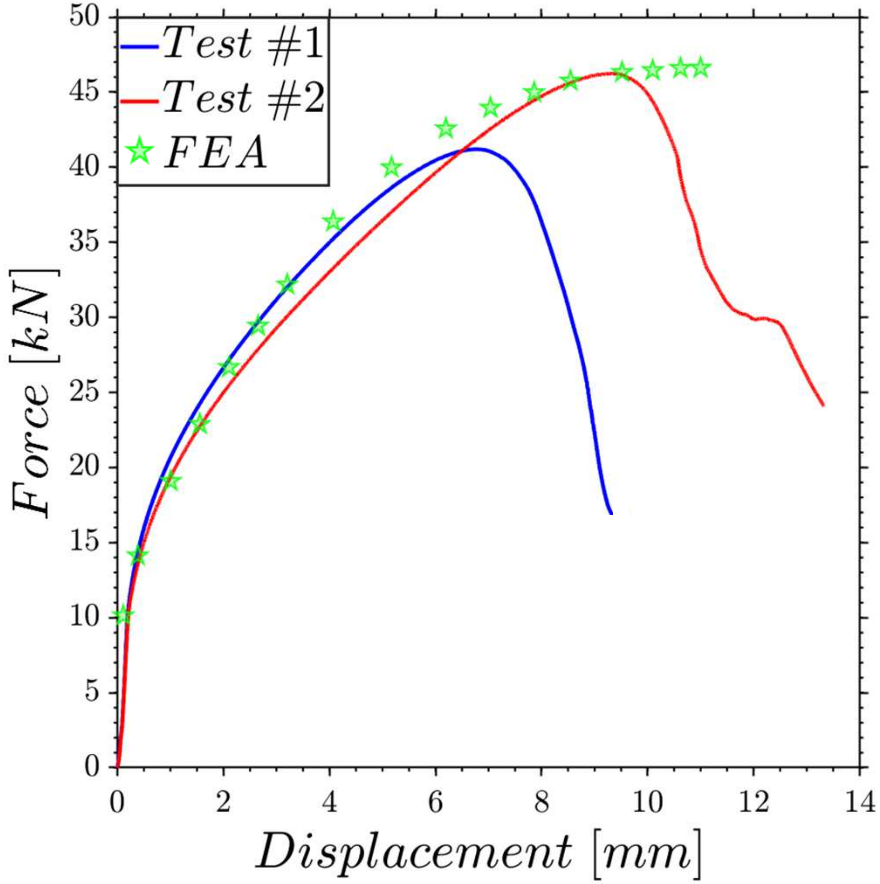
Mechanical characterization: Finite Element Analysis (FEA)

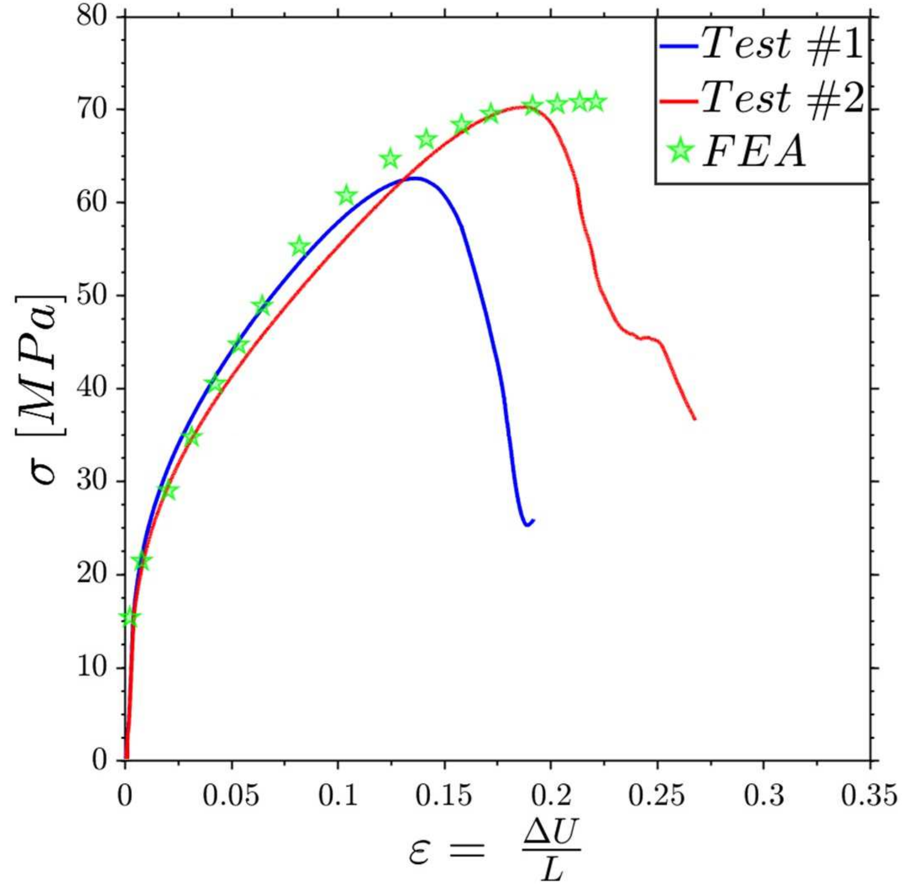
Results



Research results: 3D lattice

Mechanical characterization: Experimental Analysis and (FEA)



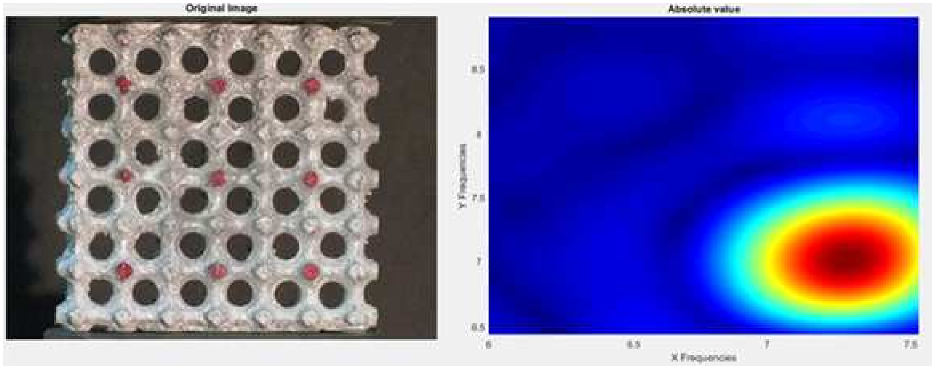


Research results: 3D lattice

Mechanical characterization: DFT and DIC

Discrete Fourier Transform

Number of periodic repetitions of the structure in terms of frequencies in the two-dimensional digital image



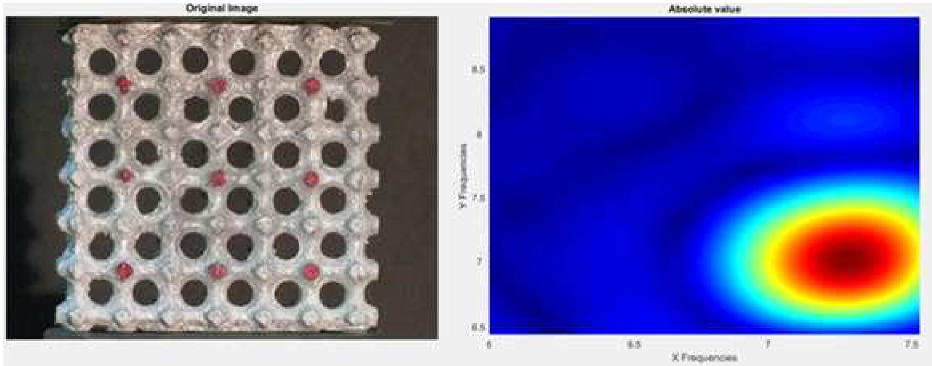
- $\varepsilon_y = \frac{f_{y_n} - f_{y_0}}{f_{y_0}}$

Research results: 3D lattice

Mechanical characterization: DFT and DIC

Discrete Fourier Transform

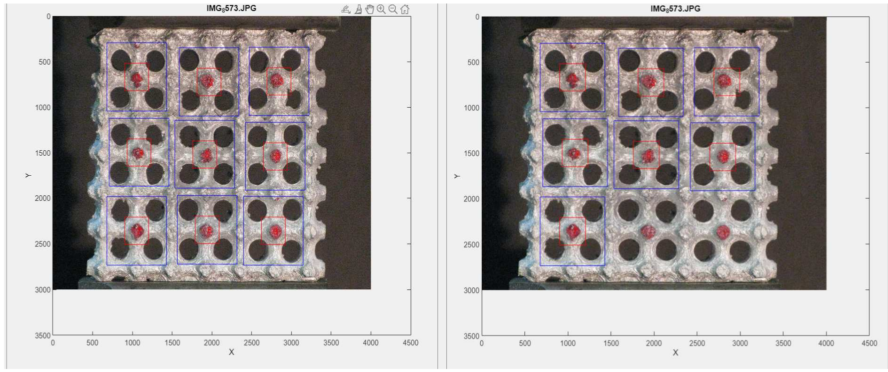
Number of periodic repetitions of the structure in terms of frequencies in the two-dimensional digital image

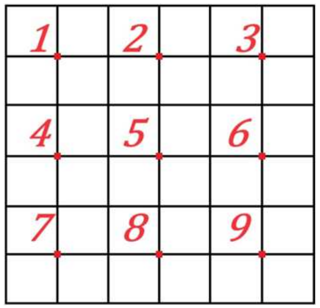


- $\varepsilon_y = \frac{f_{y_n} - f_{y_0}}{f_{y_0}}$

Digital Image Correlation

Displacement of a portion of the image that has undergone deformation within the original image



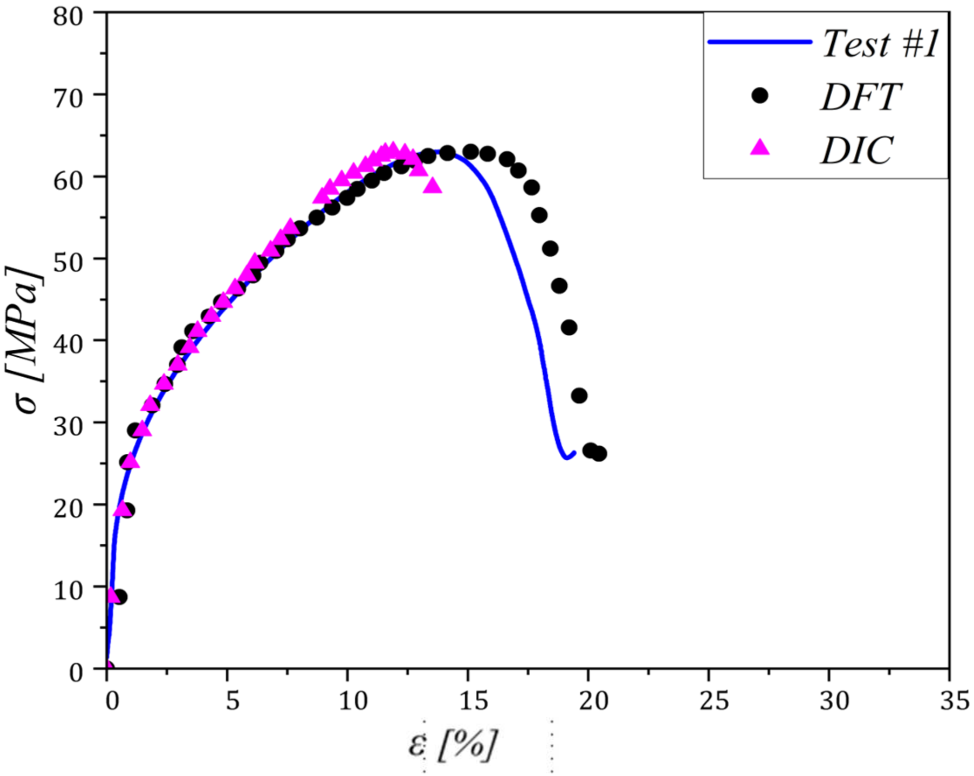


- $\varepsilon = \frac{L_n - L_0}{L_0}$
- $\bar{\varepsilon_y} = \frac{\varepsilon_{1-7} + \varepsilon_{2-8} + \varepsilon_{3-9}}{3}$

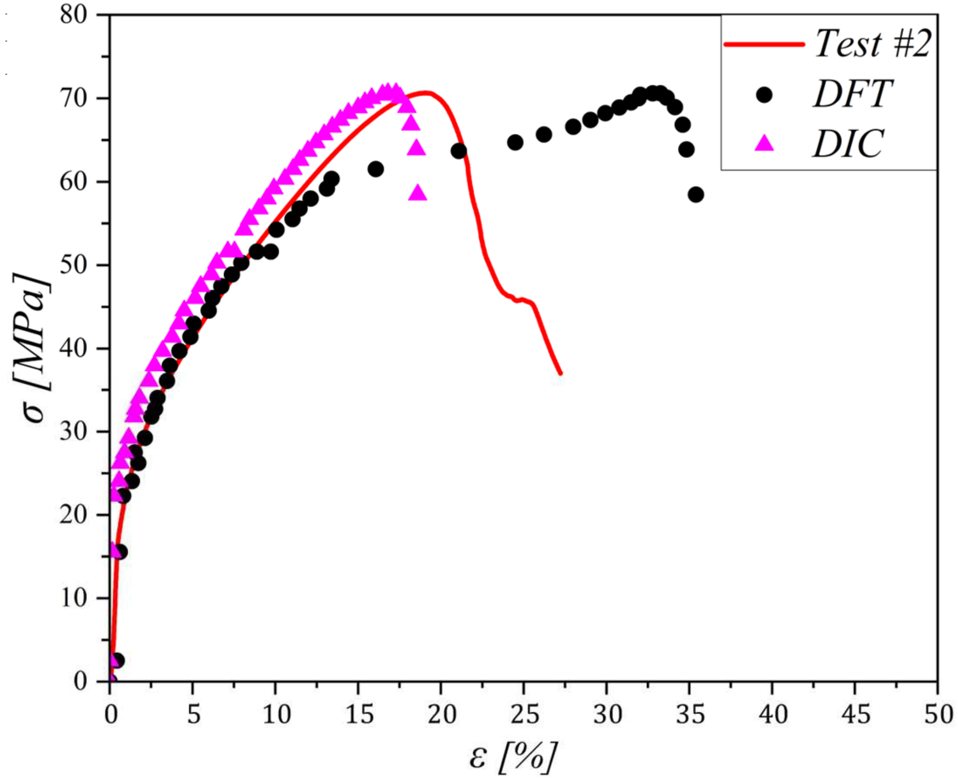
Research results: 3D lattice

Mechanical characterization: DFT and DIC

Discrete Fourier Transform



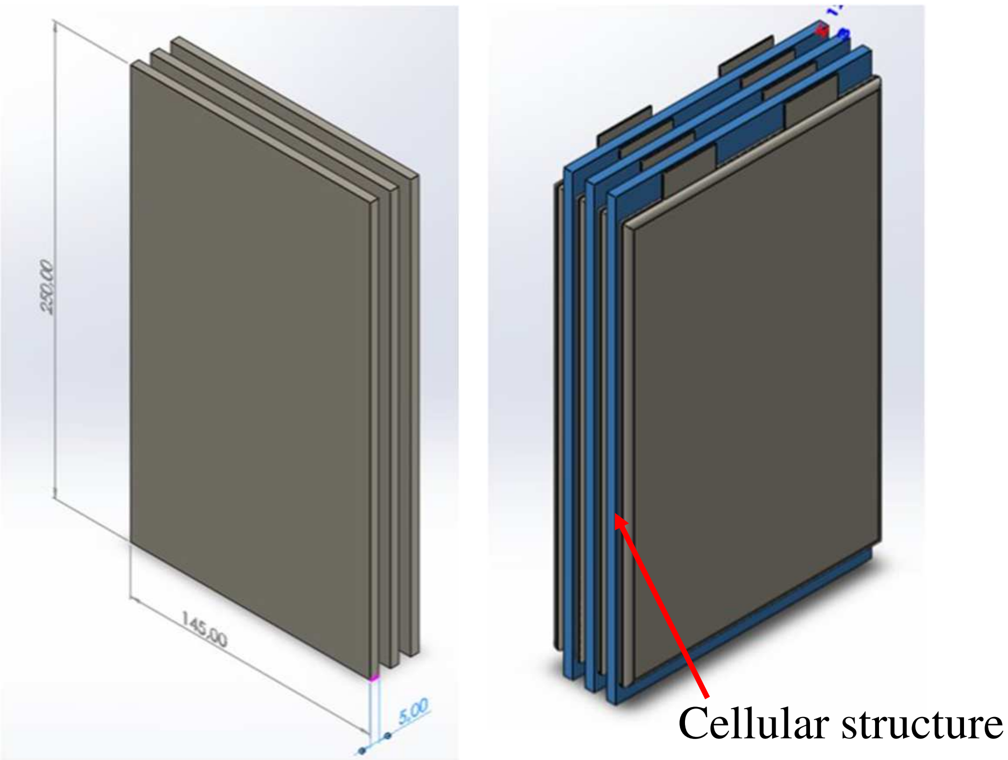
Digital Image Correlation



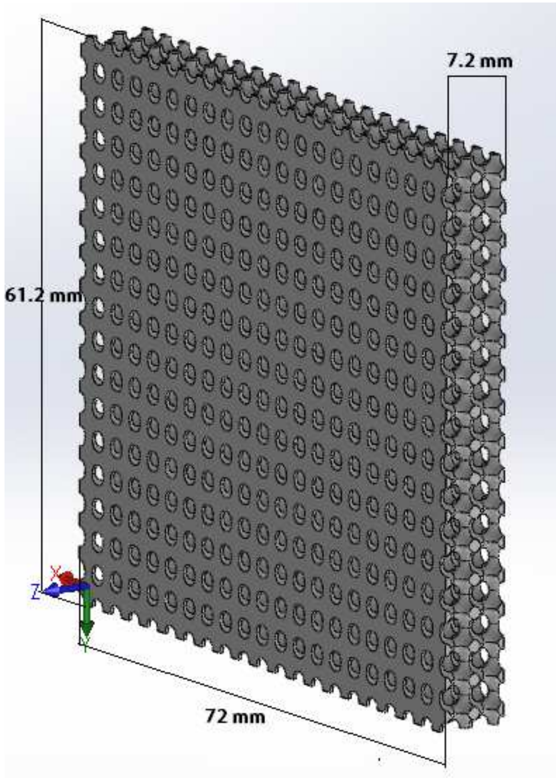
Research results: 3D lattice

Heat exchanger for electric vehicle batteries (collaboration with STEMS - CNR)

Space for housing the cell structures



Proposed cell structure



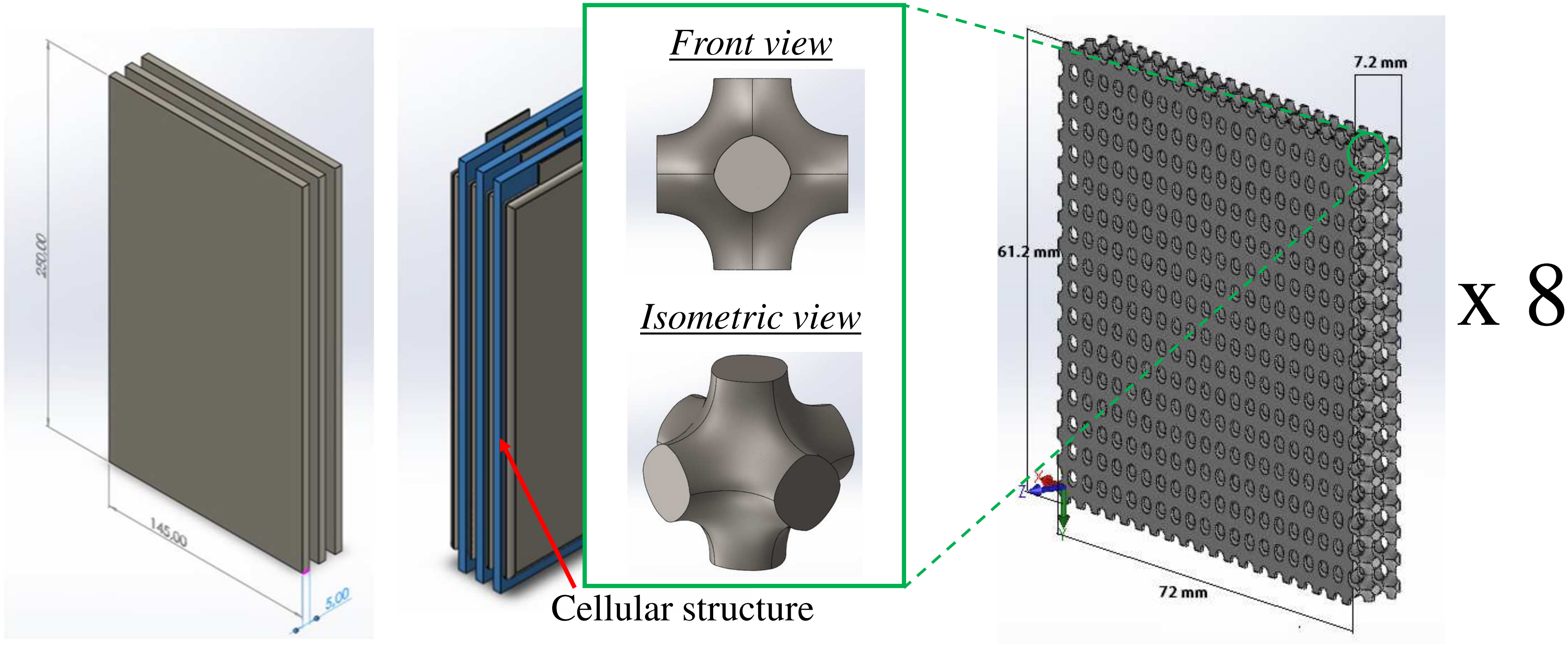
x 8

Research results: 3D lattice

Heat exchanger for electic vehicle batteries (collaboration with STEMS - CNR)

Space for housing the cell structures

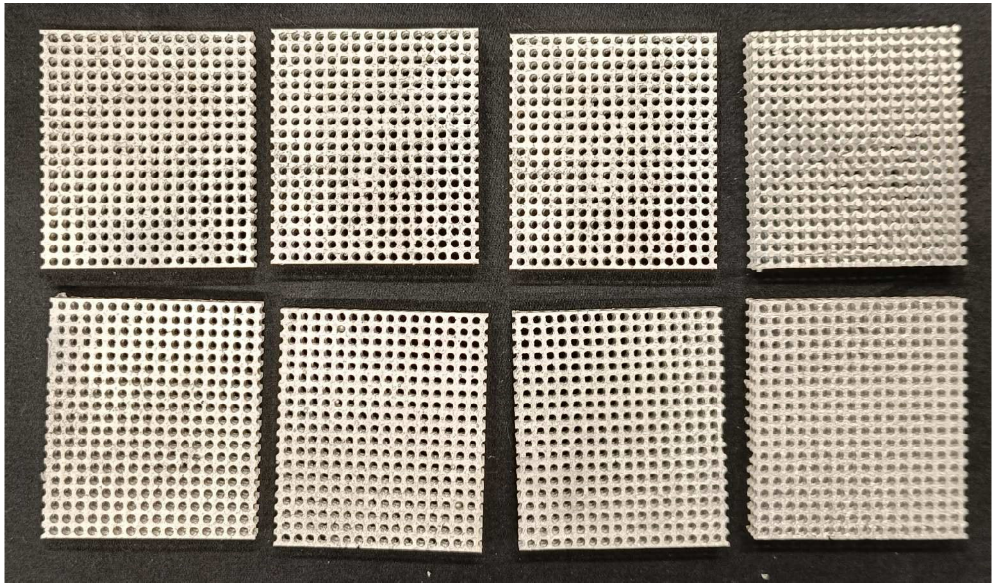
Proposed cell structure



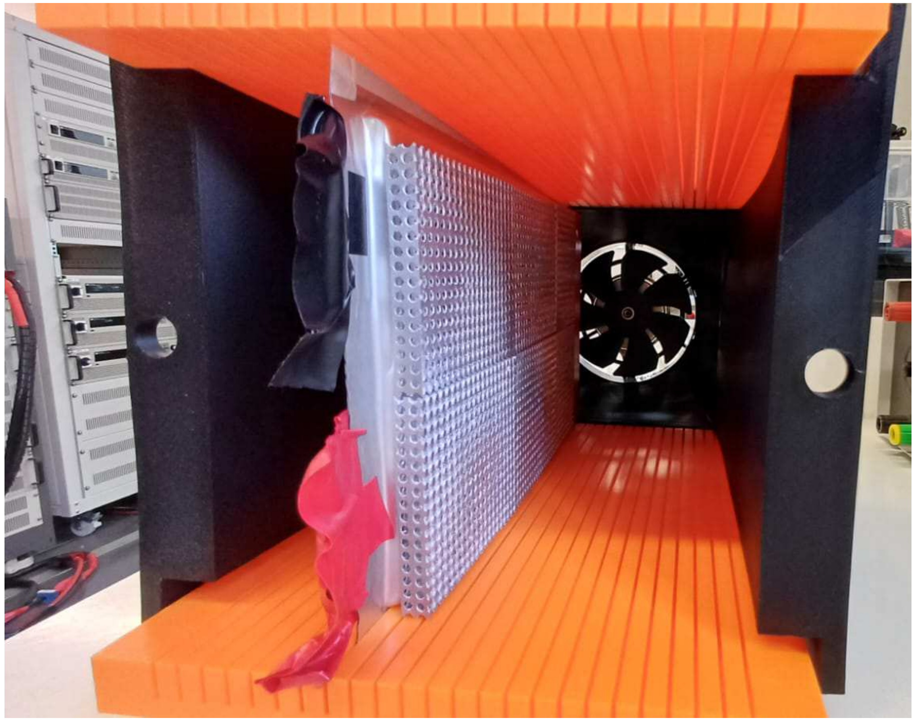
Research results: 3D lattice

Heat exchanger for electic vehicle batteries (collaboration with STEMS - CNR)

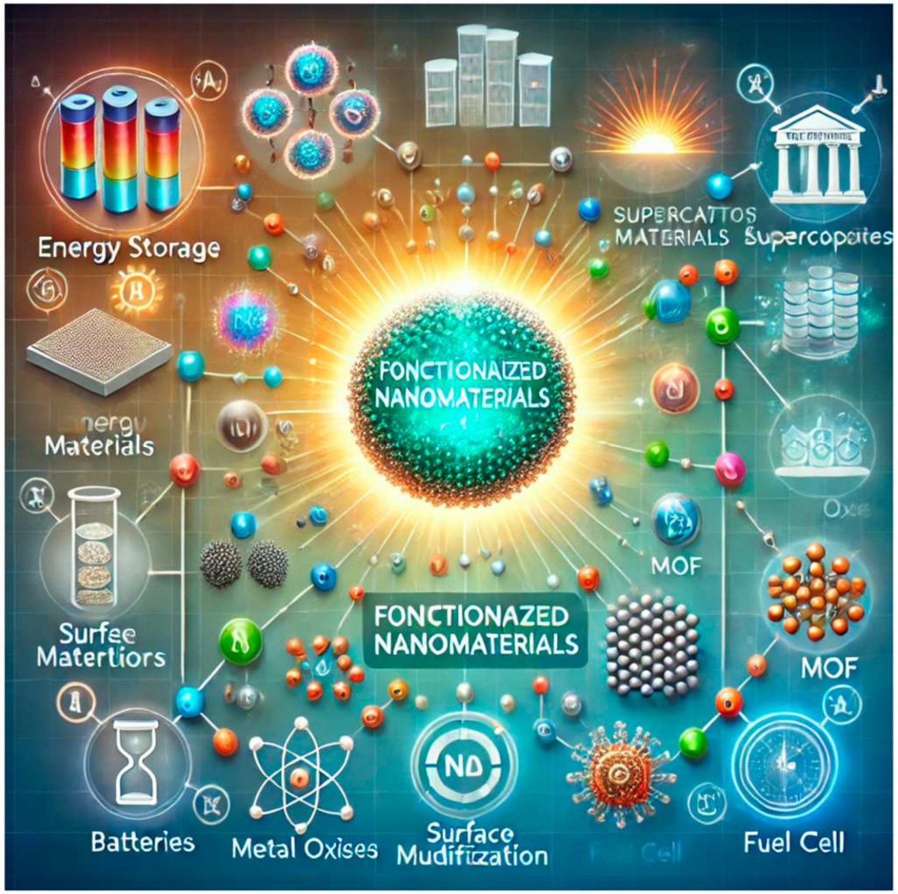
Cellular structures in aluminum alloy



Application



Further results: functionalization of nanomaterials



Scheme showing functionalization of nanomaterials and their different energy applications

Agenda

- Introduction and Objectives
- *Research results*
- Publications
- Future Developments

Publications

Recent published papers:

1. A. Ceci, G. Costanza, G. Savi, M.E. Tata, "Optimization of the lost PLA production process for the manufacturing of Al-alloy porous structures: Recent developments, macrostructural and microstructural analysis" - International Journal of Lightweight Materials and Manufacture, September 2024, 7 (2024) 682-687. SCOPUS: s2.0-85197511971, doi.org/10.1016/j.ijlmm.2024.05.007
2. C. Iandiorio, G. Mattei, E. Marotta, G. Costanza, M.E. Tata, P. Salvini, The beneficial effect of a TPMS-based fillet shape on the mechanical strength of metal cubic lattice structures. Materials, 2024, 17, 1553, doi.org/10.3390/ma17071553.
3. A. Ceci, G. Costanza, M.E. Tata, "Theoretical Modeling and Mechanical Characterization at Increasing Temperatures under Compressive Loads of Al Core and Honeycomb Sandwich" Metals 2024, 14(5), 544; SCOPUS:2-s2.0-85194355068; ISSN 20754701; doi.org/10.3390/met14050544
4. A. Ceci, G. Costanza, M.E. Tata, "Confronto del comportamento a compressione, proprietà meccaniche ed energia assorbita dell'honeycomb e delle schiume a celle chiuse in alluminio" – Atti 40° Convegno nazionale AIM, Napoli 11-13 settembre 2024 articolo n. (40_040). ISBN 978-88-898990-39-9
5. A. Ceci, G. Costanza, M.E. Tata, Compressive behavior, mechanical properties and energy absorption of Al honeycomb and Al closed-cell foam: a comparison, Aerospace, 2025, 12, 32, doi.org/10.3390/aerospace12010032.
6. A. Ceci, C. Cerini, G. Costanza, M.E. Tata, Production of Al alloys with Kelvin cells using the lost-PLA technique and their mechanical characterization via compression tests, Materials, 2025, 18, 296. doi.org/10.3390/ma18020296
7. A. Ceci, C. Cerini, G. Costanza, M.E. Tata, Production and Mechanical Characterization by Compression Tests of Al Alloys with Weaire–Phelan Cells Manufactured by the Lost-PLA Technique, Materials, 2025, 1, 1261, doi.org/10.3390/ma18061261.

Agenda

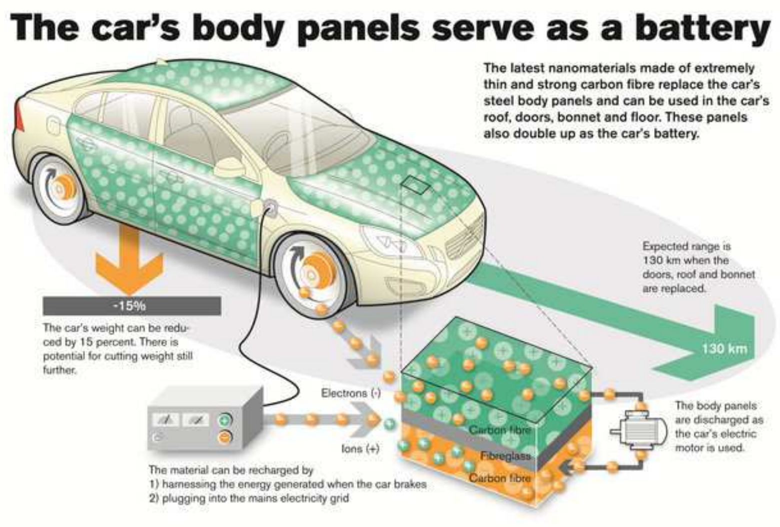
- Introduction and Objectives
- *Research* Results
- Publications
- Future Developments

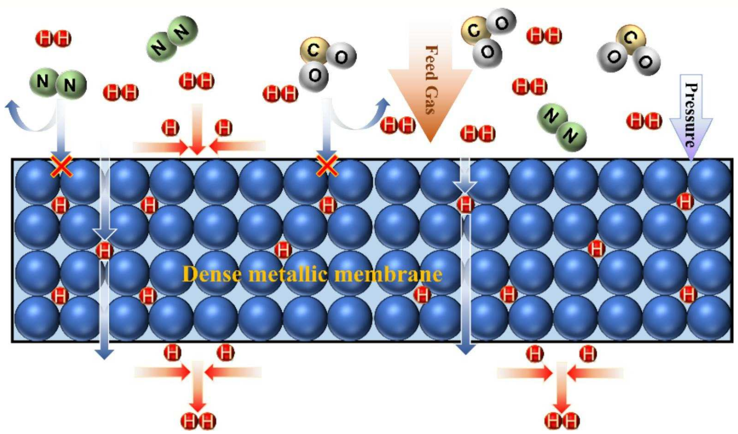
Future Developments

- Design, manufacturing of different types of 3D lattice structures with mechanical and thermal characterization

- Design and manufacturing of different structural batteries

- Set-up of the experimental conditions for the production of microporous foams





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Materiali porosi per la transizione energetica

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