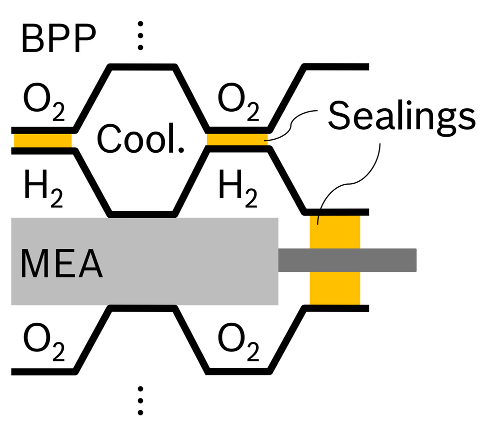
# Stencil printing of adhesive-based fuel cell sealings

## The influence of rheology on bubble formation during the separation step

**F.I. Indicatti[1,2], M. Rädler[1], F. Günter[1], E. Stammen[2], K. Dilger[2]**
**[1]Robert Bosch GmbH, Germany | [2]Technische Universität Braunschweig, Germany**
fabiano.indicatti@de.bosch.com | +49 162 3326374

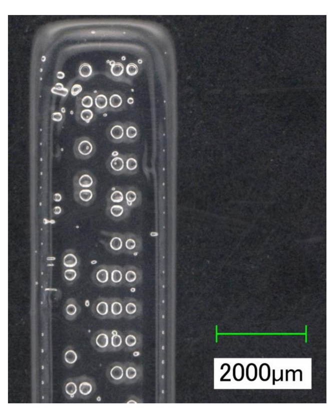
## Background

Stencil printing is one of the highest throughput techniques for applying adhesives and presents high potential to produce fuel cell sealings in a large scale




**Print requirements[1]:**
- High process reproducibility
- Layer heights up to 500 µm
- Cycle times <3 sec

**Main challenges:**
- A mesh on the upper region of the aperture is required to print sealings
- As result, bubbles and irregularities are formed and can affect the print quality and sealing performance



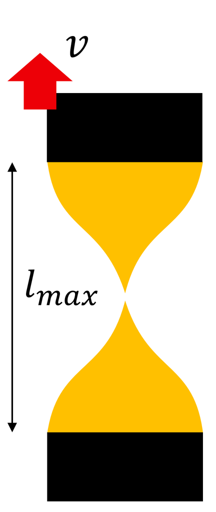

## Objectives

- Enhance the understanding on mechanisms driving the adhesive separation from the stencil mesh
- Correlate the <u>quantity and size of bubbles</u> formed during the separation step on stencil printing with the <u>adhesive tendency to stretch filaments</u>

## Materials and Methods

- Print experiments varying decisive parameters:
  - ▶ Separation speed $v$ (1 and 5 mm/s)
  - ▶ Mesh opening size (300 and 400 µm)
  - ▶ Three adhesive systems (A, B and C) with distinct concentrations of fumed silica (<10 wt%)

- Filament stretching behavior assessed with $\varepsilon_{He,mat}$:
  - ▶ Compare materials stretched at identical separation speeds and initial dimensions[2]




$$\varepsilon_{He,mat} = n \sin(\delta) \ln(Ca)$$

| | |
|---|---|
| $\varepsilon_{He,mat}$ | Material part of maximum Hencky-strain |
| $n$ | Flow index |
| $\delta$ | Phase angle within the LVE region |
| $Ca = \frac{\eta v}{\sigma}$ | Capillary number: viscosity $\eta$ at $s^{-1}$, separation speed $v$ and surface tension $\sigma$ |

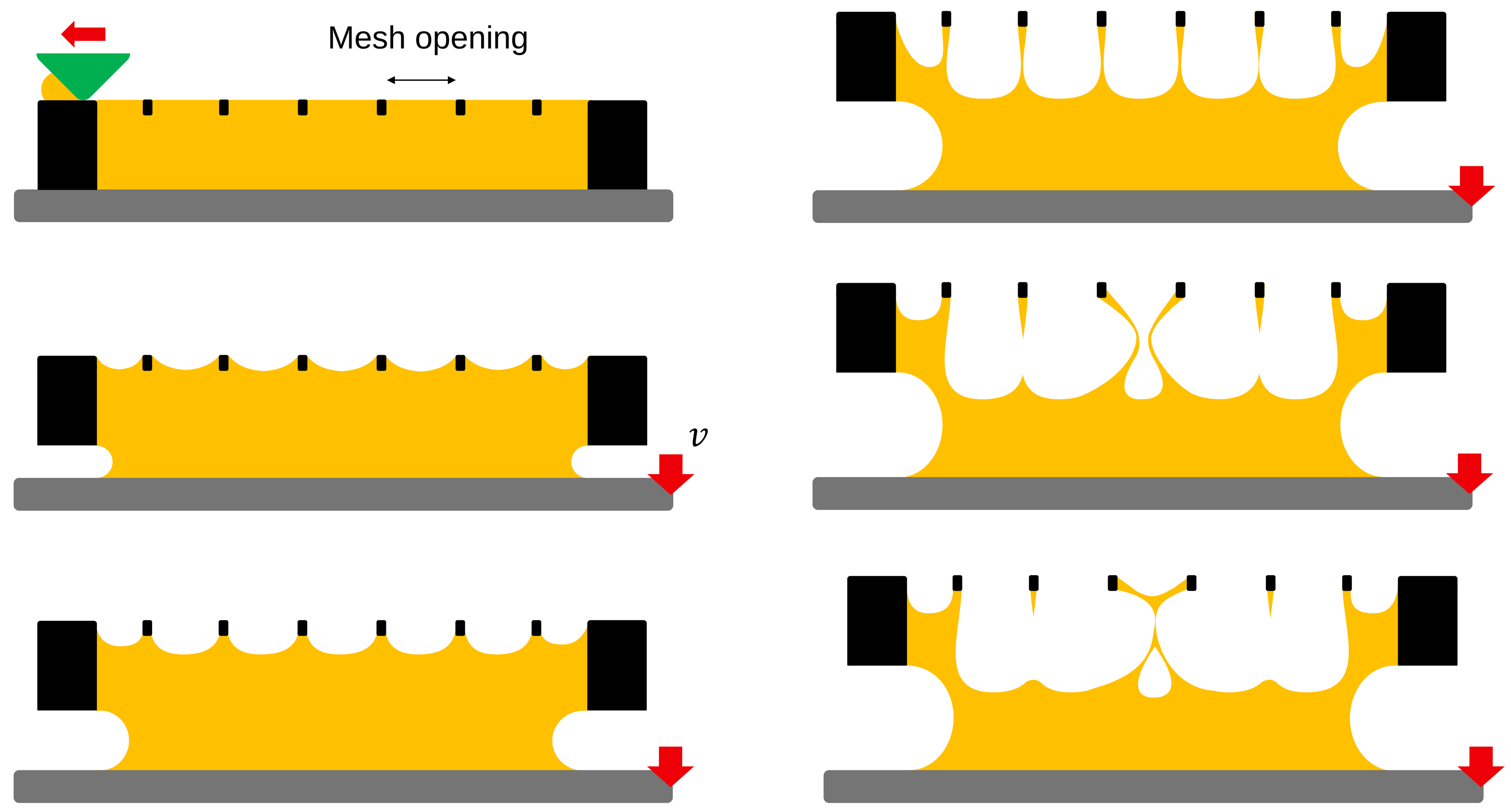
| Adhesive system | $n$ [–] | $\delta$ [°] | $\eta$ [Pa·s] | $\sigma$ [mN/m]* |
|---|---|---|---|---|
| A | 0,722 | 32,6 | 178 | 23,5 |
| B | 0,714 | 23,5 | 252 | 23,5 |
| C | 0,690 | 14,4 | 435 | 23,5 |

* $\sigma$ measured with the unfilled adhesive

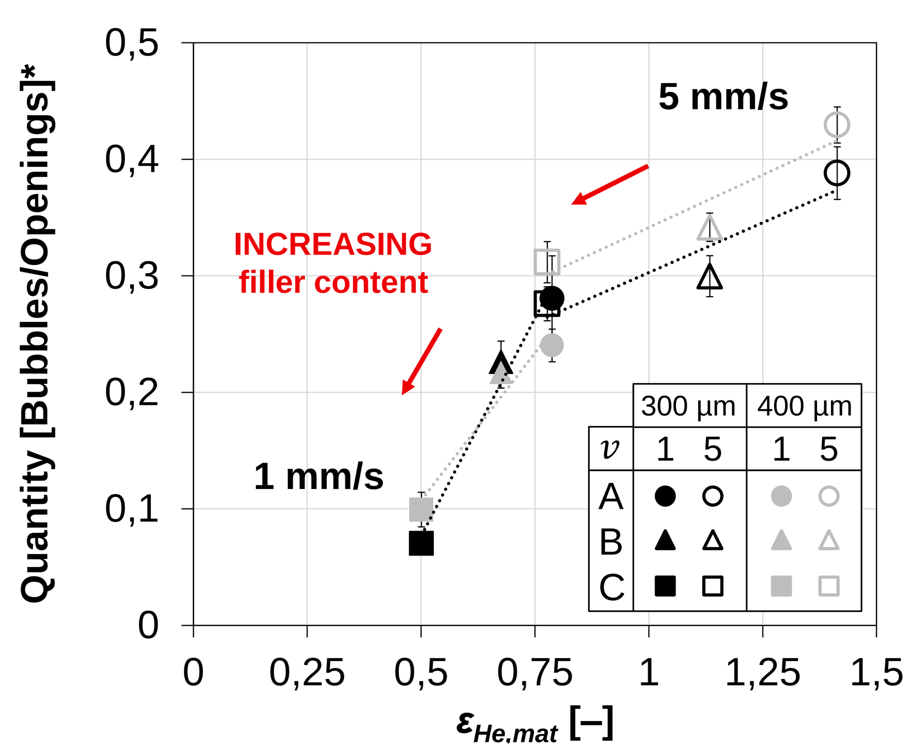
## Results

**Bubble formation:**

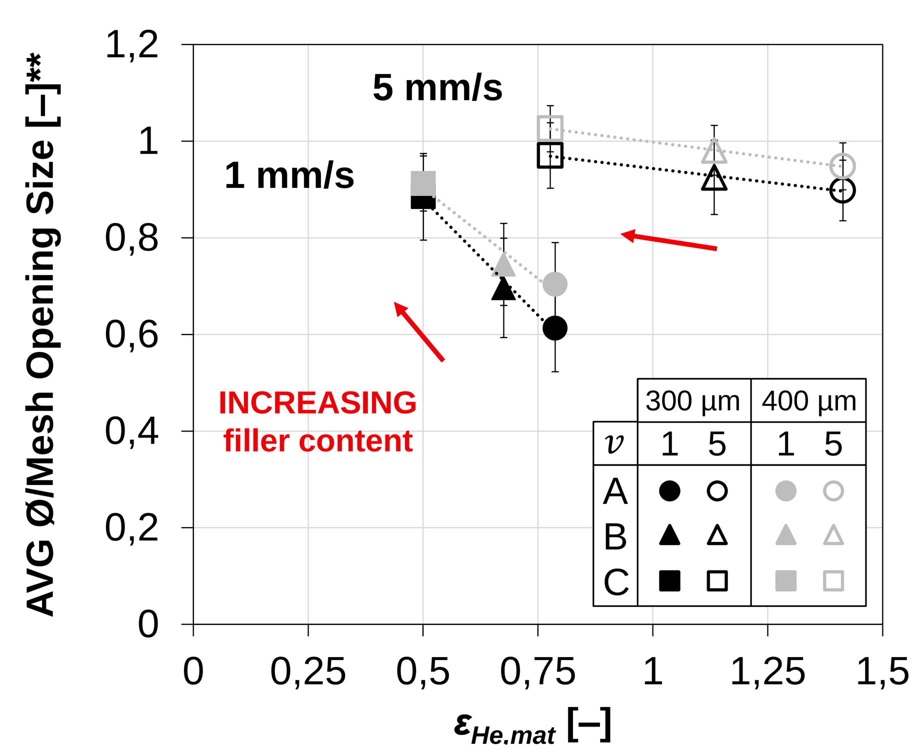
- Filament stretching as a dominant mechanism on bubble formation




**Bubble quantity and size correlated with filament stretching behavior:**




**Bubble quantity and $\varepsilon_{He,mat}$:**
- High <u>positive</u> correlation due to the strong decrease of $\delta$ with increasing filler content
- Shift towards a more elastic behavior beneficial to reduce filament breaking length and thus interactions that produce bubbles




**Bubble size (Ø) and $\varepsilon_{He,mat}$:**
- High <u>negative</u> correlation due to the adverse impact of a stronger elastic behavior on the reduction of the adhesive surface area
- Yet, high <u>positive</u> correlation between bubble size and $\ln(Ca)$. Lower viscosities due to smaller filler contents result in a larger impact of surface tension effects on minimizing the bubble size

* Indicates the percentage of mesh openings that formed bubbles
** Normalized by mesh opening size for better comparison between distinct meshes

## Conclusions

- $\varepsilon_{He,mat}$ applicable to optimize rheological properties for the separation process
- Minimize $\varepsilon_{He,mat}$ and $Ca$ to reduce bubble quantity and size

**References**
[1] A. Kampker, P. Ayvaz, C. Schön, P. Reims and G. Krieger, 'Production of fuel cell components', 1st Ed., PEM of RWTH Aachen University and VDMA (2020)
[2] F. J. Fassbender, H. Fricke, B. Mayer and T. Vallée, 'Filament breaking length - Experimental and numerical investigations', Int J Adhes Adhes, 87, p. 47-63 (2018)

Technische Universität Braunschweig

Institut für Füge- und Schweißtechnik

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