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Advanced multilayer slot-die coating of lithium-ion battery electrodes

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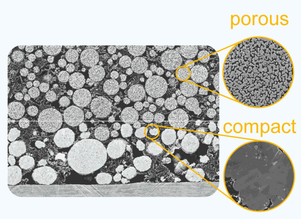
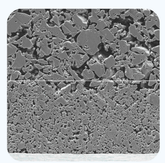
Multilayer electrode applications

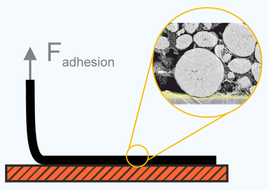
Multilayer structures enable beneficial electrode properties [1-7]



Advanced material combinations [3,4]



Particle sizes and shapes [5,6]



Enhanced mechanical properties by primer layers [7]

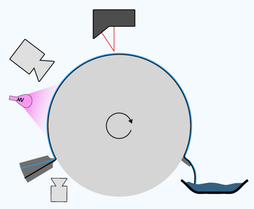


Lower production cost at higher speeds [1,2]

TFT coating lines: self-developed and self-built

Development mode

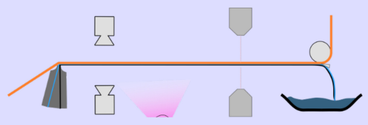
Fixed-Gap coating on a steel roller



Up to 650 m/min
Motorized slot-die positioning
No drying required
Single- and multilayer
Measurement systems (thickness profile)

Web mode

Fixed gap and/or Tensioned Web coating on a substrate



Up to 150 m/min
Motorized slot-die positioning
No drying required
Single- and multilayer
Measurement systems (thickness profile)

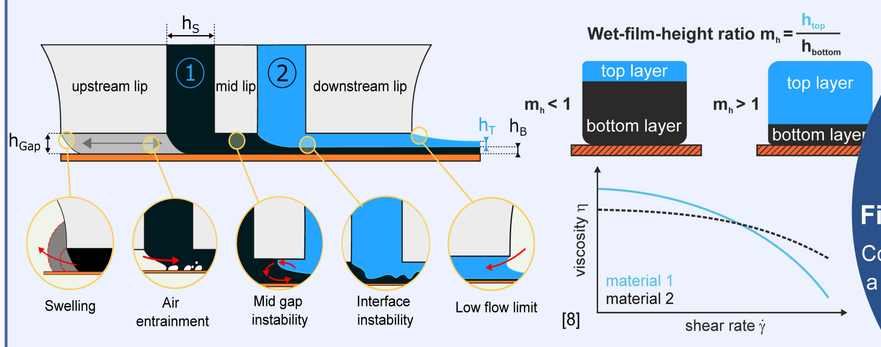
Pilot mode

Coupling coating station with dryers
Fixed-Gap, Tensioned-Web, Simultaneous double sided

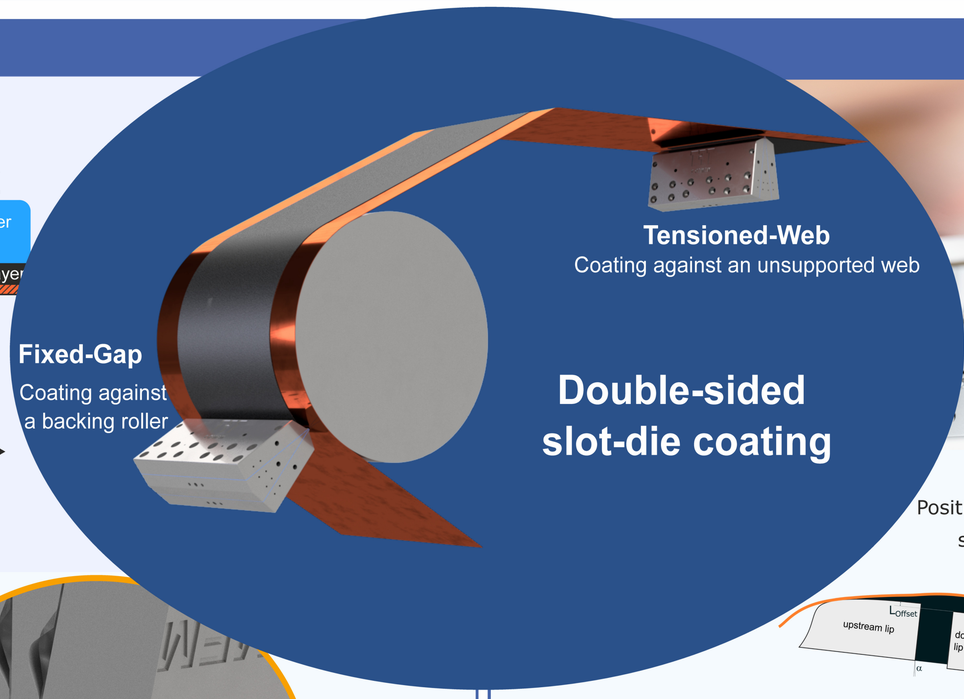


Fixed-Gap coating

Simultaneous multilayer coating



Stable coating conditions require proper adjustments of process parameters and formulation properties

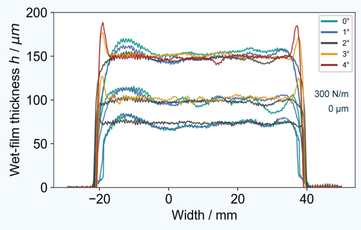


Tensioned-Web coating

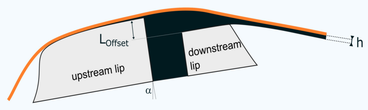


Mode 1
Positive angle (1 to 4°)
small lip-offset

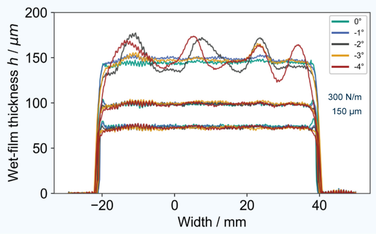
Lip offset in the range of **0 to 0.3x** of the wet-film thickness
Diverging gap with no substrate contact at the slot outlet

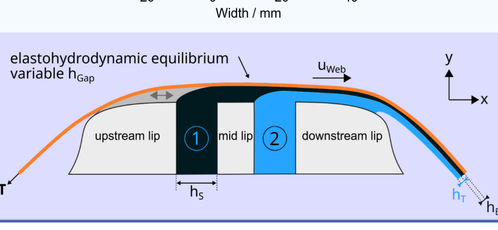


Mode 2
Negative angle (-1 to -4°)
small lip-offset



Lip offset in the range of **1 to 2x** of the wet-film thickness
Converging gap with substrate contact at the slot outlet



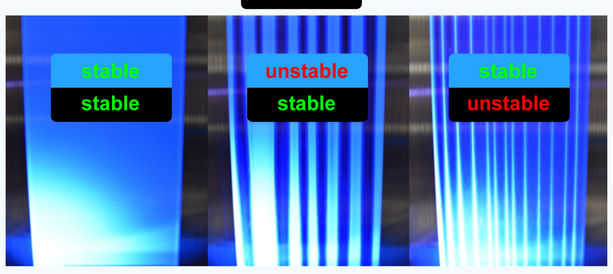


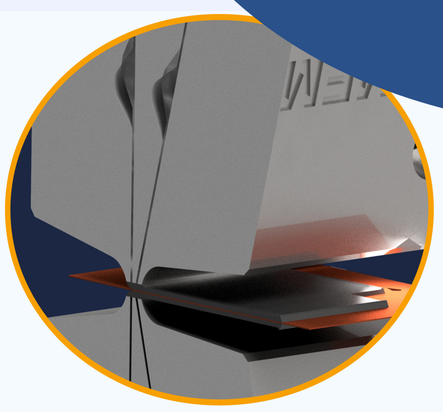
Simultaneous multilayer coating on the Tensioned-Web side

Web handling and **web tension** are critical

Film geometries must be matched carefully

UV marker **Black** — **Fluid coloring** Visibilty of defects in both layers





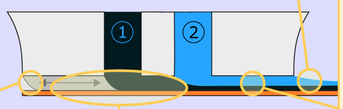
Simulations

Equation of motion $\frac{\partial p}{\partial x} = \frac{\partial}{\partial y}\left(\eta\left(\frac{\partial u}{\partial y}\right)\frac{\partial u}{\partial y}\right)$

Power Law $\eta = \kappa\left(\frac{\partial u}{\partial y}\right)^{n-1}$

Free surface

$\Delta p_{(i,j)} = f(\mathrm{Ca}), \quad \mathrm{Ca} = \frac{\eta u}{\sigma}$



Capillary pressure

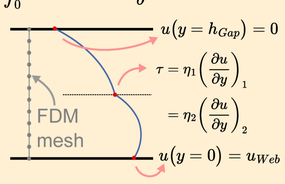
$\Delta p_{(i,j)} = \frac{\sigma}{R}(\cos\theta + \cos\phi)$

Upstream and mid gap
single layer, shear thinning

$\frac{\partial u}{\partial y} = -\left(\frac{1}{\kappa}\left(-\frac{\partial p}{\partial x}\right)(y+c)\right)^{\frac{1}{n}}$

Downstream gap

$\int_0^{h_G} \mathbf{u}(\mathbf{y})\, dy = \frac{\dot{V}}{b} = q$

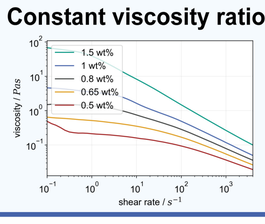


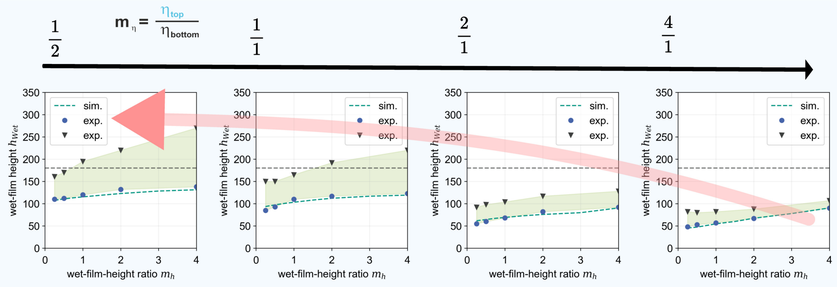
two layers, shear thinning

coupling velocity field to flow by numerical solution

Fast simplified method
to predict operability windows for stable coatings

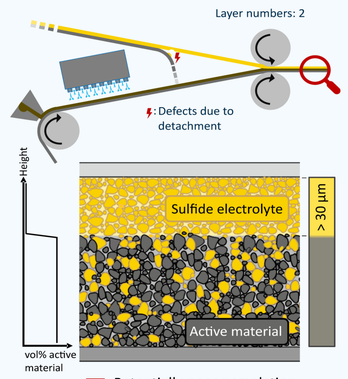
Constant viscosity ratios





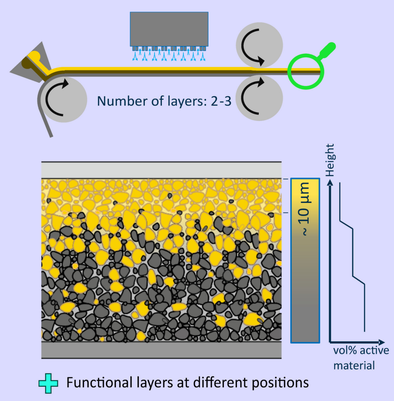
Multilayer use case: All-solid-state batteries

Laminating multilayer



Potentially poor percolation
High internal resistance

Simultaneous multilayer-coating



Functional layers at different positions
Thinner separator → energy density ↑

References

[1] R. Diehm et al., Scharfer, Philip; Schabel, Wilhelm (2020)
[2] J. Kumberg et. al, Scharfer, Philip; Schabel, Wilhelm (2021)
[3] J. Klemens et al., P. Scharfer, W. Schabel (2023)
[4] J. Klemens et al., P. Scharfer, W. Schabel, (2022)
[5] J. Klemens et al., P. Scharfer, W. Schabel, (2023)
[6] J. Klemens et al., P. Scharfer, W. Schabel, (2023, in progress)
[7] Diehm, Ralf et al., P. Scharfer, W. Schabel (2020)
[8] A. Hoffmann et al., P. Scharfer, W. Schabel (2025)

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