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TFT Thin Film Technology

Predictive modeling and experimental study of bead stability in two-layer slot-die coating of battery electrodes

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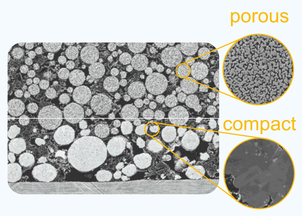
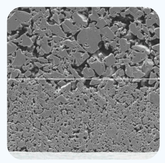
Multilayer electrode applications

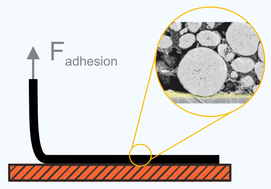
Multilayer structures enable beneficial electrode properties [1-7]



Advanced material combinations [3,4]



Particle sizes and shapes [5,6]

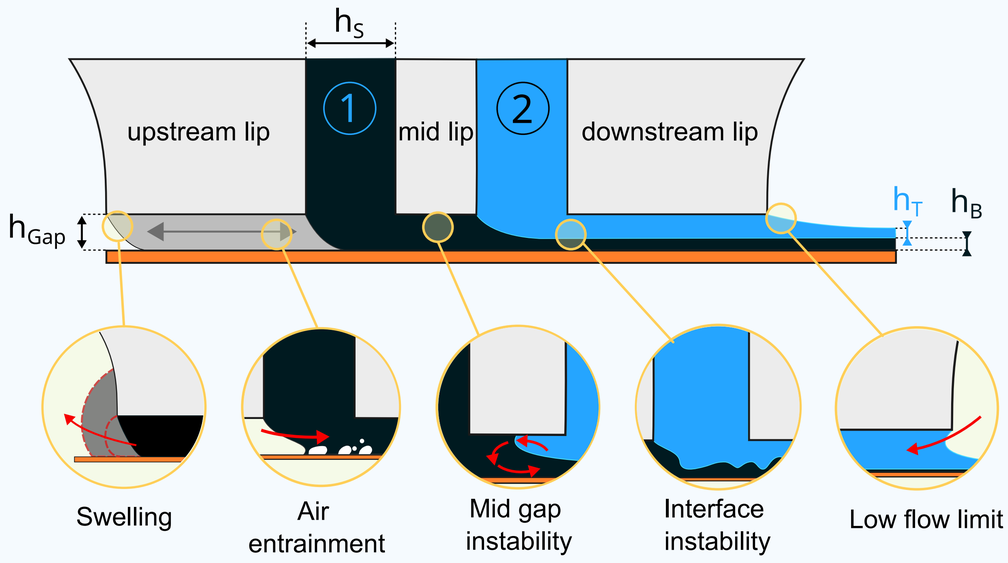


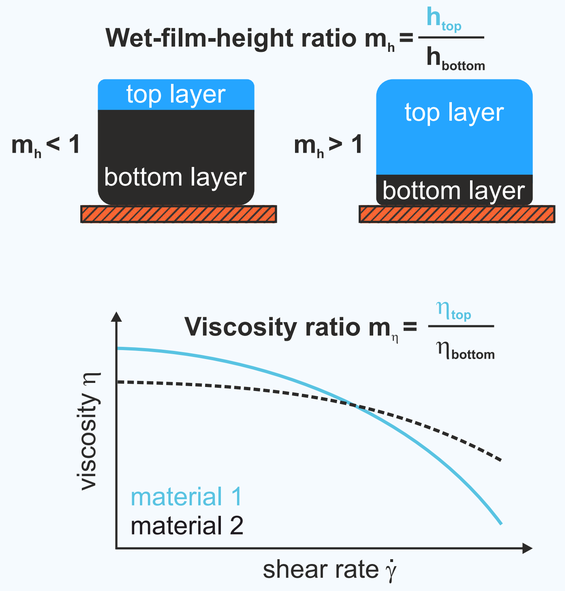
Enhanced mechanical properties by primer layers [7]

Lower production cost at higher speeds [1,2]

Simultaneous multilayer slot-die coating

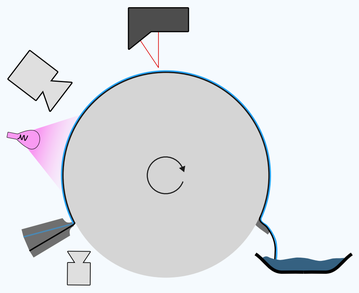
Stable coating coditions require proper adjustments of process parameters and formulation properties

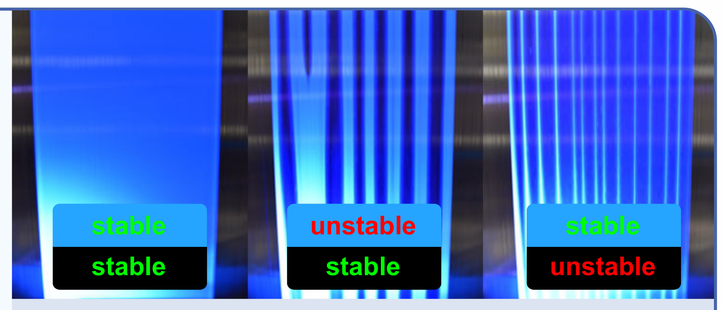




Experimental methods

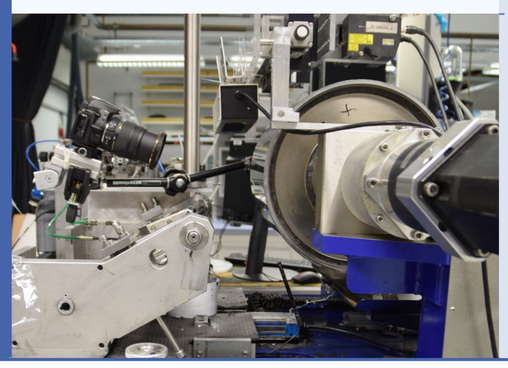
Development coater



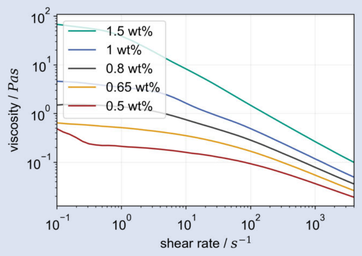


UV marker
Black

Fluid coloring
Visibilty of defects



Model material systems



Prediction models for multilayer bead breakup

Numerical modelling

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

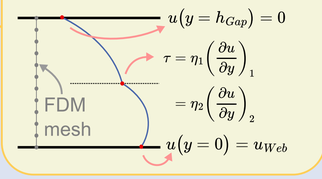
Free surface
$\Delta p_{(i,j)} = f(\mathrm{Ca}), \quad \mathrm{Ca} = \frac{\eta u}{\sigma}$

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

Upstream and mid gap
single layer, shear thinning
$\frac{\partial u}{\partial y} = -\left(\frac{1}{\kappa}\left(-\frac{\partial p}{\partial x}\right)(y+c)\right)^{\frac{1}{n}}$

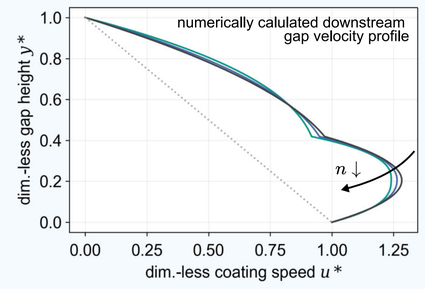
Downstream gap
two layers, shear thinning coupling velocity field to flow by numerical solution

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



Numerical loop

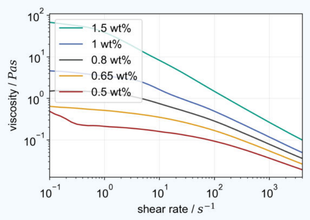
fix meniscus position (lower limit, upper limit)
guess wet-film height
calculate velocity field and pressure gradient
check pressure balance deviation



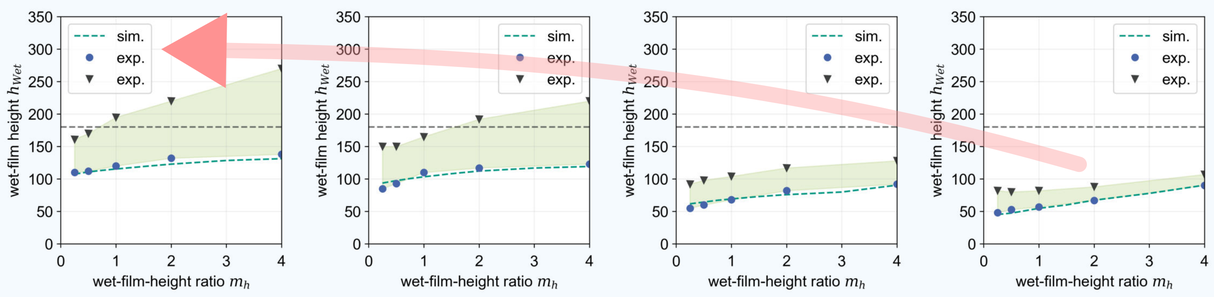
Predictions

Constant viscosity ratios

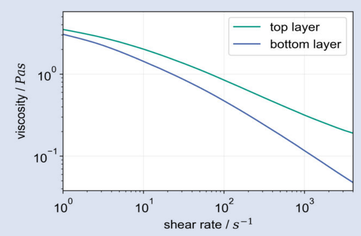
$m_\eta = \frac{\eta_{top}}{\eta_{bottom}}$: $\frac{1}{2}$ — $\frac{1}{1}$ — $\frac{2}{1}$ — $\frac{4}{1}$ — 5 m min^{-1}



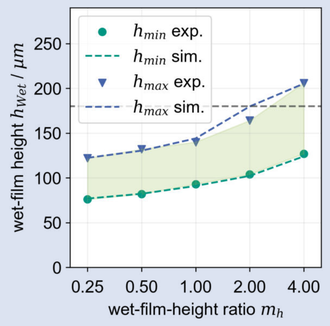
Parallel shift of rheology profiles



Variable viscosity ratios



Viscosity ratio depends on shear rate / coating speed



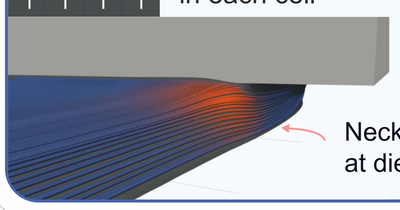
CFD simulations

Single- and multilayer slot-die coating CFD model (Volume-of-Fluid) [8]

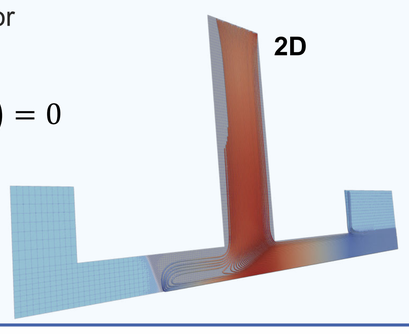
0	0	0	0
0,4	0,3	0,3	0,1
0,6	0,5	0,5	0,4
1	0,9	0,9	0,8
1	1	1	1

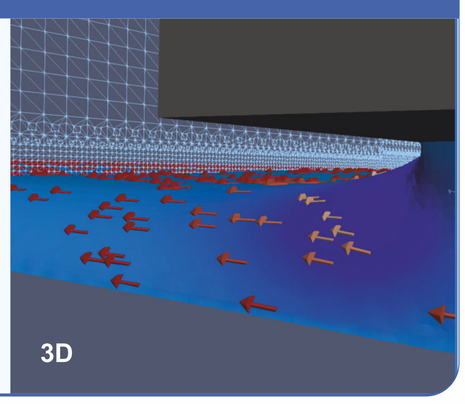
Interface tracking by conservation factor $0 < \alpha_f < 1$. Fluid properties result from local values of α_f in each cell

$$\frac{\partial \alpha_f}{\partial t} + \nabla\left(\alpha_f\, \vec{v}_f\right) = 0$$



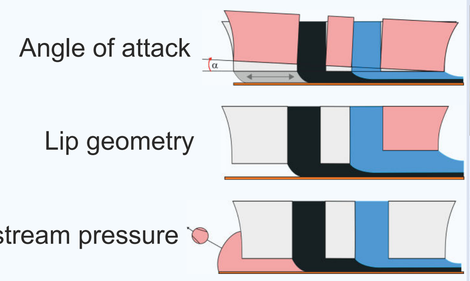
Neck-in flow at die outlet



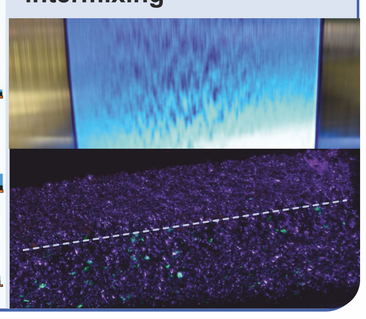


Outlook

Manipulation of flow fields and bead pressure



Detailed study on intermixing



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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] Hoffmann, Alexander et. al, Scharfer, Philip; Schabel, Wilhelm (2022)