POLYTECHNIQUE MONTRÉAL
TECHNOLOGICAL UNIVERSITY

DEVELOPMENT OF A NOVEL ABRADALBE COMPOSITE FOR THE 3D PRINTING OF MICRO-SCAFFOLDS

LABORATOIRE DE MÉCANIQUE MULTI-ÉCHELLES
LM2

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Laboratory of multiscale mechanics

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REGULATORY BACKGROUND

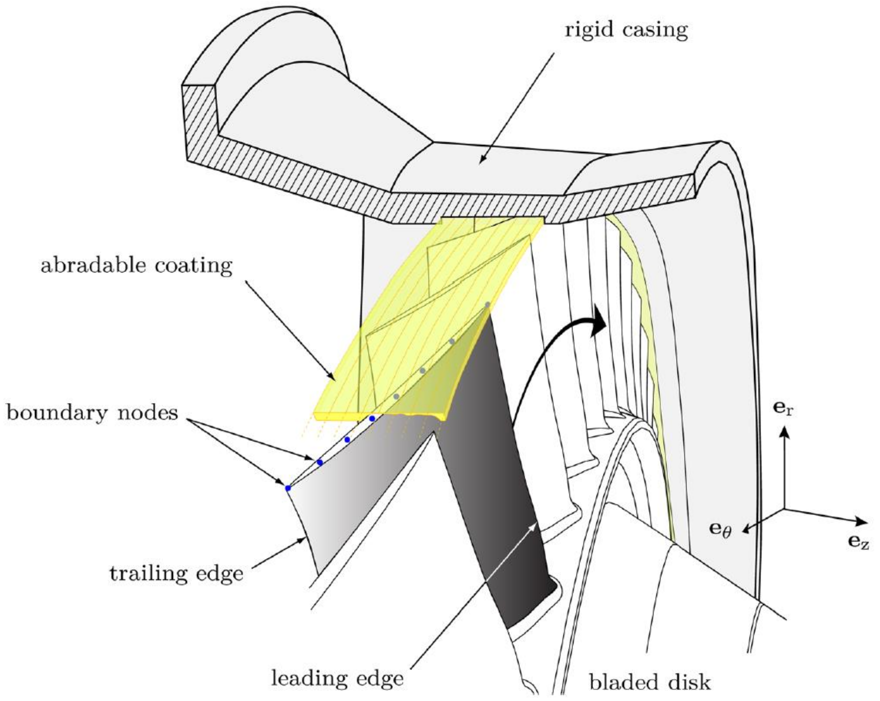

[1]

ICAO environmental objectives for 2050:
1- Reduce CO_2 emissions by 75%
2- Reduce noise level by 65%

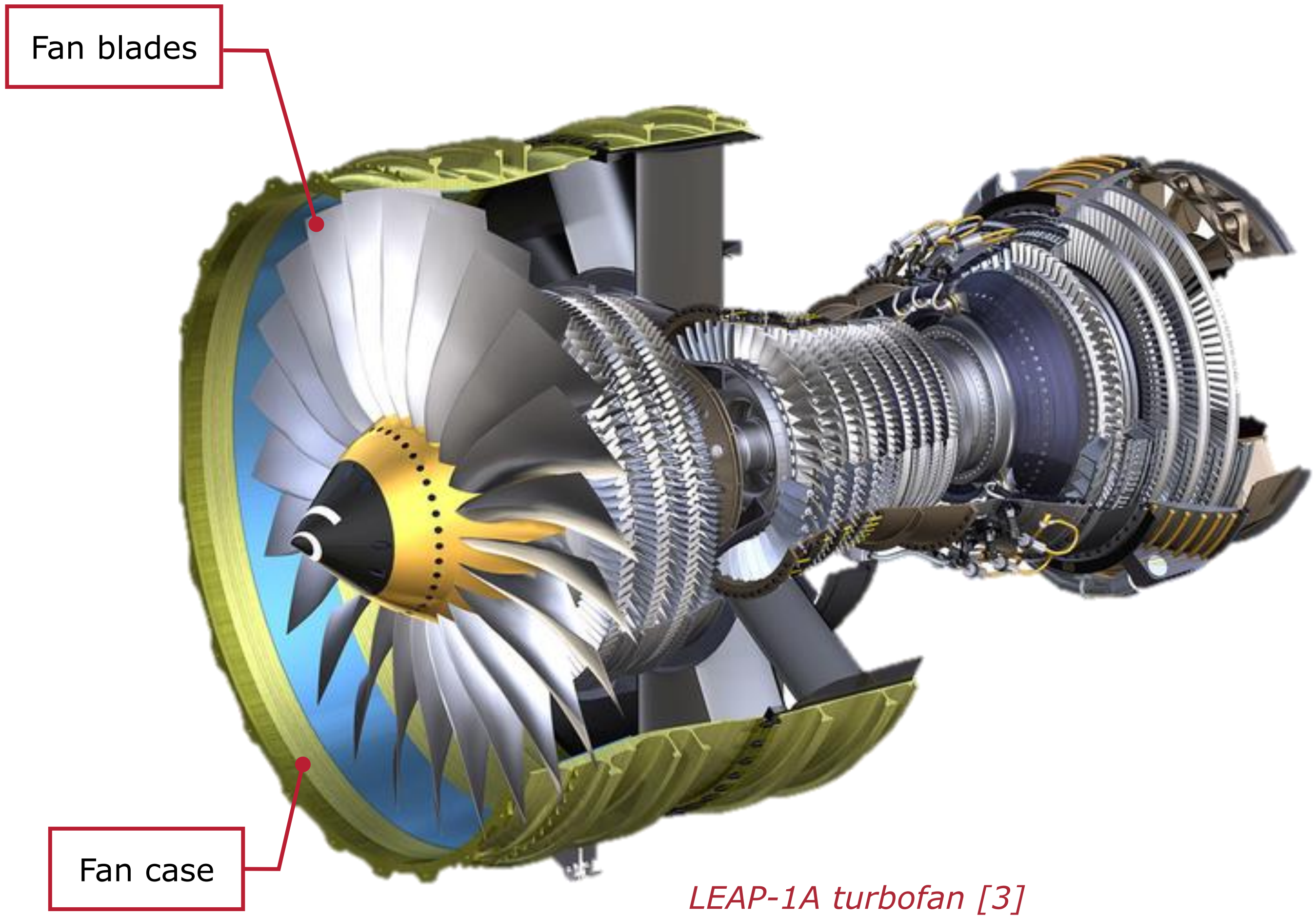
[1] Venturebeat.com, 2017

TECHNICAL CHALLENGE OVERVIEW

- Reduce clearance
- Limit aerodynamic losses
- Blade tip sealing
- Preferential coating wear
- Decrease fuel consumption



Abradable coating [2]

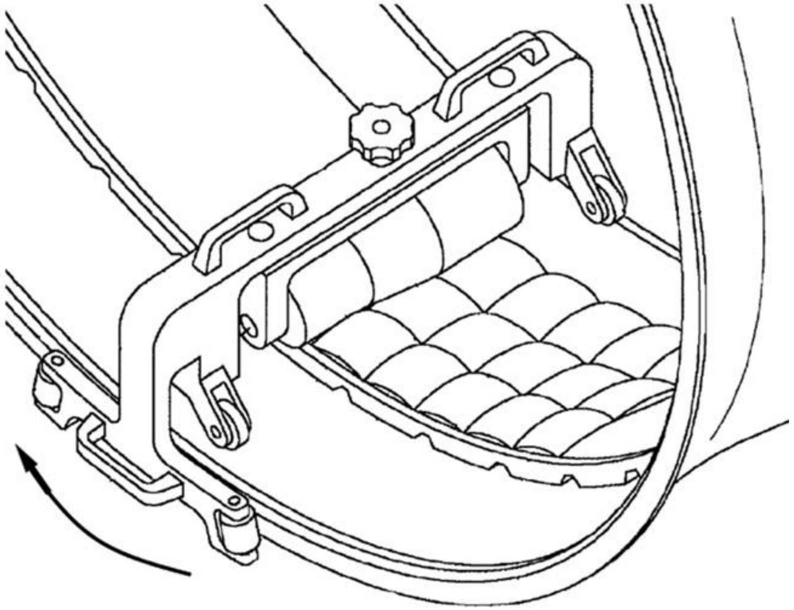


LEAP-1A turbofan [3]

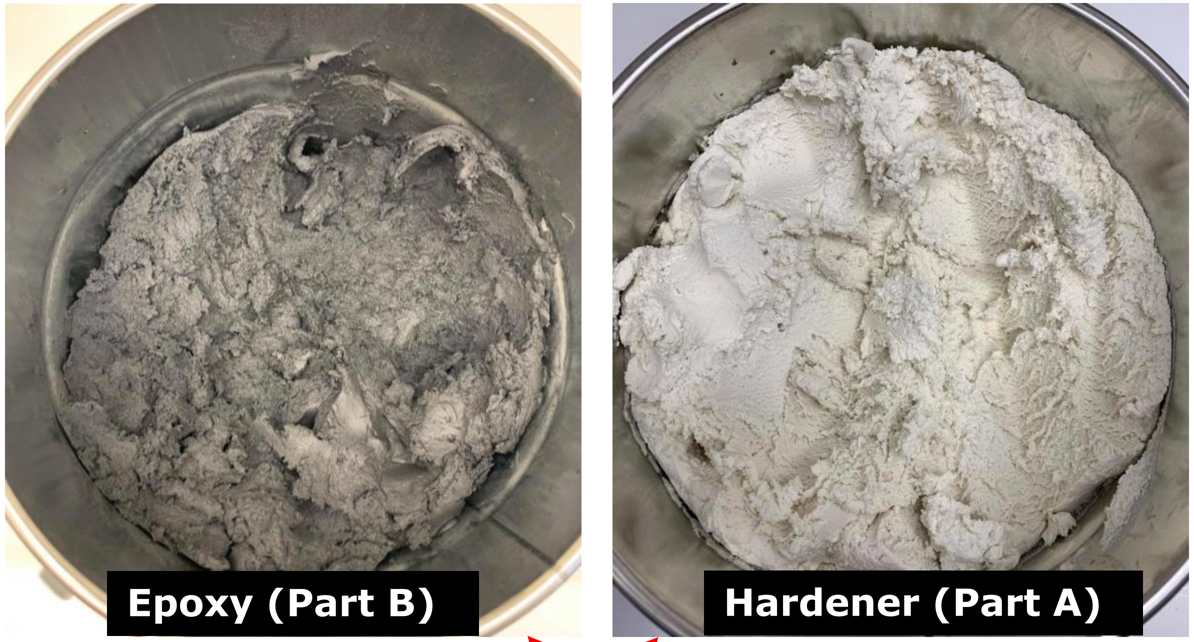
[2] Legrand et al., 2012 & [3] safran-group.com, 2016

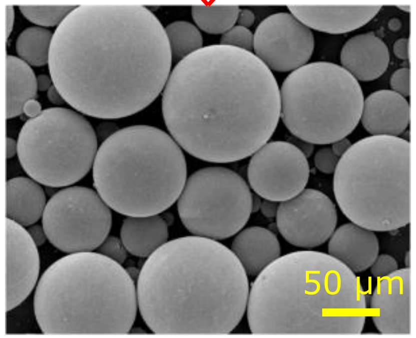
CURRENT INDUSTRIAL SOLUTION

- Inefficient coating application:
  - Time-consuming,
  - Poor geometric control.
- Benchmark* coating cannot be functionalized.



Abradable coating application device [5]

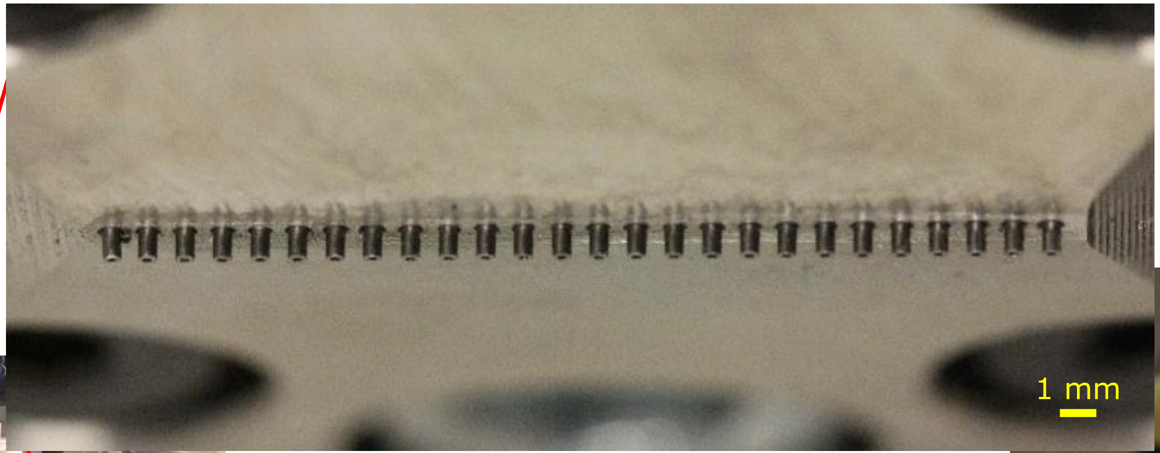




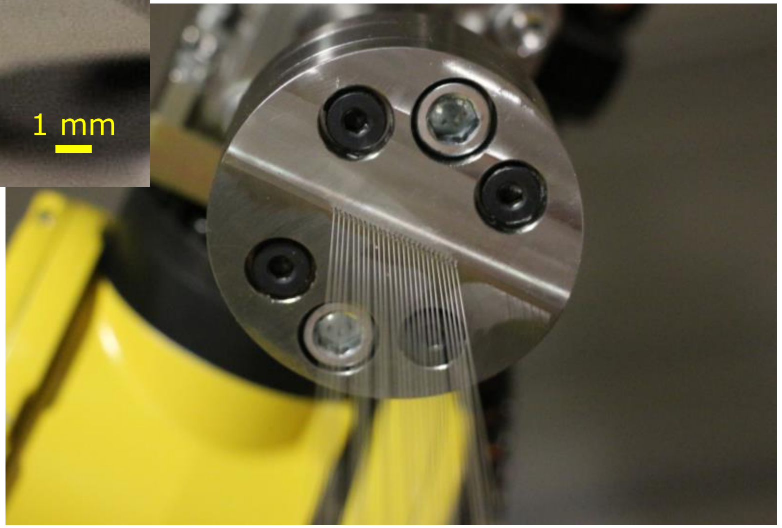
Hollow glass microspheres [4]

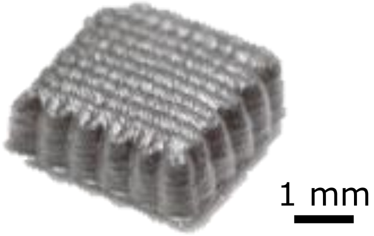
[4] 3M & [5] Mathon et al., 2019 / **Benchmark* composite material is EC3524 B/A Black (3M™, France)

DESIRED TECHNOLOGICAL OUTCOME

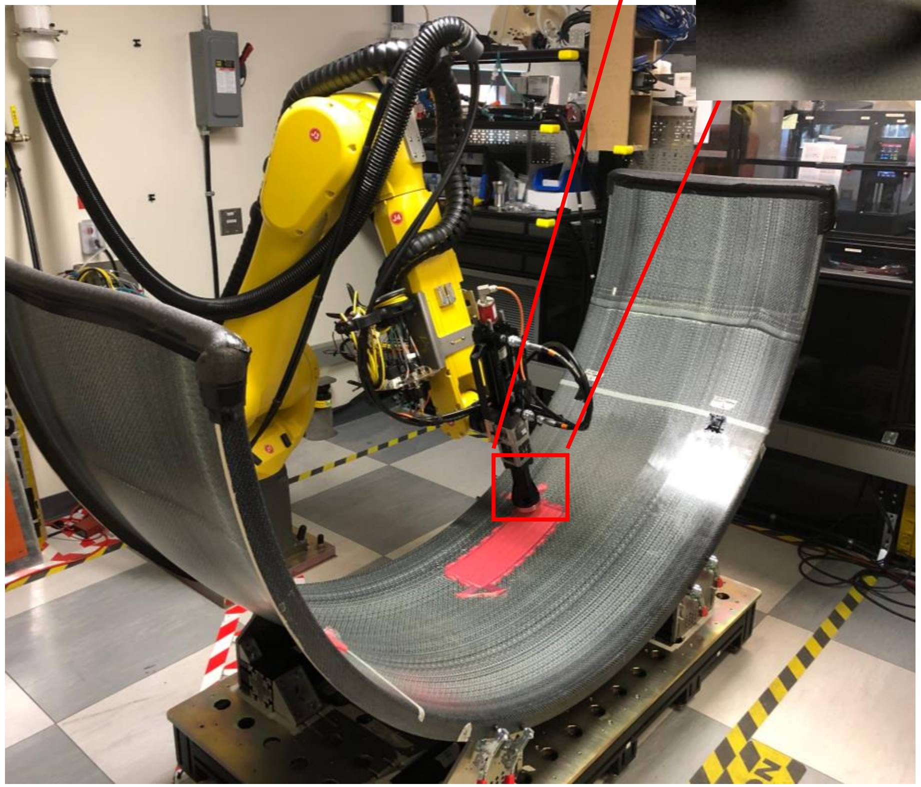


Multinozzle printhead





Benchmark



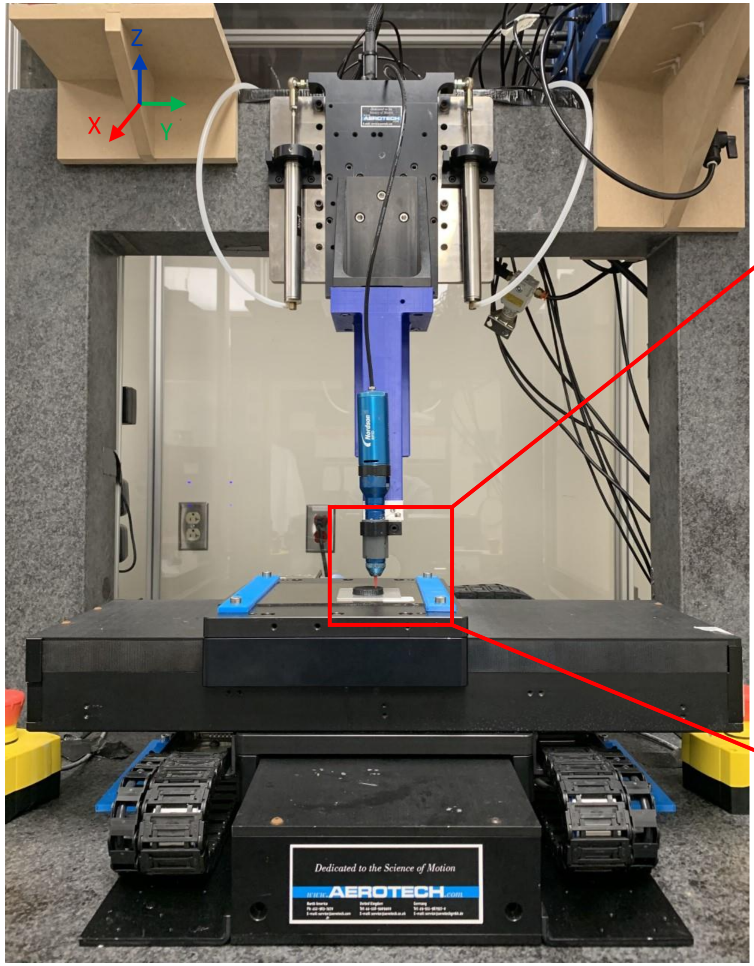
6-axis robot with half a fan case

O1: Develop a printable abradable material

O2: Perform a functional characterisation

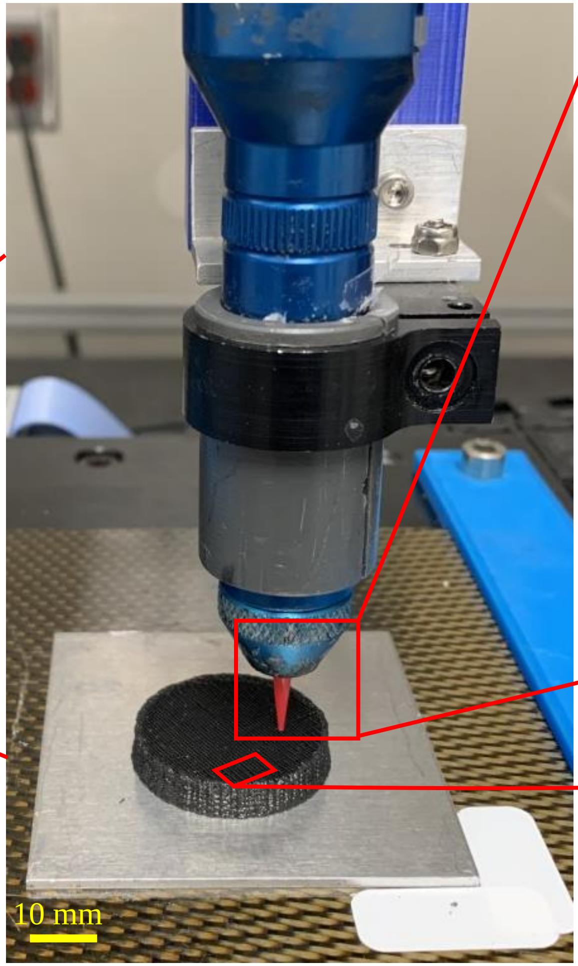
⇨ Acoustic & Abradability

EXPERIMENTAL SETUP



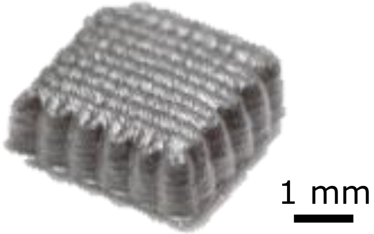
Aerotech printing setup

Pressure, $P < 4.55\ \mathrm{MPa}$
Speed, $u = [0; 300]\ \mathrm{mm/s}$
Nozzle DIA (tapered), $D_o =\ 250\ \mu\mathrm{m}$

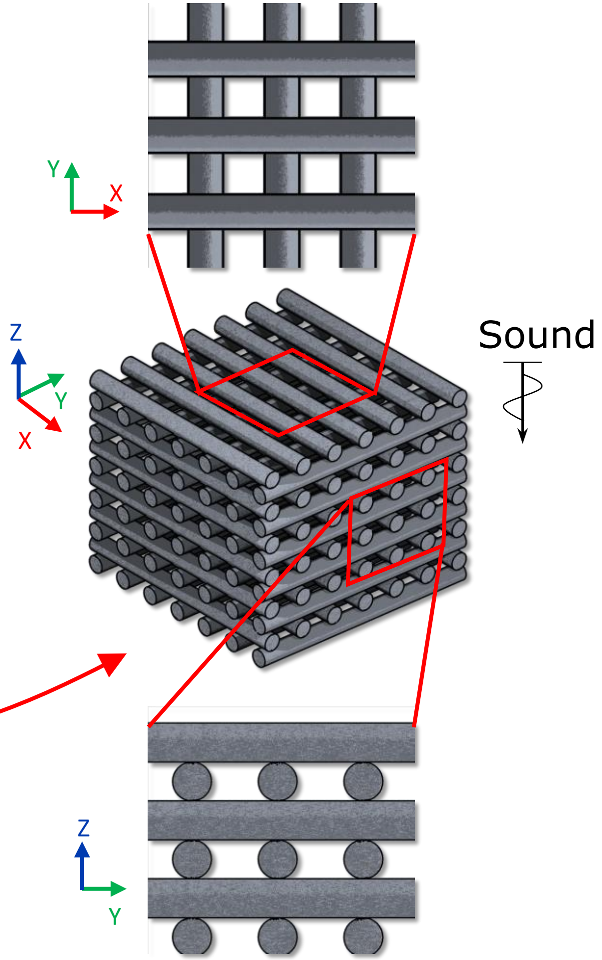


Extrusion head

Filament extrusion [6]



Benchmark

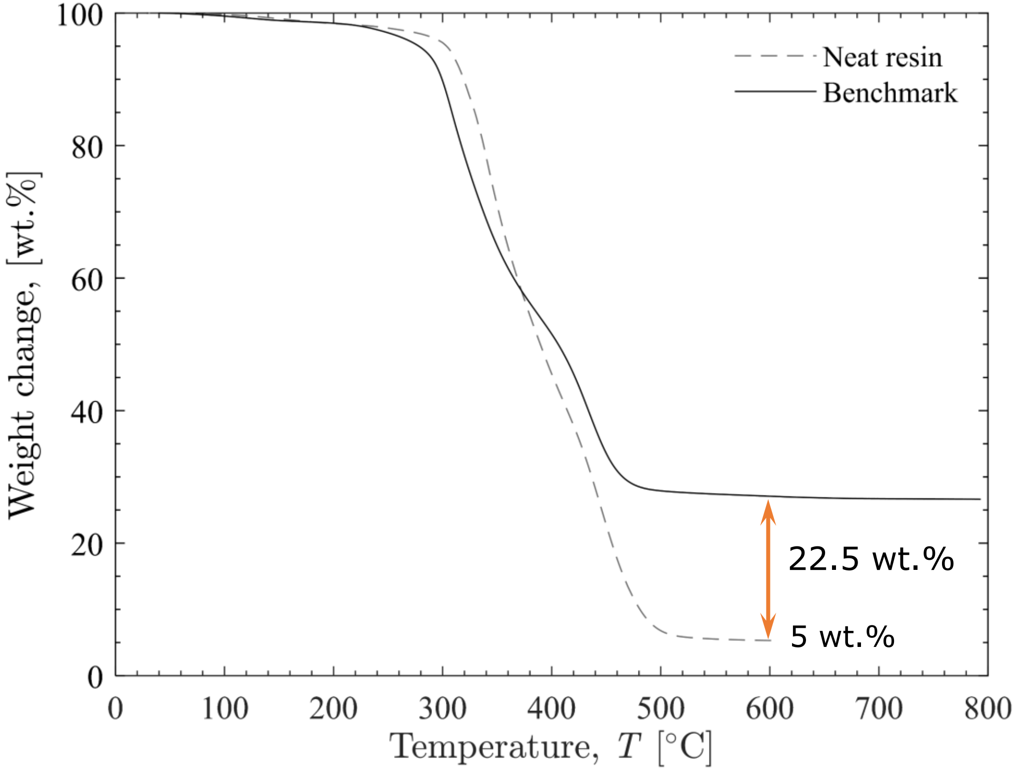


Micro-scaffold design

[6] Lewis, 2006

SAFRAN

BENCHAMARK MATERIAL COMPOSITION



Thermogravimetric analyses

~~↑ Glass microsphere (GM) content = {25, 30, 35} wt.%~~

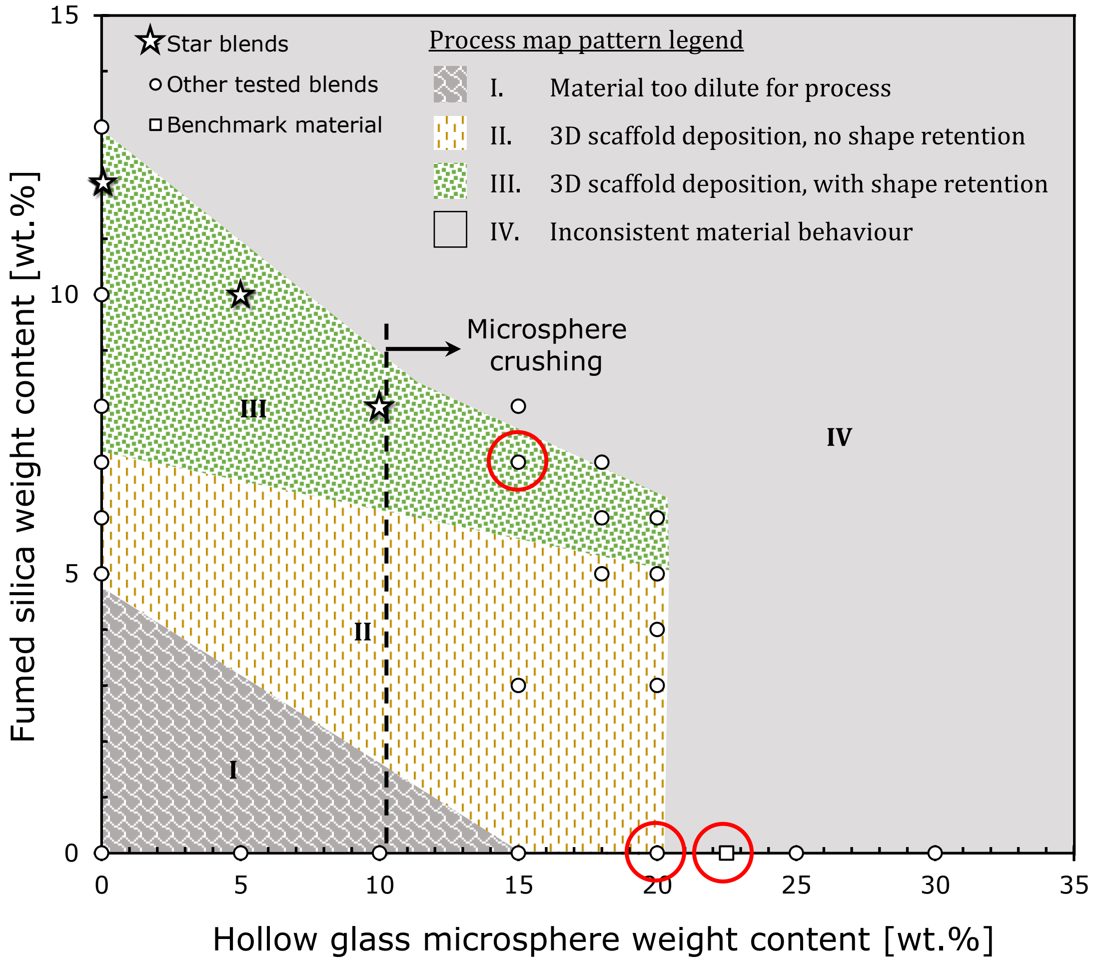
↓ Glass microsphere (GM) content = {0, 5, 10, 15, 20} wt.%

+

Fumed silica (FS)*

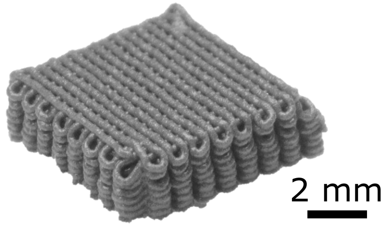
*Hydrophilic FS (Aerosil 200, Evonik, USA) + GM (Glass Bubbles Floated Series, A20/1000, 3M™, France)

PROCESSABILITY OF TESTED MATERIALS

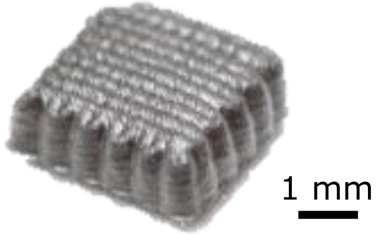


Process map of filled epoxy

20GM:0FS

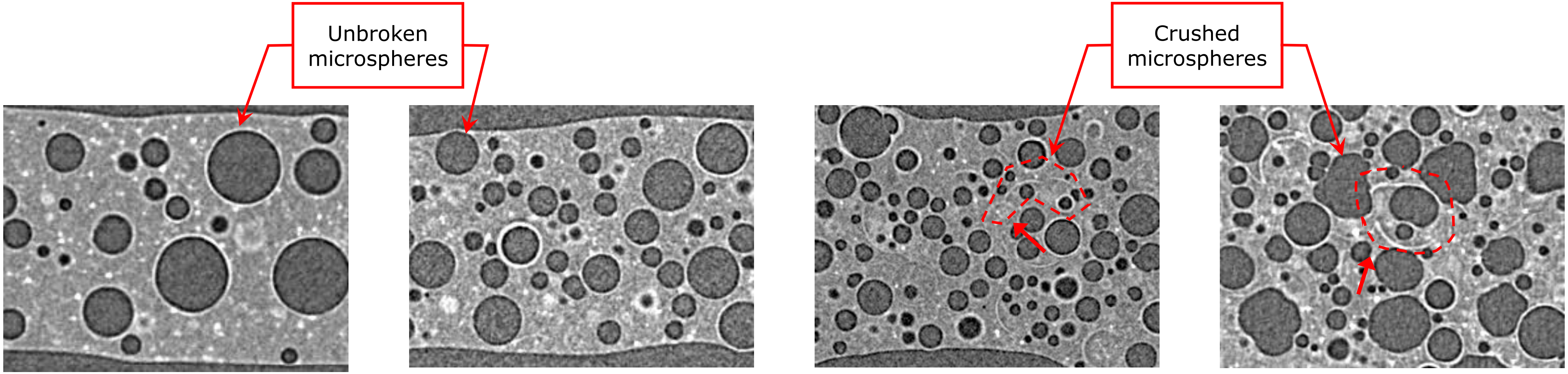


15GM:7FS



Benchmark

FILLER INTEGRITY

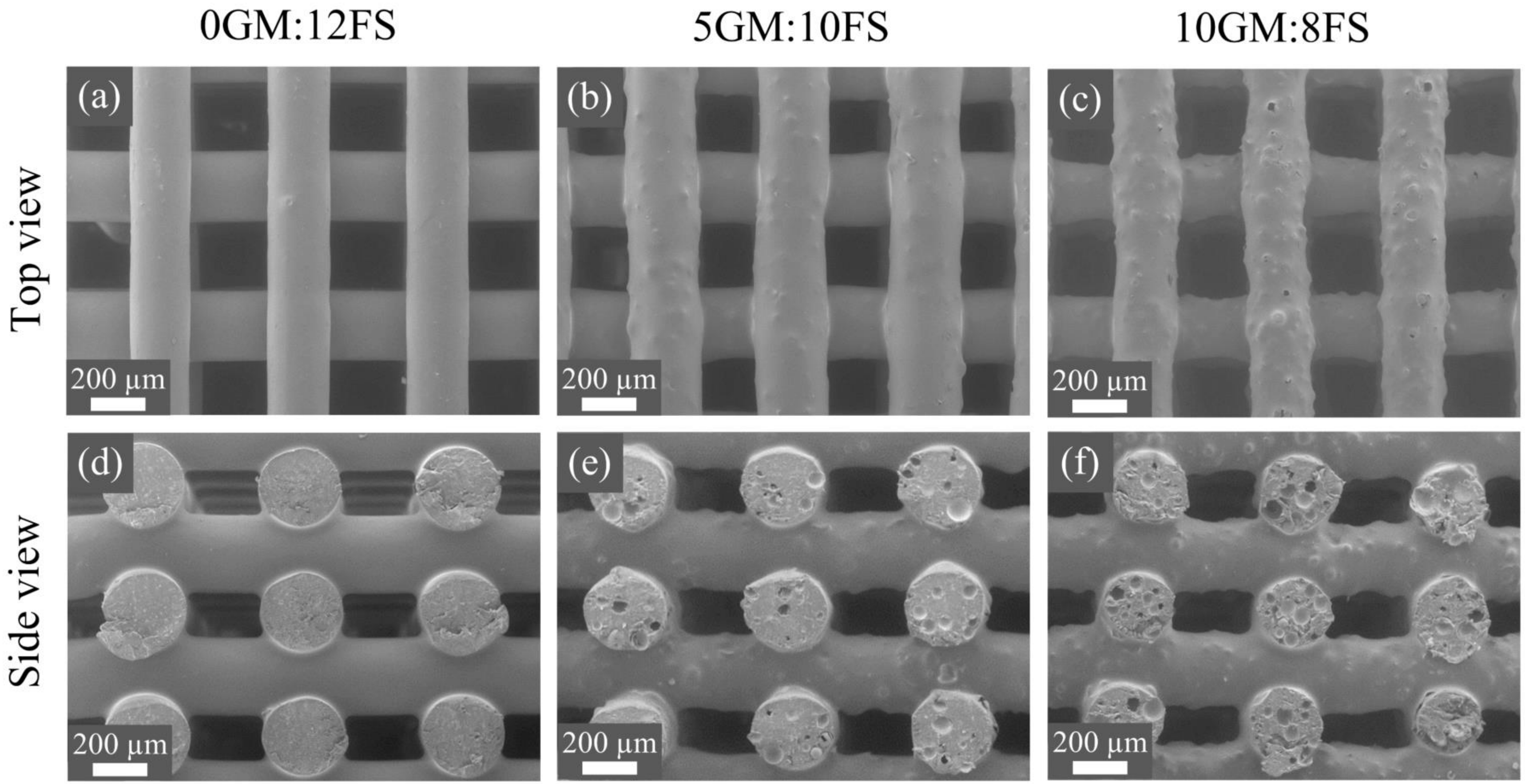


5GM:10FS | 10GM:8FS | 15GM:7FS | Benchmark

µCT cross-sections 50 µm

15GM:7FS

SHAPE RETENTION STUDY

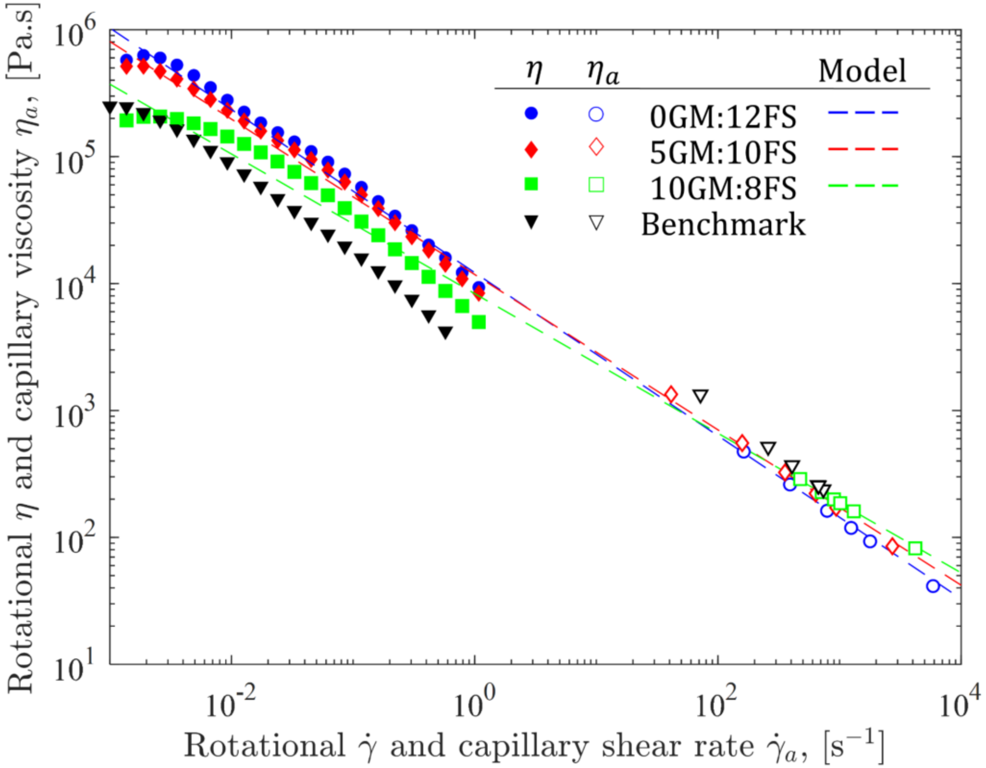


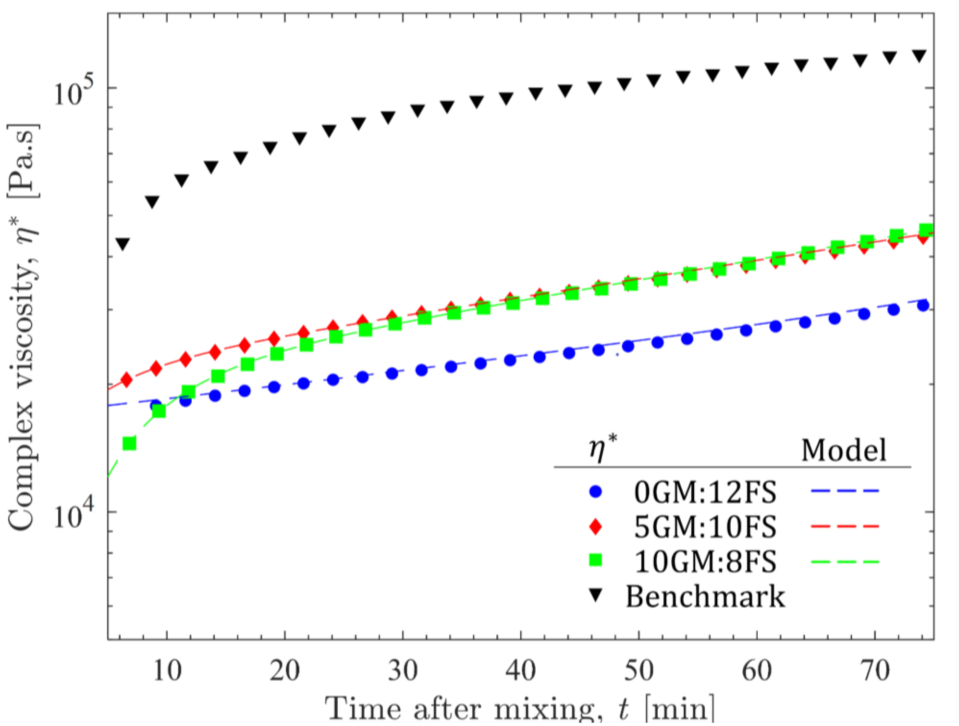
$\psi = .90 \pm .02$ $\psi = .86 \pm .05$ $\psi = .84 \pm .04$

SEM images of 3D printed micro-scaffolds with top view (a-c) and side view (d-e), showing post-deposition shape retention and filament roughness.

Printability index: $\psi = c_1[\psi^{top}] + c_2[\psi^{side} + \psi^{f}] = \frac{1}{2}\left[\frac{A_p}{A_e}\right] + \frac{1}{4}\left[\frac{h_p}{h_e} + \frac{4\pi A_p^f}{L^2}\right]$

DIW PROCESS MODELLING





Process-related rheology, rotational and capillary data sets with power law fit.

Oscillatory rheology time sweeps, complex viscosity, with 1st order isothermal cure model fit.

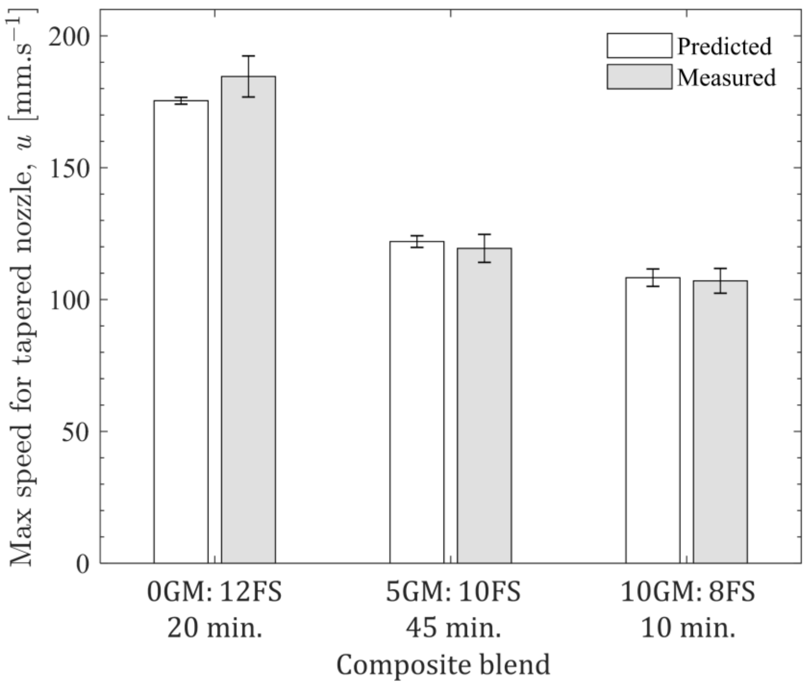
$$\eta(\dot{\gamma}) = K\dot{\gamma}^{n-1}$$

$$\eta^*(t) = a_1 e^{b_1 t} + a_2 e^{b_2 t}, \eta_0 := \eta^*(t=0)$$

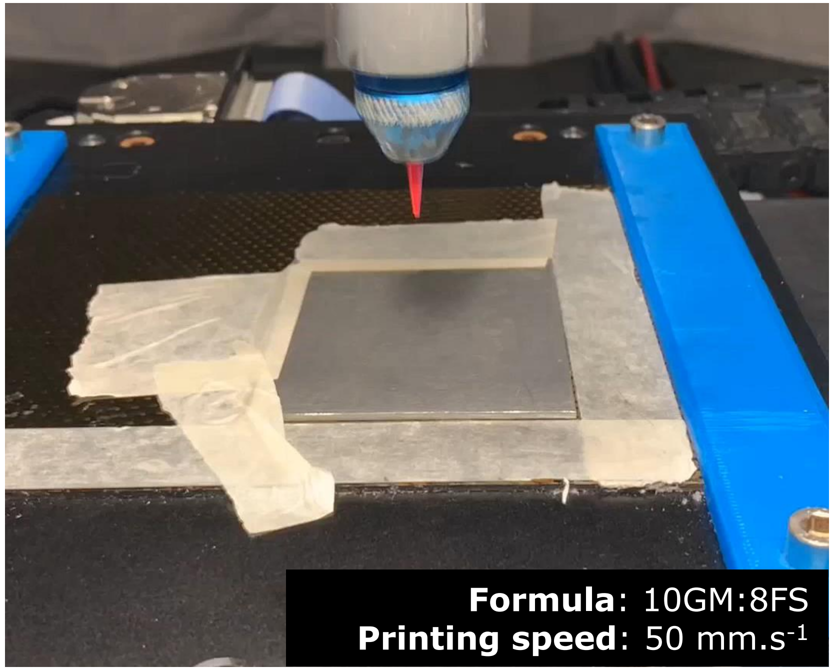
$$\hat{\eta} = \eta(\dot{\gamma}) \cdot \frac{\eta^*(t)}{\eta_0} = \overbrace{K\dot{\gamma}^{n-1}} \cdot \overbrace{\frac{1}{\eta_0}\left(a_1 e^{b_1 t} + a_2 e^{b_2 t}\right)}$$

$\Longrightarrow$ Material processing simulations

HIGH SPEED PRINTING



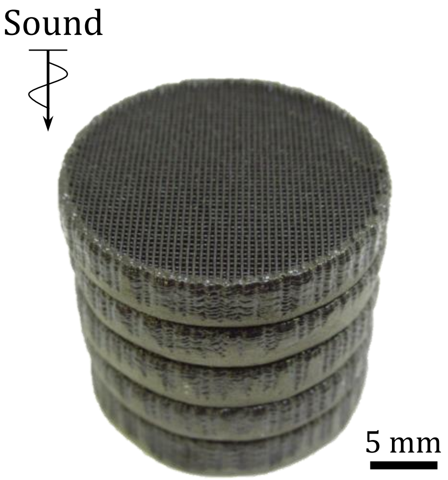
Printing speed prediction and measured for star blends at maximum pressure and a set time after mixing, DIA .250 µm *(tapered).*



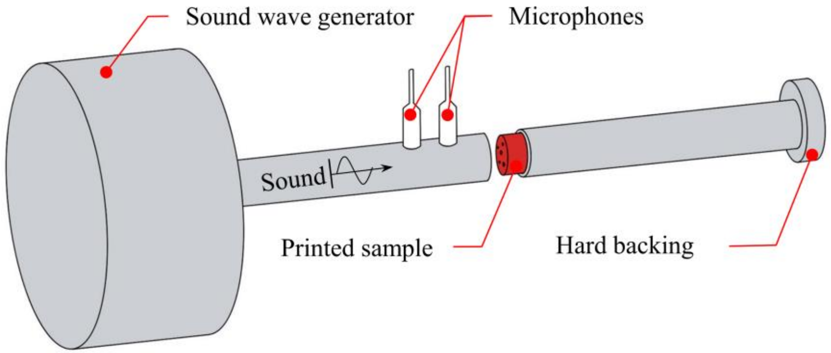
Acoustic sample section printing (×35 video speed)

- Programmed extrusion pressure adjustments to account for material gelation derived from time-shear models = controlled process for coating functionalization.

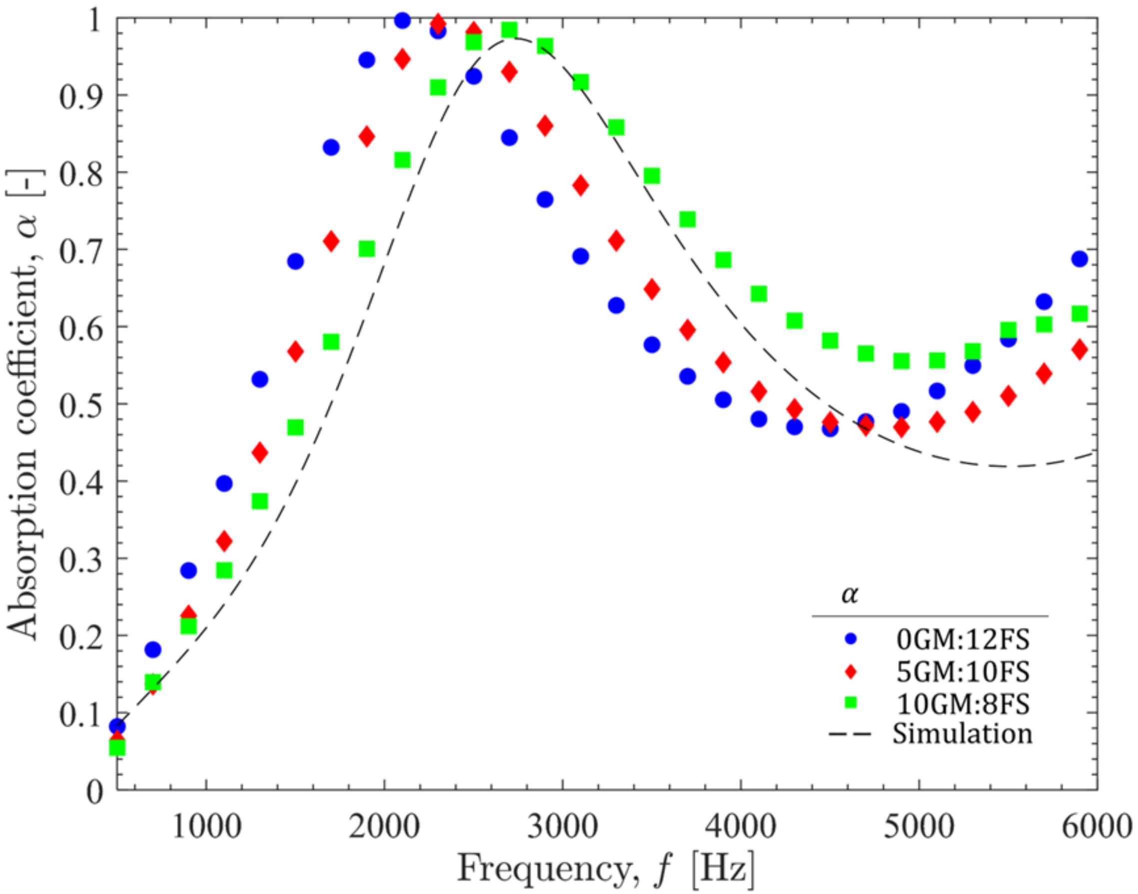
ACOUSTIC ABSORPTION



Printed acoustic sample stack



Kundt's tube acoustic performance setup



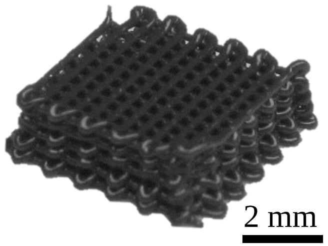
Hard-backed acoustic absorption coefficients of the star blends compared to the simulated absorption using the JCAL model [7].

[7] In collaboration with J. Boulvert

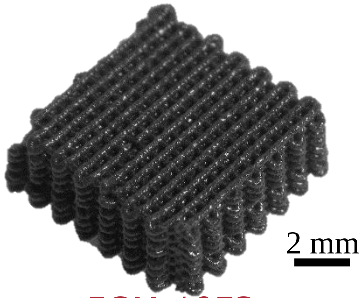
SUMMARY OF FINDINGS

- 3D printable epoxy systems contain hollow glass microspheres and/or fumed silica.
- High fumed silica contents improve material elasticity and enable shape retention.
- A modified empirical model predicts the flow behaviour of developed materials.
- Printing speeds up to $175\ \mathrm{mm.s^{-1}}$ pave the way for large area industrial production, while retaining high-resolution features.
- Efficient sound absorbing micro-scaffolds are printed using the developed composites.

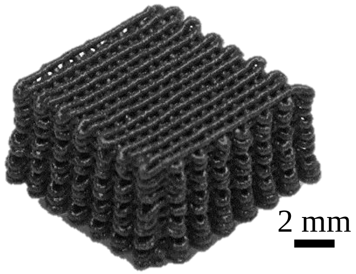
0GM:12FS µCT scan



0GM:12FS

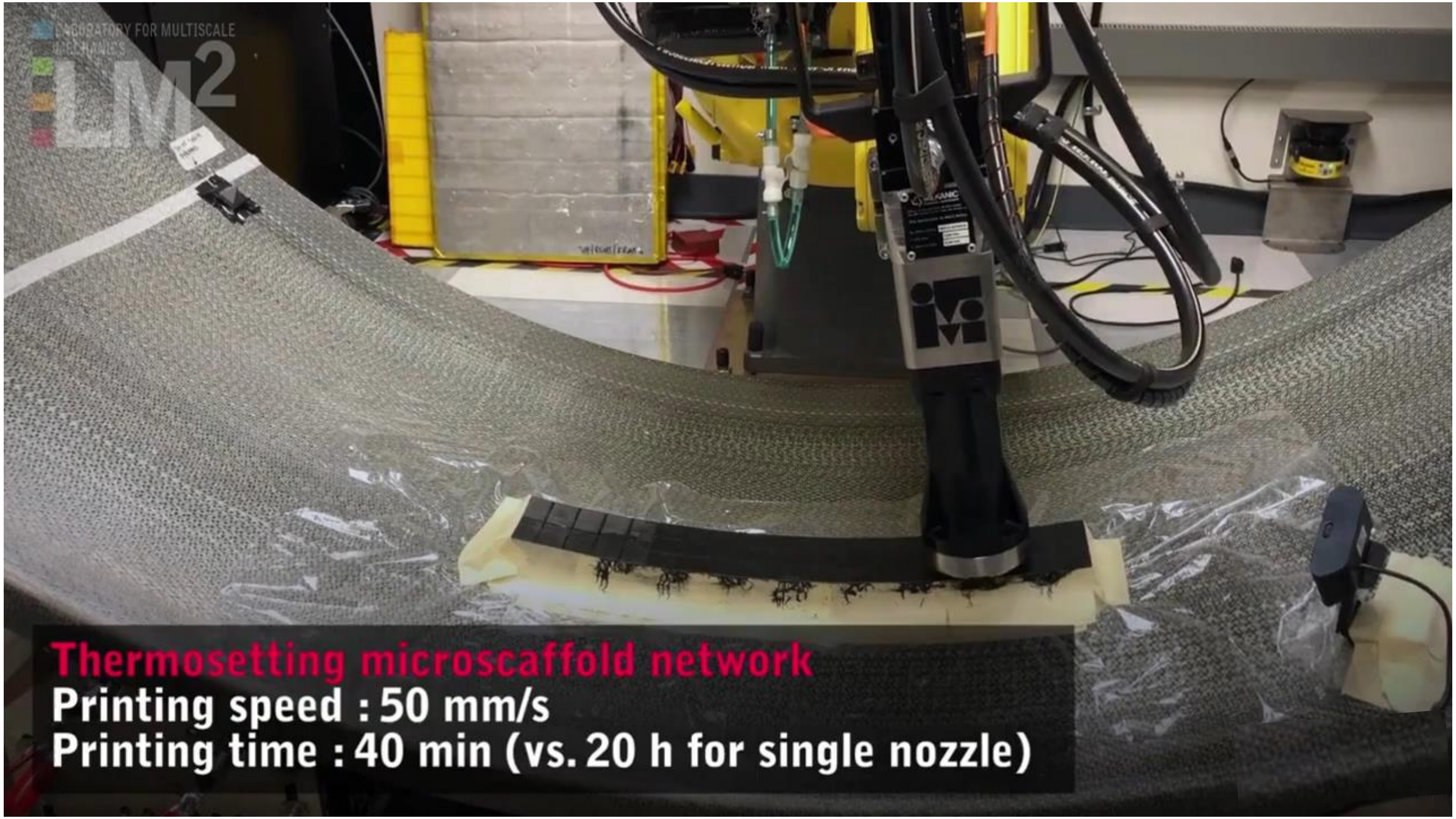


5GM:10FS



10GM:8FS

TECHNOLOGY PROOF OF CONCEPT



Multinozzle printing of EC3524 B/A Black filled with 0GM:12FS, 50 mm.s^{-1}, on a heterogenous curved HTRT substrate [13].

[13] Reproduced with the permission of J.-F. Chauvette. For full video, see https://youtu.be/rOM-yvUt5iw.

THANK YOU!

- Questions?
- Further reading:

  - **Brzeski, David** (2021). *Development of Thermosetting Composite Materials for Producing Multifunctional Coatings by Direct Ink Writing* [Master's thesis, Polytechnique Montréal]. PolyPublie. https://publications.polymtl.ca/9131/
  - **Brzeski, David** & Hia, Iee & Chauvette, Jean-François & Dermanaki Farahani, Rouhollah & Piccirelli, Nicola & Ross, Annie & Daniel, Therriault. (2021). *Design of thermoset composites for high-speed additive manufacturing of lightweight sound absorbing micro-scaffolds*. Additive Manufacturing. 47. 102245.10.1016/j.addma.2021.102245.
  - Chauvette, Jean-François & Brzeski, David & Hia, Iee & Dermanaki Farahani, Rouhollah & Piccirelli, Nicola & Daniel, Therriault. (2021). *High-speed multinozzle additive manufacturing and extrusion modeling of large-scale microscaffold networks*. Additive Manufacturing. 47. 10.1016/j.addma.2021.102294
  - Chauvette, Jean-François & Hia, Iee & Dermanaki Farahani, Rouhollah & Plante, Raphaël & Piccirelli, Nicola & Therriault, Daniel. (2023). *Non-planar multinozzle additive manufacturing of thermoset composite microscaffold networks*. Composites Part B: Engineering. 256. 110627. 10.1016/j.compositesb.2023.110627.
  - Pierre, Juliette & Iervolino, Filippo & Dermanaki Farahani, Rouhollah & Piccirelli, Nicola & Lévesque, Martin & Therriault, Daniel. (2022). *Material extrusion additive manufacturing of multifunctional sandwich panels with load-bearing and acoustic capabilities for aerospace applications*. Additive Manufacturing. 61. 103344. 10.1016/j.addma.2022.103344.
  - Baptista, Josué & Fotsing, E.R. & Mardjono, Jacky & Daniel, Therriault & Ross, Annie. (2022). *Design and fused filament fabrication of multilayered microchannels for subwavelength and broadband sound absorption*. Additive Manufacturing. Volume 55. 10.1016/j.addma.2022.102777.

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