Strength of an SOFC Electrolyte-Supported Cell

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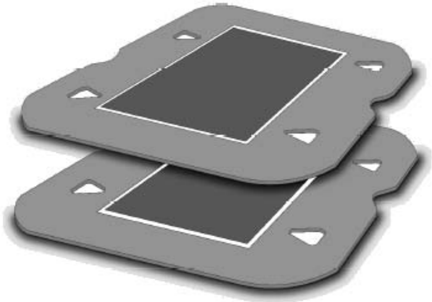
Introduction

Solid Oxide Cell (SOC) technology

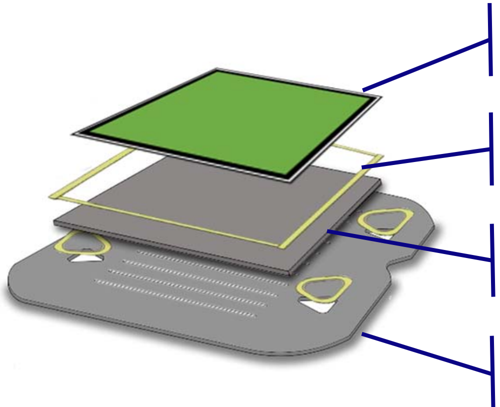
- MEA = Membrane Electrolyte Assembly

Stack

Repetition Units



Components



Pros

- High electric efficiency
- High power density
- Low pollutant emissions
- Multi-fuel compatibility

Weaknesses

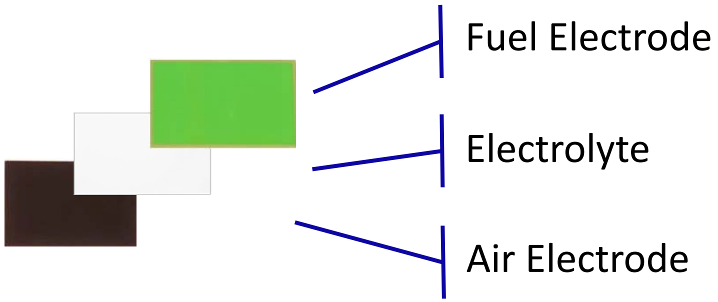
- High temperature
- Harsh operating conditions
- Elevated stresses

↑ Material degradation

↓ Mechanical stability

Methodology

MEA

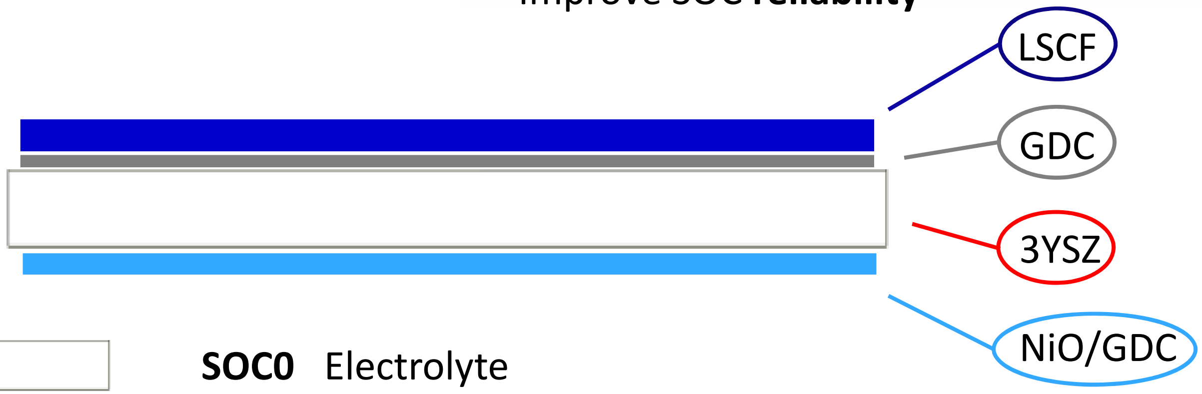


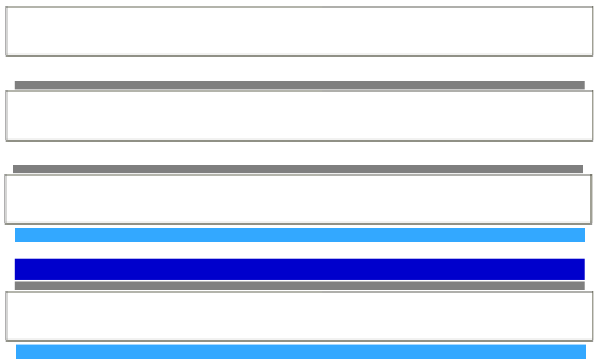
Mechanical characterisation of the **MEA**

Flexural strength of MEA

Interactions between layers

Improve SOC **reliability**





SOC0 Electrolyte

SOC1 Electrolyte + Barrier

SOC2 Electrolyte + Barrier + Fuel Electrode

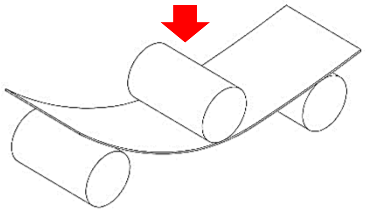
SOC3 Electrolyte + Barrier + Fuel & Air Electrode

Results

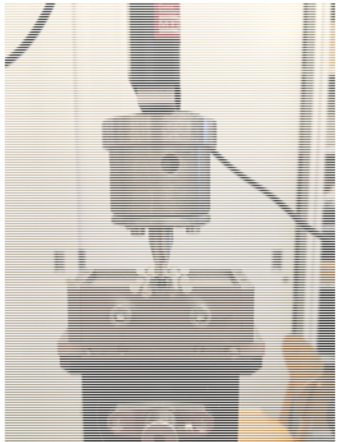
Flexural tests

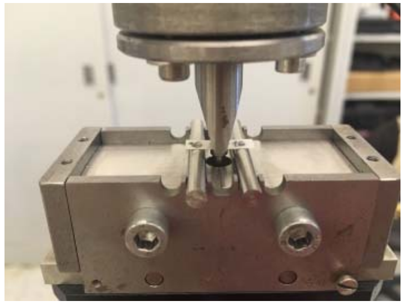
Uni-axial Strength

Three-Point Bending

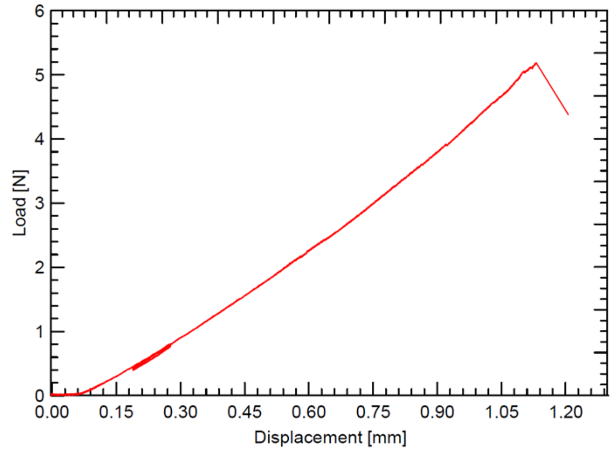


Test setup



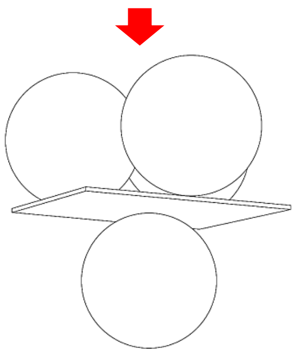


Load VS Displacement



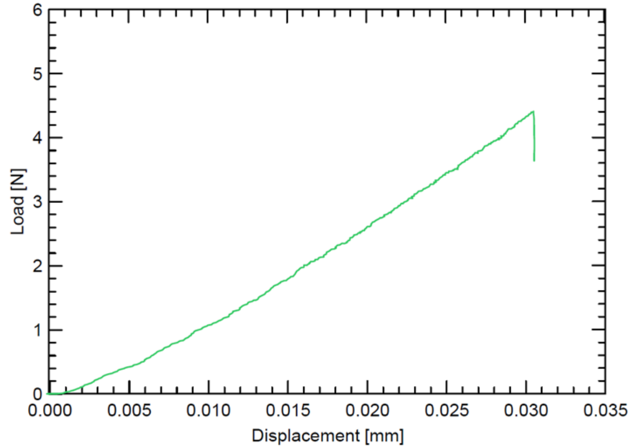
Bi-axial Strength

Ball-On-Three-Balls



Test setup

Load VS Displacement



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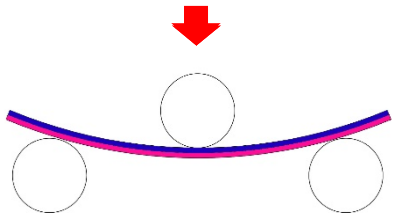
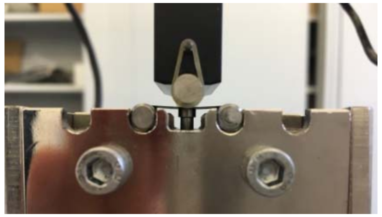
Results

Three-Point Bending

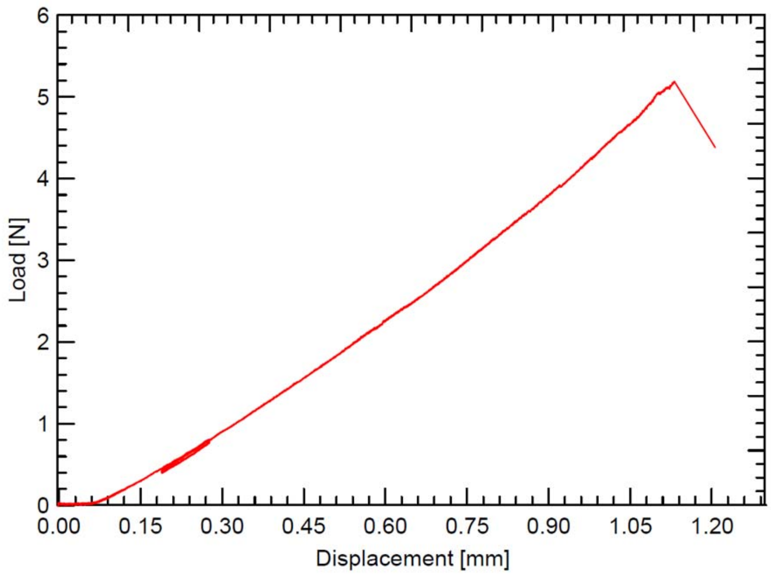
Test setup



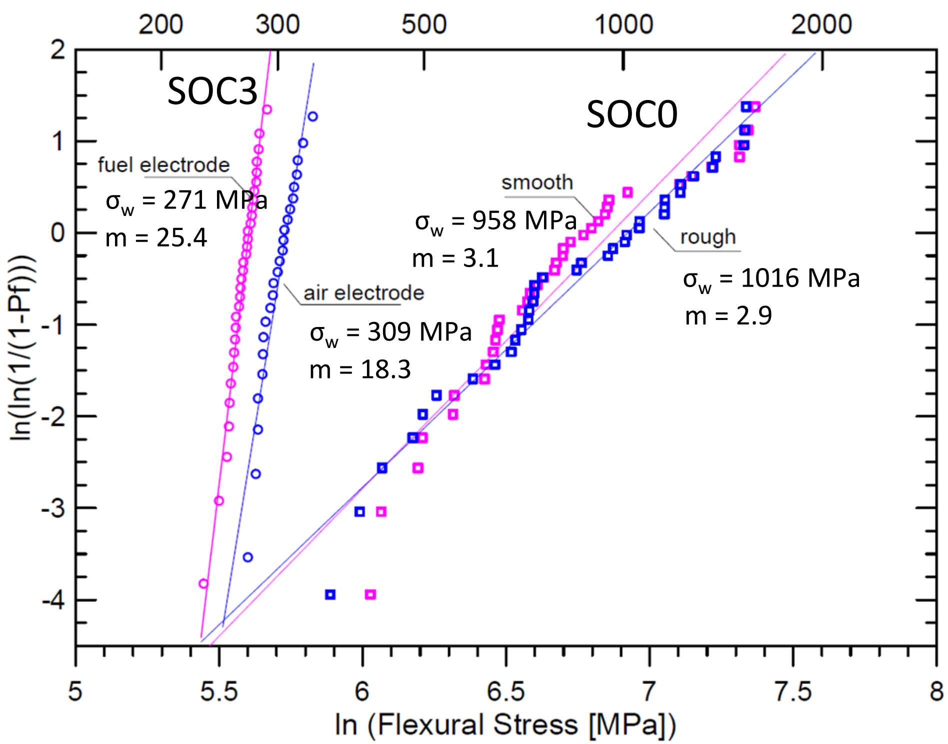


Fractured sample

Load VS Displacement



Weibull plot



- (5 x 13) mm^2
- 10 mm span
- 100 μm/min
- 30 valid measurements

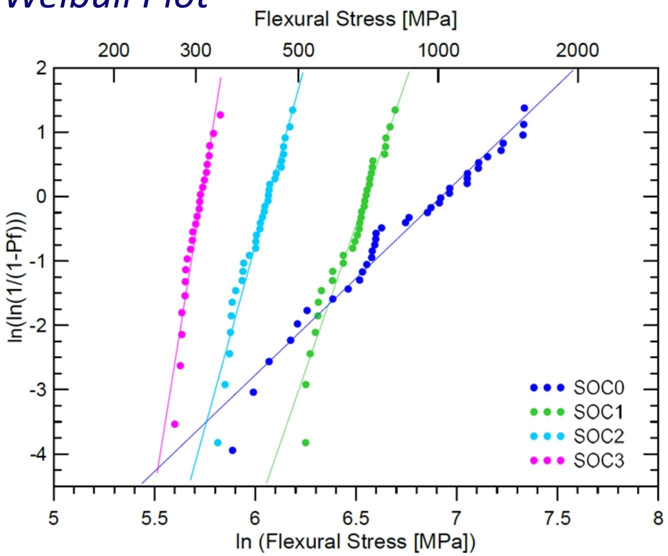
$$\sigma = \frac{3FS}{2bt^2}$$

EN 843-2

Results

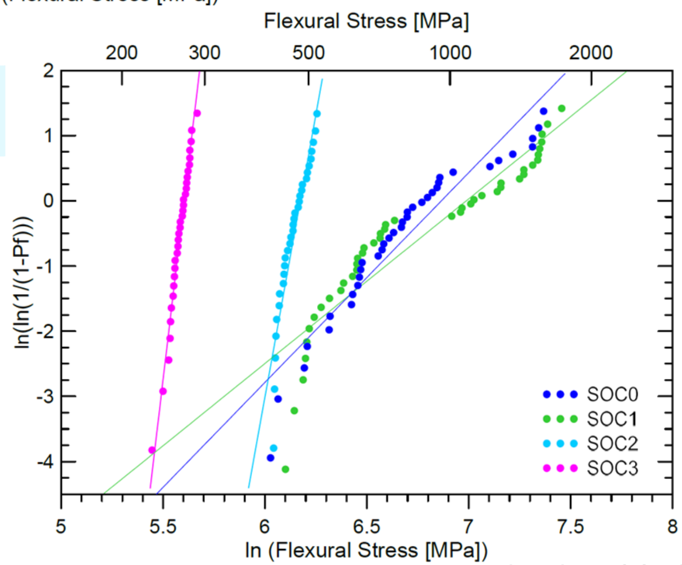
Three-Point Bending

Weibull Plot

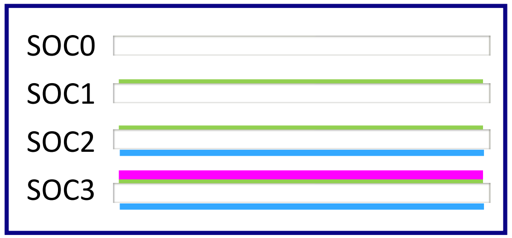


Air Electrode side in tension

Fuel Electrode side in tension



	Tested side	σ_0 [MPa]	*m*
SOC0	Smooth	958.6 (878.7|1079.2)	3.1 (2.3|4.1)
	Rough	1016.2 (891.8|1154.0)	2.9 (2.2|3.8)
SOC1	Electrolyte	1083.7 (941.9|1242.1)	2.4 (1.9|3.1)
	GDC	698.5 (666.8|730.8)	8.6 (6.4|11.5)
SOC2	Fuel Electrode	479.9 (468.2|491.6)	16.6 (12.2|22.2)
	GDC	431.2 (415.5|447.0)	10.9 (8.0|14.5)
SOC3	Fuel electrode	271.4 (267.1|275.6)	25.4 (18.7|33.8)
	Air Electrode	309.1 (301.3|317.0)	18.3 (12.9|25.6)

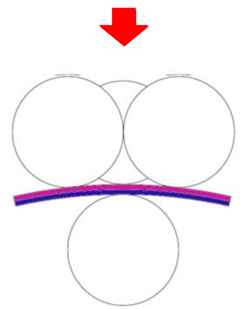


- **Continuous decrease** in flexural strength
- **Increase of *m*** with increasing number of layers
- $\boldsymbol{\sigma_{SOC0} \approx 3\,\sigma_{SOC3}}$

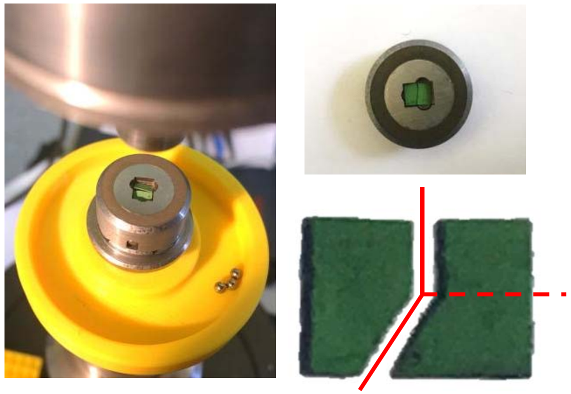
Results

Ball-on-Three-Balls

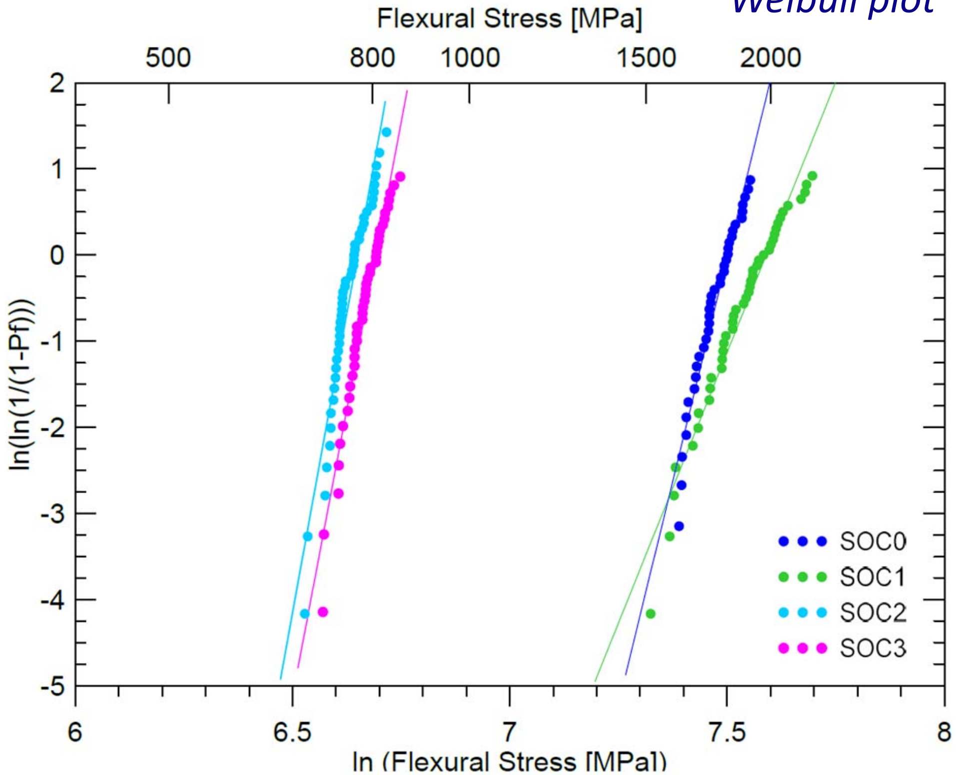
Test setup



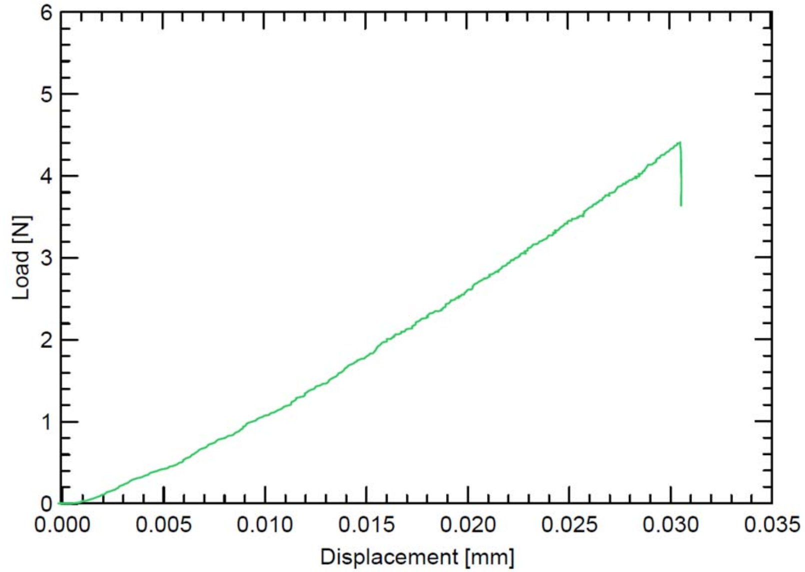
Fractured sample



Weibull plot



Load VS Displacement



- (4 x 3) mm^2
- 2.38 mm balls
- 500 µm/min
- 30 valid measurements

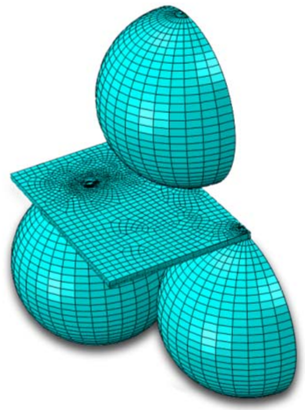
$$\sigma = f \cdot \frac{F}{t^2}$$

Results

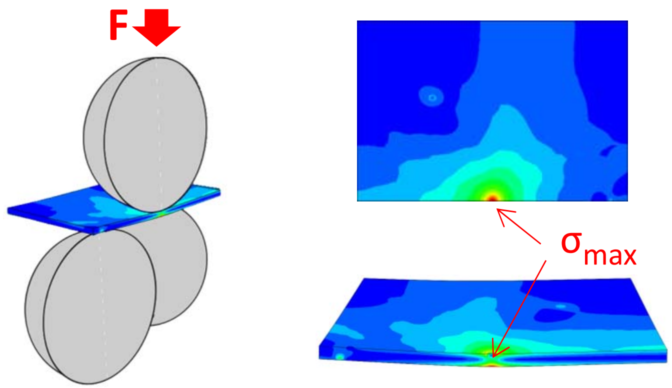
B3B – FE model

$$\sigma = f \cdot \frac{F}{t^2}$$

- F = fracture force [N]
- t = thickness [mm]
- f = dimensionless factor



Finite Element Analysis



F , σ

$$f = \sigma \cdot \frac{t^2}{F}$$

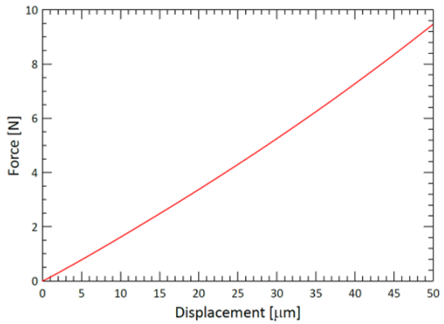
$$f = -0.018\, F + 2.39$$

Experimental fracture force

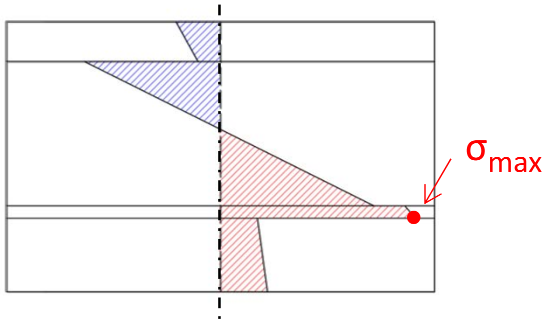
f for every sample

$$\sigma_{max} = f \cdot \frac{F_{max}}{t^2}$$

Force vs Displacement



Stress across Thickness



Results

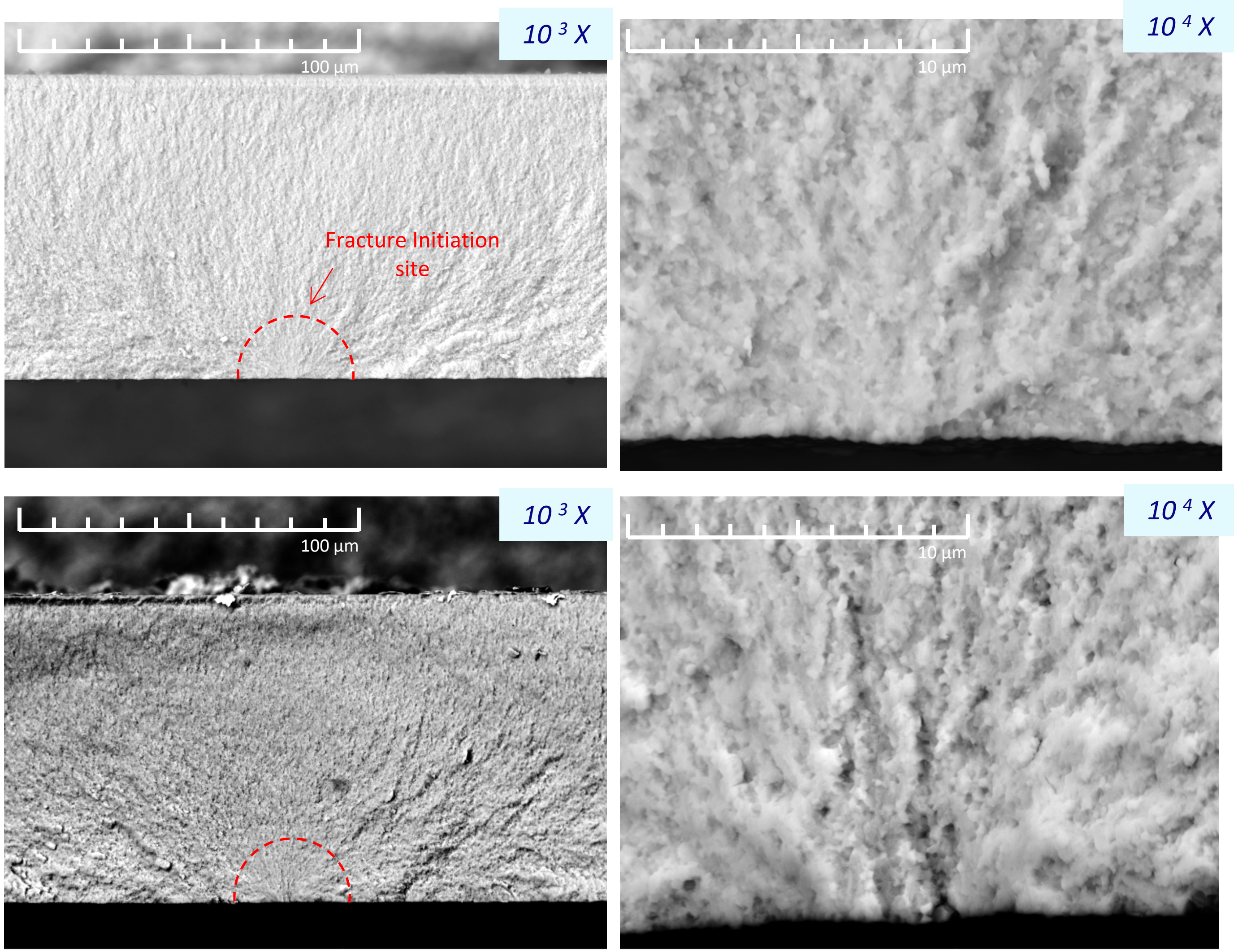
B3B - Fractography

SOC0

SOC1

SOC2

SOC3



Typical fracture mechanism

Transition from **inter-granular** to **trans-granular** crack

Clear initiation point on the outer surface of the electrolyte

Results

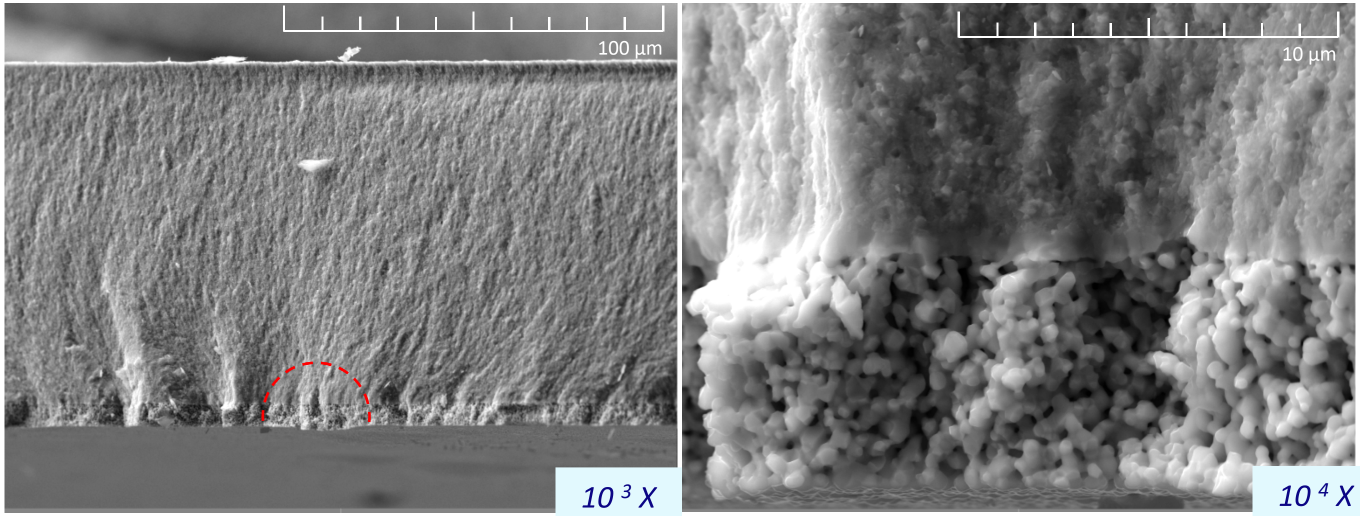
B3B - Fractography

SOC0

SOC1

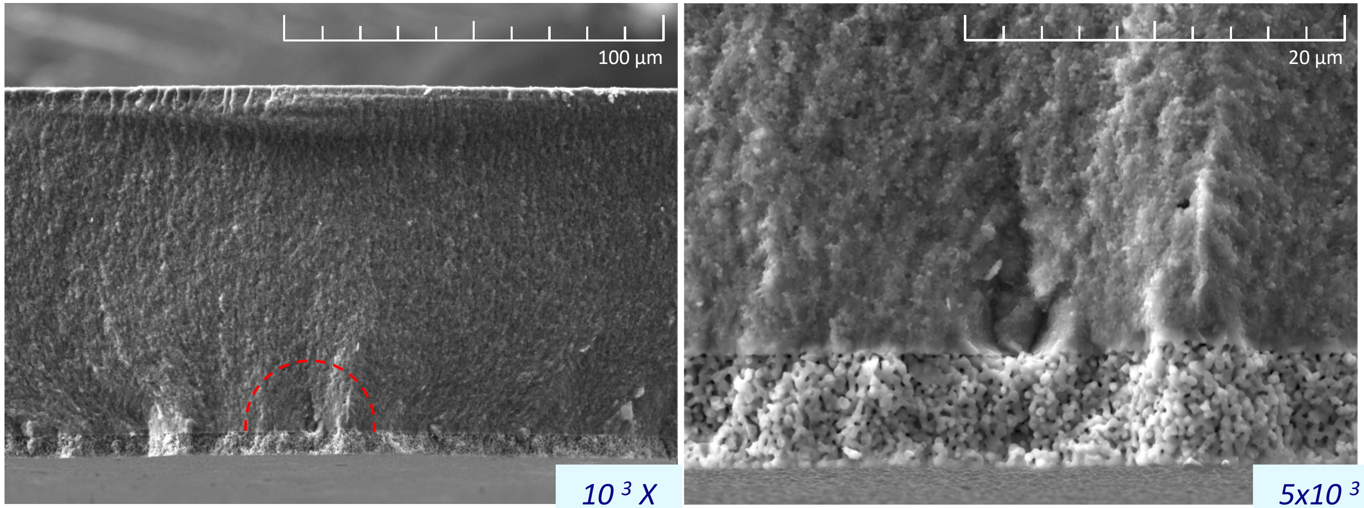
SOC2

SOC3



10^3 X

10^4 X



10^3 X

$5x10^3$ X

Typical fracture mechanism

Fracture **initiating at the surface**, in the barrier layer and propagates through the electrolyte

Exceptional fracture mechanism

Big defect causing fracture initiating in the electrolyte

Results

B3B - Fractography

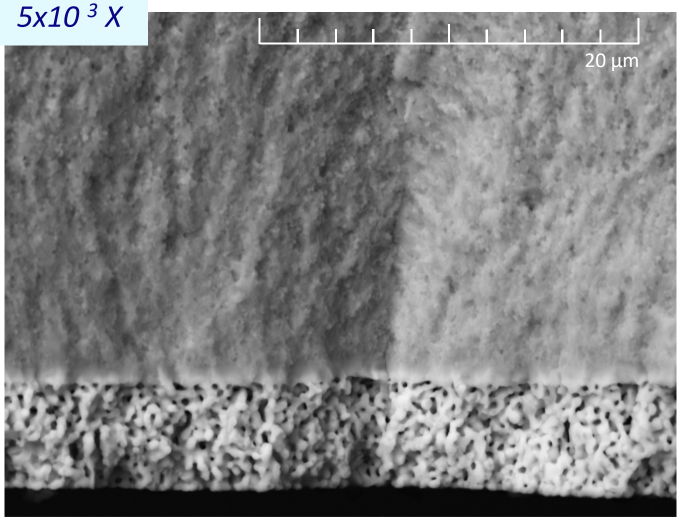
SOC0

SOC1

SOC2

SOC3

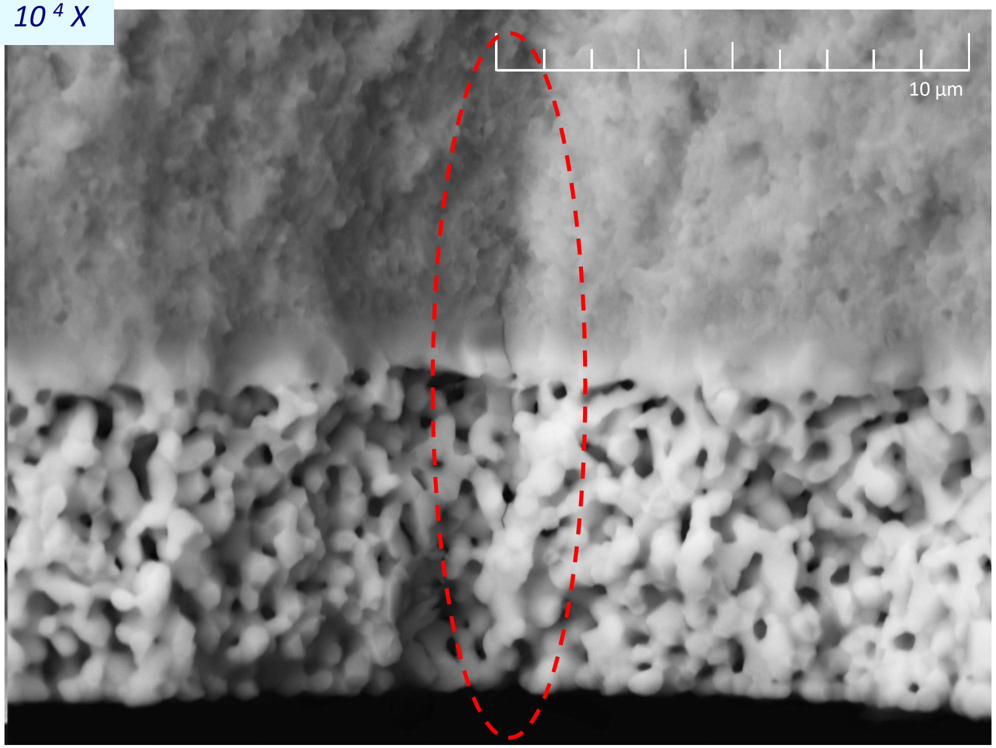
5x10 ^{3} X



Typical fracture mechanism

Fracture **initiating at the surface**, in the barrier layer and propagates through the electrolyte

10 ^{4} X



Detail of the crack crossing the barrier layer and propagating into the electrolyte

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Results

B3B - Fractography

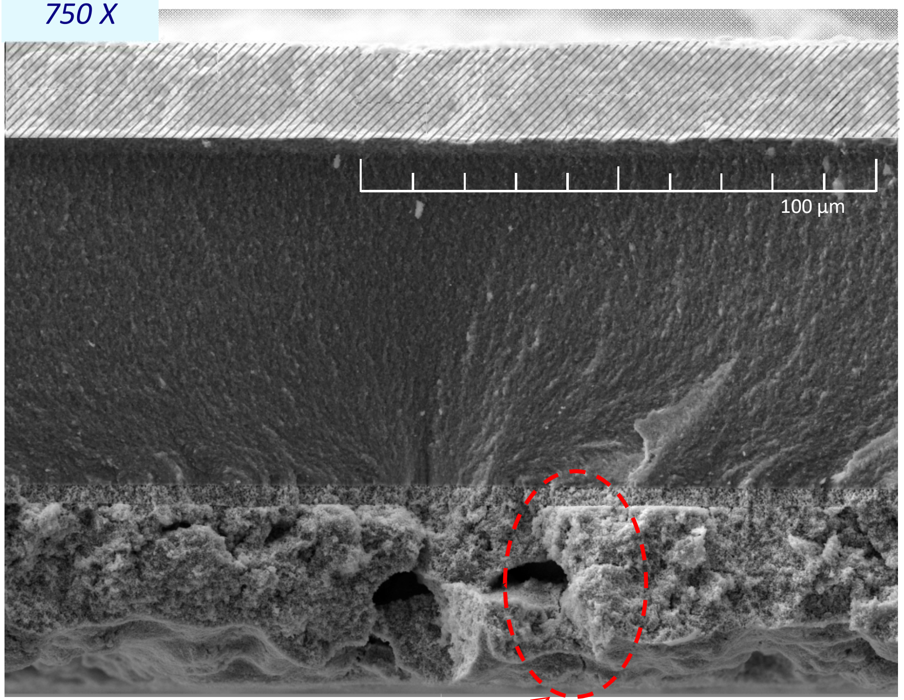
SOC0

SOC1

SOC2

SOC3

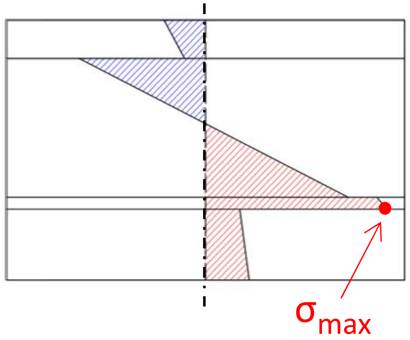
750 X



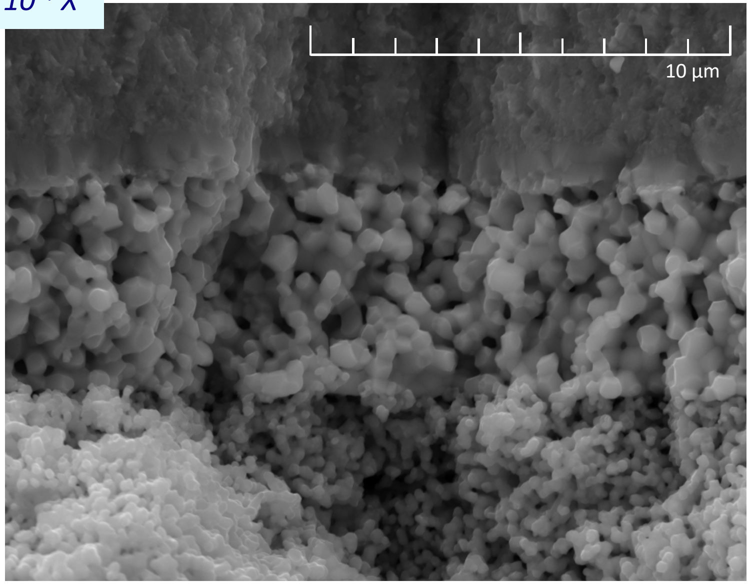
Pre-crack in the air electrode layer

Typical fracture mechanism

Fracture **initiating at the interface** between the barrier layer and the fuel electrode



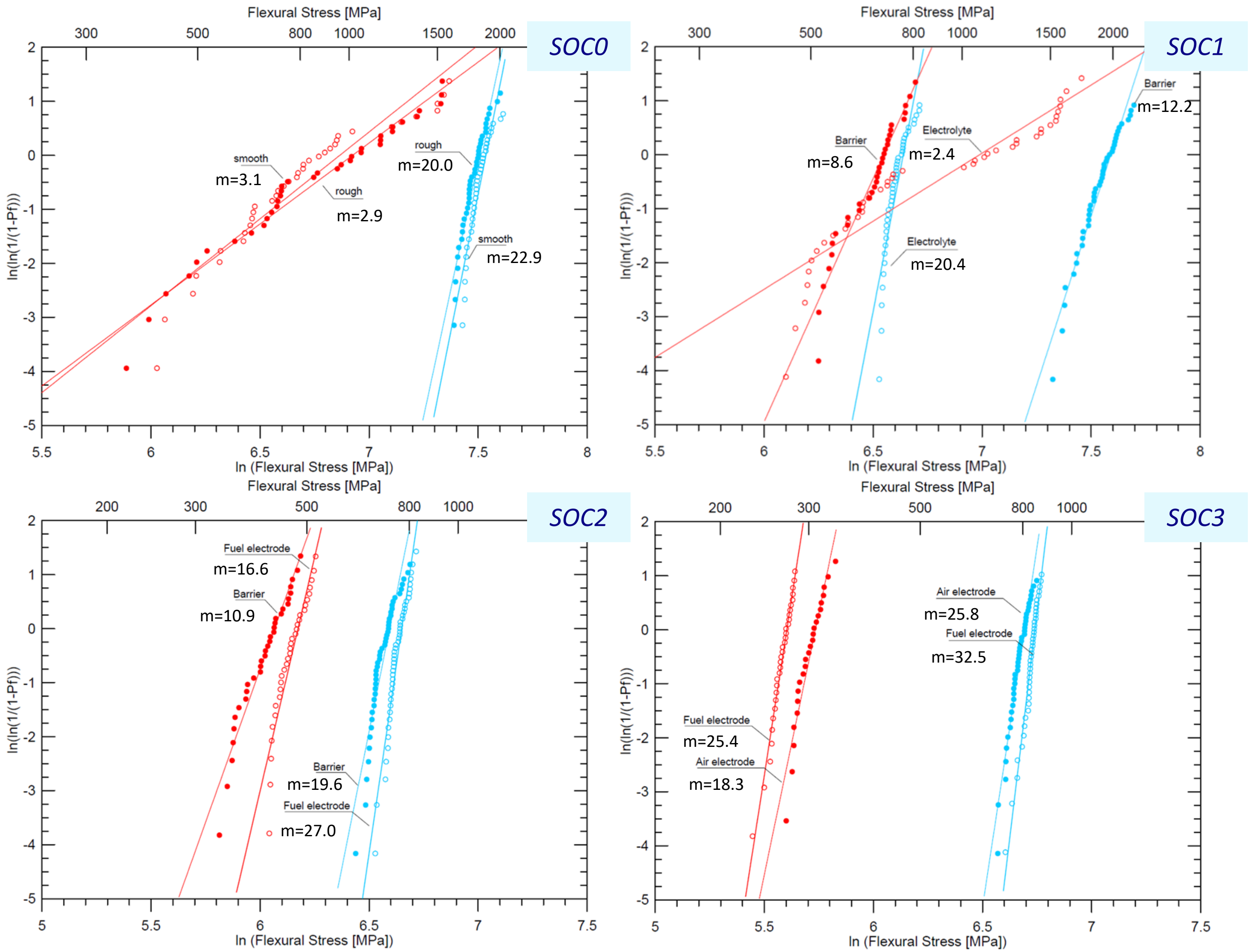
10 ⁴ X



Detail of the crack initiating point, at the interface between GDC and air electrode

Results

Conclusion



- Significant strength decrease
- B3B values higher than 3PB values
- Different effective volumes

GrInHy Green Industrial Hydrogen

COACH European Training Network

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Thanks for your attention