Composites comprising additively manufactured lattice structures and resorcinol-formaldehyde xerogels

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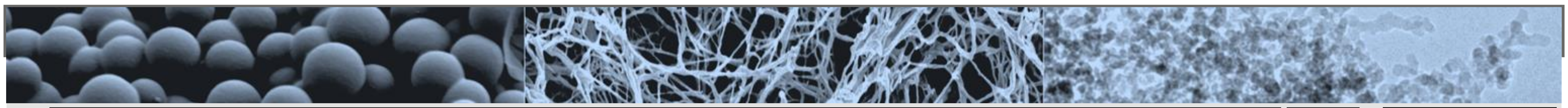


Motivation

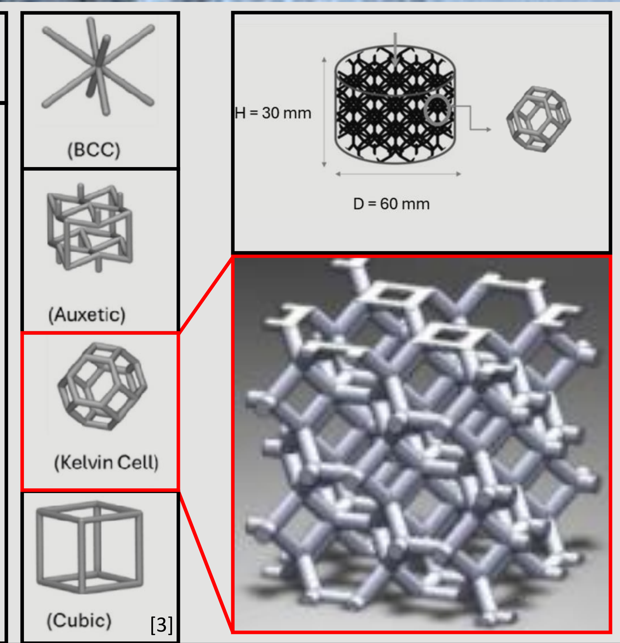
Objective: Development of subcritically dried resorcinol-formaldehyde (RF) xerogels, combined with additive manufactured Polyamide 12 (PA12) lattice structures for functionally integrated lightweight structures with insulating effect in the transport sector.

RF-Xerogels:
- Porous materials with low density
- Thermal isolating material
- Variable pore size and reactive hydroxyl groups
- Temperature resistance up to 200-300°C
- but very fragile due to their porosity [1]

Additive manufactured PA12 lattice structure:
- High compressive strength
- Capacity to absorb energy upon impact
- Chemical resistance to oils, fats, fuels and more
- Extremely customizable [2]

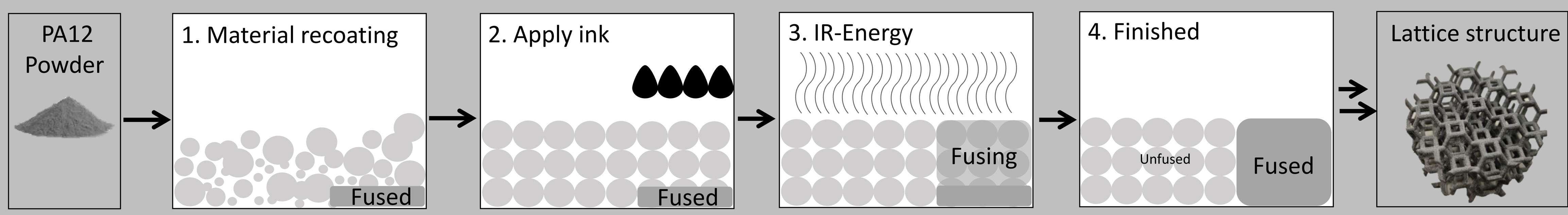
RF-Lattice-Composites:
- Lightweight construction (High strength to low weight proportion)
- Customize structural optimization: enables precise adjustment of the mechanical and thermal properties.
- Low emission due to lower heating and cooling requirements
- Energy efficient
- Resource savings

Preselection:
- 4 different structure geometries
  - body centered (BCC)
  - auxetic
  - truncated octahedron (TO; kelvin cell)
  - primary cubic (cubic)
- Simulated under thermal and mechanical aspects
- Selected **Truncated octahedron** lattice structure exhibit highest stiffness with low thermal conductivity in parallel



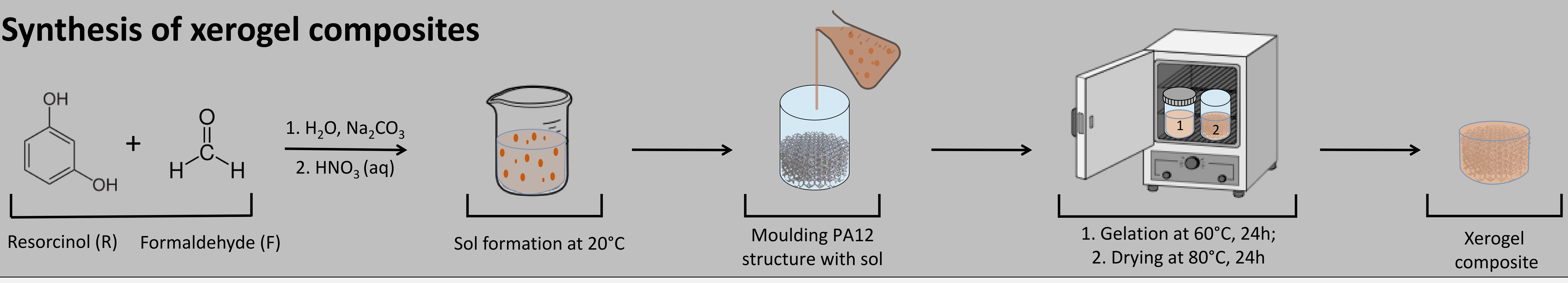
Experimental

High Speed Sintering (HSS) of lattice structures



1. Application of a thin layer of PA12 powder to a heated building platform
2. Inkjet print head wets the areas of the build platform where the prototype is to be created with infrared light-absorbing ink
3. Wetted areas absorb infrared light, causing the underlying powder layer to sinter
4. After the sintering process, the build platform lowers by one layer thickness
5. Process is repeated until the component has been generated
6. Unprinted powder can be removed from the component and reused.[4]

Synthesis of xerogel composites

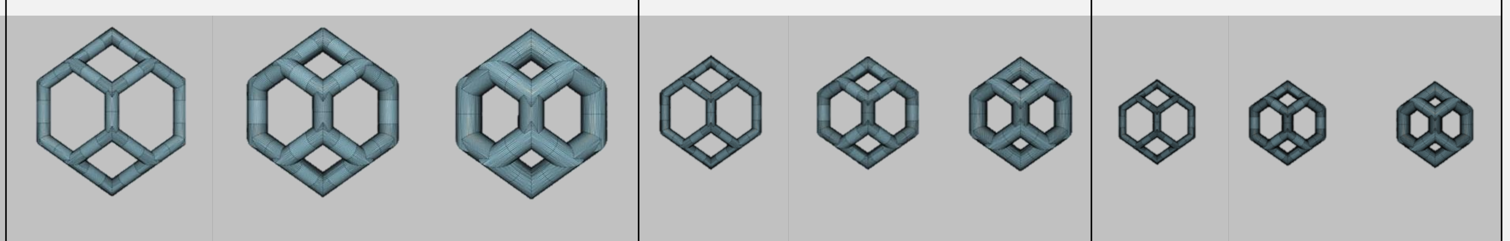


Characterization & Simulation

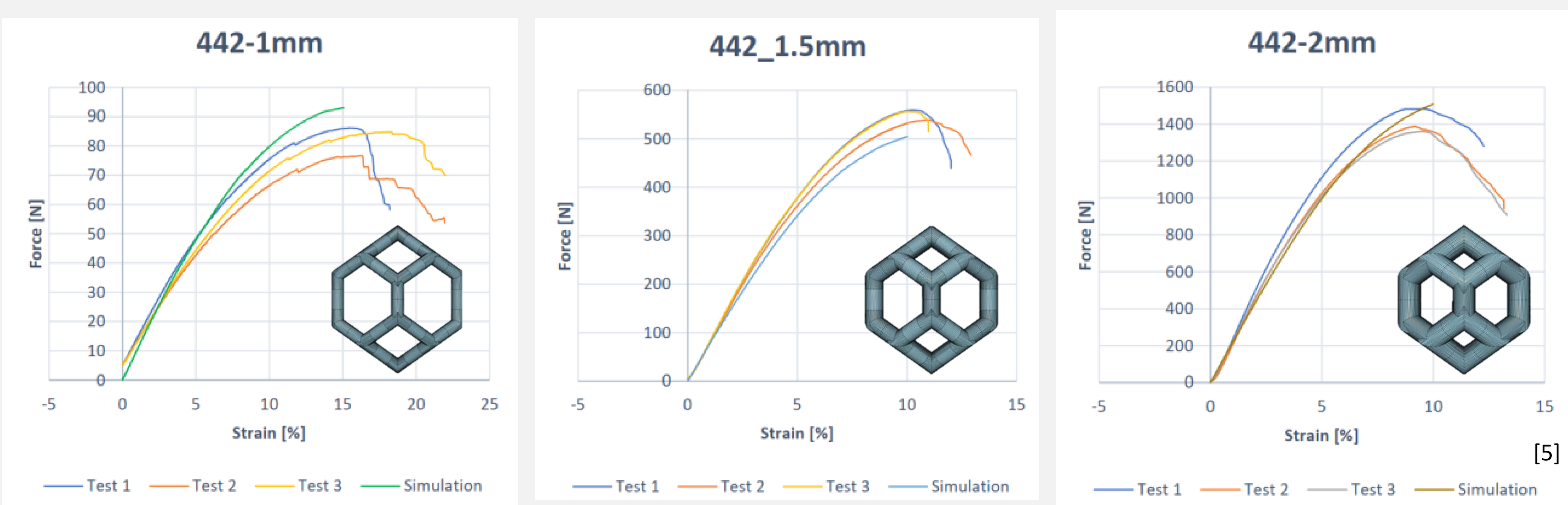
Material data

Material	Density / g·cm^{-3}	Porosity / %	Compressive strength / Mpa	Stiffness / MPa	Thermal conductivity / W·m^{-1}·K^{-1}
RF	0.3499	75.8	0.930	0.817	0.0537
PA12	0.9850	~5.00	-	104	0.1602
RF lattice composite (442-1.5)	0.3677	69.6	0.990	12.7	0.0653

Lattice data

Structure	Truncated octahedron unit cell [TO]								
Density (cells in x, y, z-direction)	442			663			884		
Strut diameter / mm	1.0	1.5	2.0	1.0	1.5	2.0	1.0	1.5	2.0
3D model									
Size of unit cell / mm	15 x 15 x 15			10 x 10 x 10			7.5 x 7.5 x 7.5		
Solid fraction	2.82	6.12	10.34	5.84	12.39	20.41	9.86	20.47	32.85

Comparison Sim vs. Exp



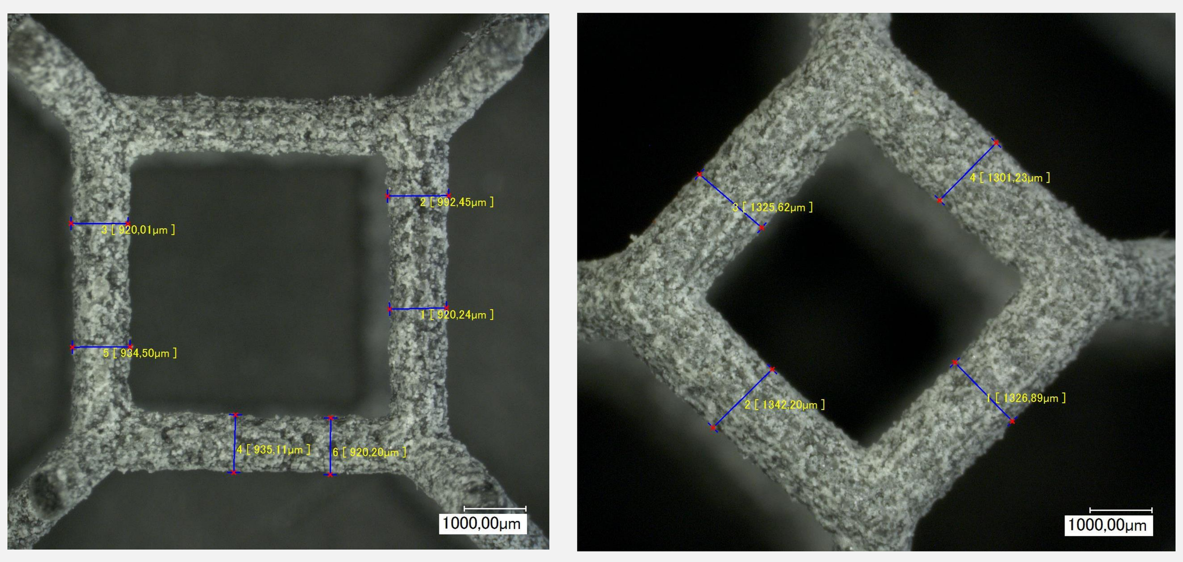
[5]

Compression test results

Density	Strut diameter / mm	Without RF-xerogel* Stiffness / MPa	Without RF-xerogel* Compressive strength / MPa	With RF-xerogel** Stiffness / MPa	With RF-xerogel** Compressive strength / MPa
442	1.0	0.304	0.031	10.42	0.744
442	1.5	1.856	0.193	12.71	0.990
442	2.0	4.711	0.499	27.91	1.253
663	1.0	1.642	0.159	13.78	0.853
663	1.5	5.167	0.800	33.73	1.779
663	2.0	14.85	2.018	91.02	3.581
884	1.0	3.600	0.335	25.11	1.300
884	1.5	14.06	2.180	75.95	3.281
884	2.0	25.42	5.727	187.2	8.050

*Evaluation based on ISO 604; **Evaluation based on ISO 844

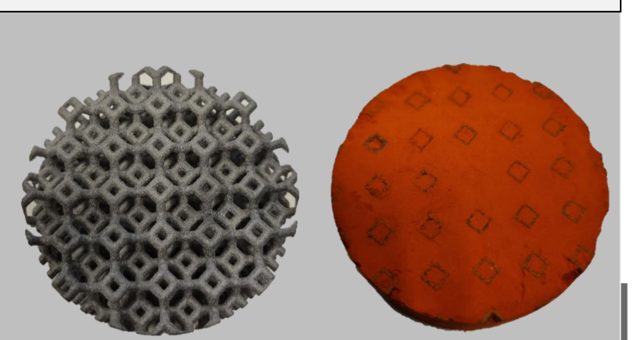
Microscopy



Optical microscopic images of strut diameters: 442-1.5mm (left) 442-1mm (right)

Conclusion

- Improvement in stiffness of one RF Lattice composite (442-1.5 mm) 5 times higher than the same lattice structure without xerogel and 15 times higher than pure RF-xerogel
- The RF lattice structure 442-1.5 mm has only 20% lower thermal conductivity than the pure RF xerogel, but insulate 190 times greater compared to the same lattice geometry without aerogel due to suppressed convection
- Simulation results deviate by only 5% from the experimentally recorded data. Deviations can result from differences between CAD data and the actual printed components.
- The combination of future-oriented aerogels and additive manufacturing technologies offers promising approaches for the optimization of existing structures and the development of new, efficient, functionally integrated lightweight structures with optimum insulating effect in the entire transport sector.



Acknowledgement
We gratefully acknowledge funding by the German Aerospace Center for the project FFAE.

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[3] L. Yuhua, J. Deyu, Z. Rong, W. Xin, W. Liqiang, Z. Lai-Chang, " *High Mechanical Performance of Lattice Structures Fabricated by Additive Manufacturing*," Metals 2024, **2024**
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FFAE Fokusanwendungen Fahrzeugstruktur Antriebsstrang Energiemanagement

Supported by: Federal Ministry for Economic Affairs and Climate Action on the basis of a decision by the German Bundestag

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