PRN 2021 Polymer Replication on Nanoscale

Simulating the layer thickness in roll-to-plate nanoimprint lithography

May 28, 2021

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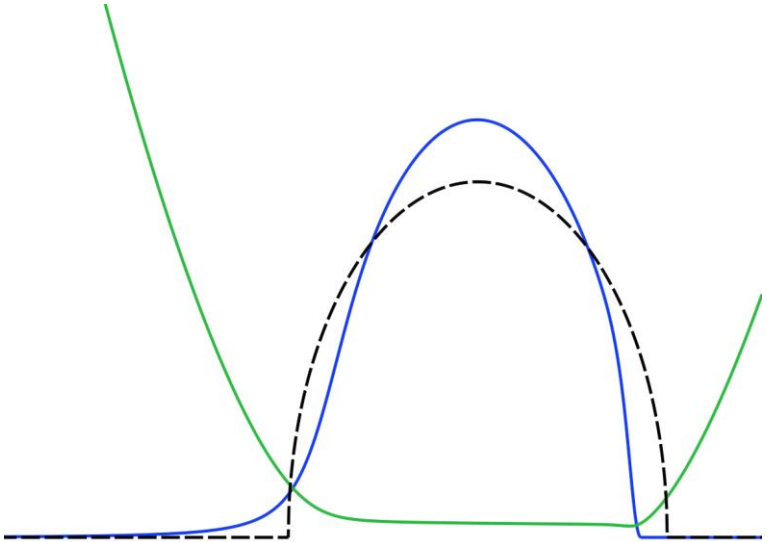
Mechatronic System Design



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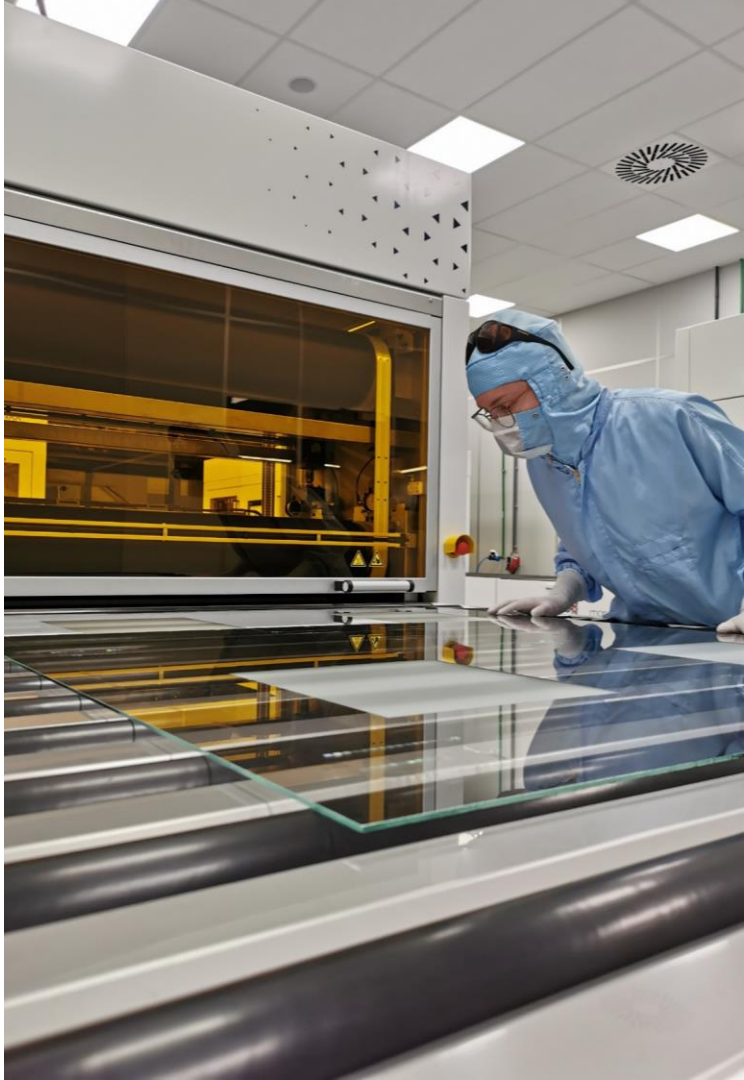
Morphotonics | about

- **Technology** – large-area roll-to-plate micro- and nanoimprinting
  - Large-area: >1 m²
  - Textures: 500 µm down to 50 nm

- **Business** – OEM supplier of equipment & consumables
  - Flexible stamps & UV curable resins



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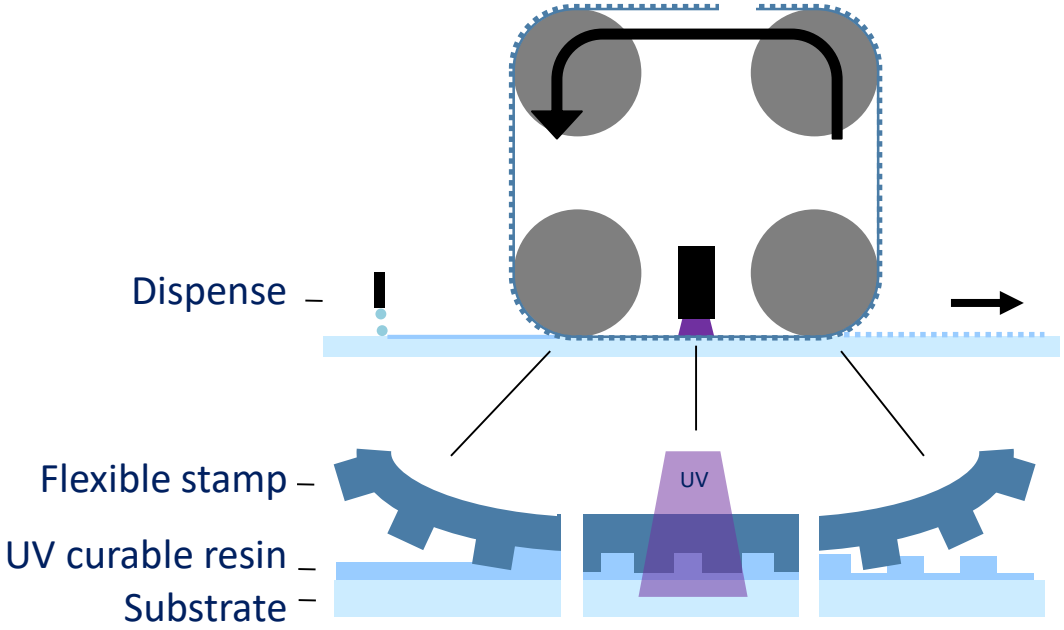
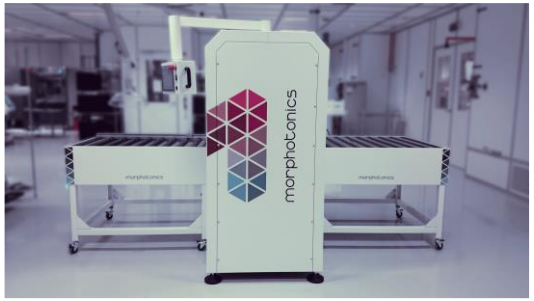
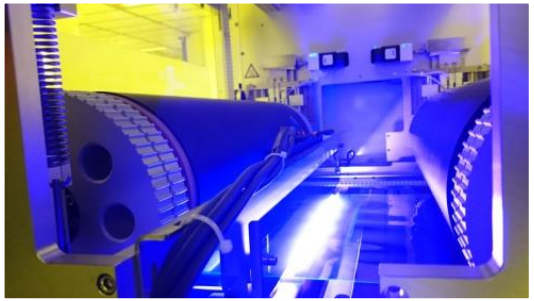
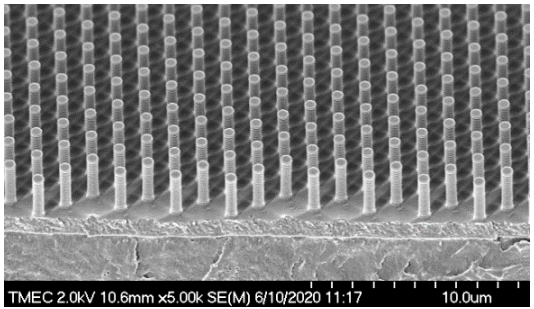
Morphotonics | R2P nanoimprinting









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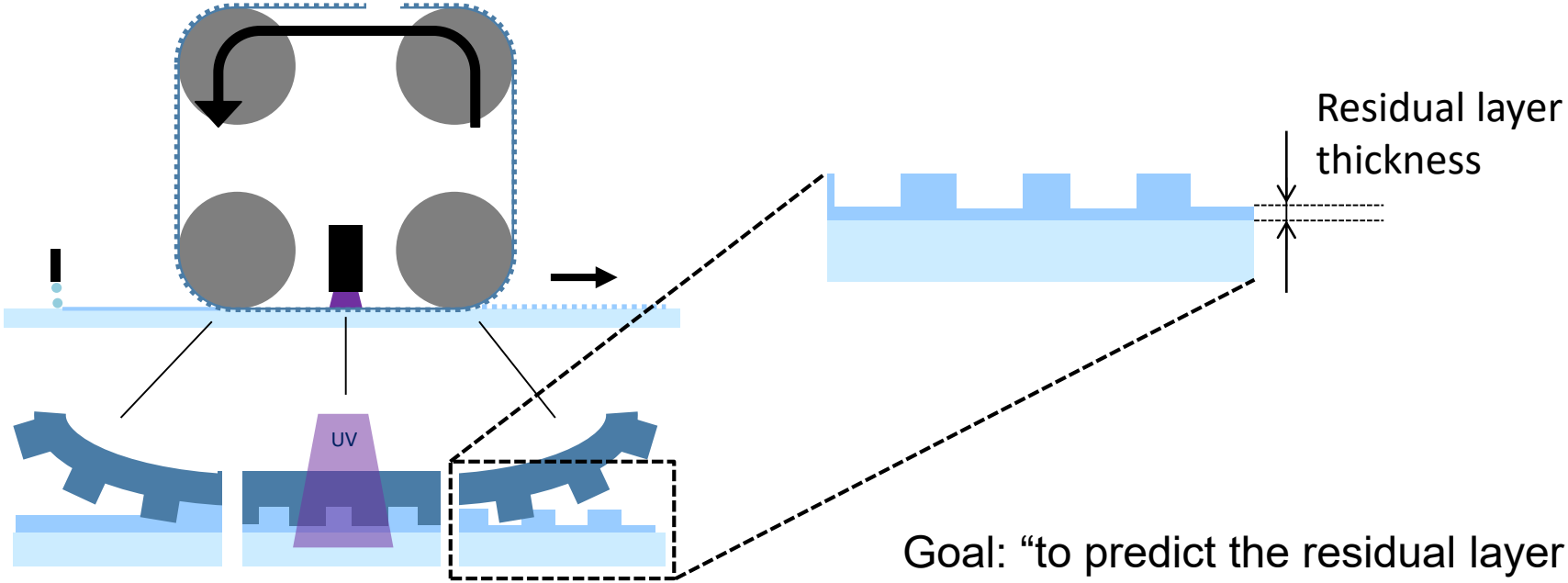
Atthi, N. *et al.* Fabrication of High Aspect Ratio Micro-Structures with Superhydrophobic and Oleophobic Properties by Using Large-Area Roll-to-Plate Nanoimprint Lithography. *Nanomaterials* **11**, 339 (2021).

Modelling | research goal



Goal: “to predict the residual layer thickness in roll-to-plate imprinting”

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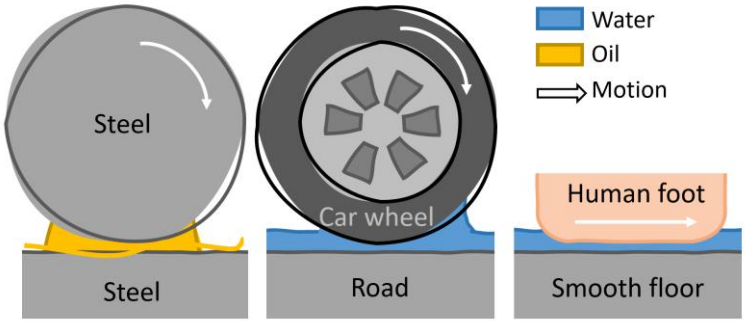
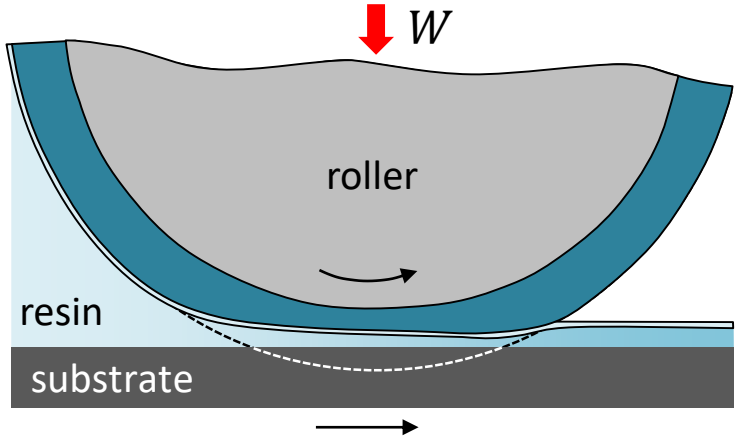
Modelling | Elasto-Hydrodynamic Lubrication (EHL)



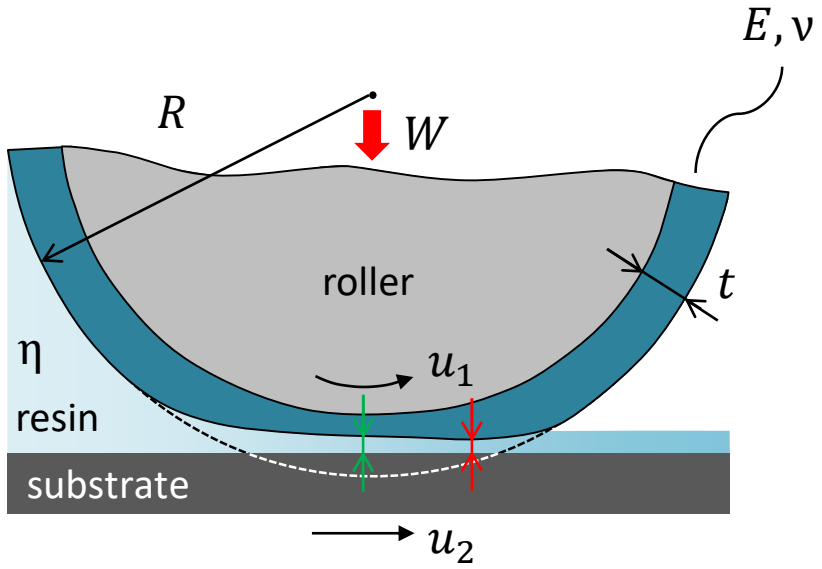


"Systems in which the **elastic deformation** due to the pressure in the lubricating film is not negligible"

Wheeler, J.D. What is EHD film thickness?. https://www.tribonet.org/wiki/what-is-ehd-film-thickness/ (2020).

Modelling | relevant variables

- Process variables
  - Load: W
  - Velocity: $U\ (= u_1 + u_2)$
- Material properties
  - Viscosity resin: η
  - Elastic modulus elastomer: E
  - Poisson ratio elastomer: ν
- Geometry
  - Roller radius: R
  - Elastomer thickness: t



- Characteristic layer heights
  - Central layer height h_C
  - Minimum layer height h_M

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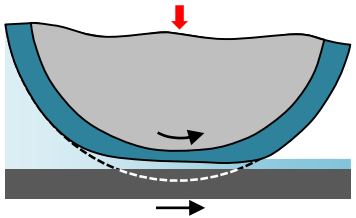
Modelling | model set-up & result



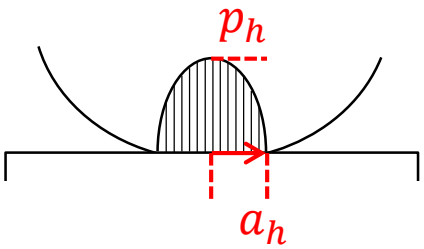
Multiphysics model

Flow modelling;
solve for pressure
$p(h,x)$

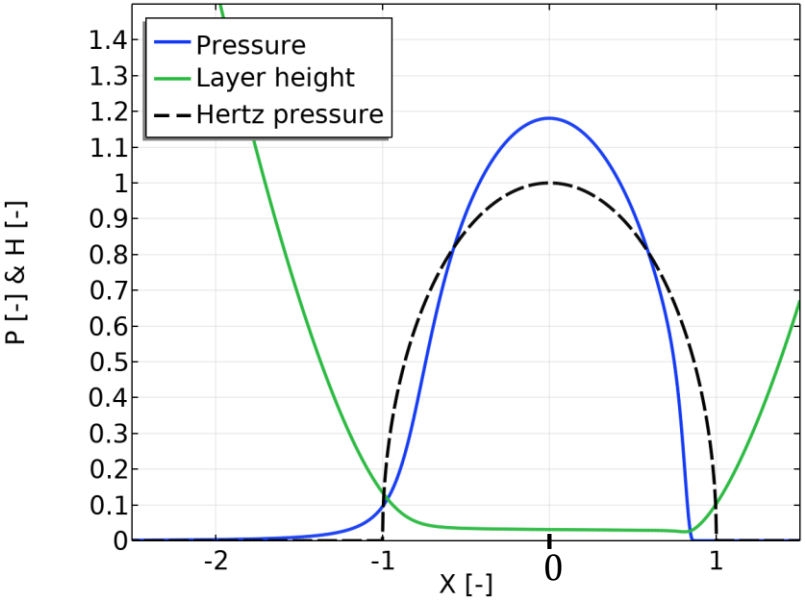
$p(h,x)$ ↓ ↑ $v(x)$

Elastic deformation;
solve for deformation
$v(x)$

Hertzian scaling

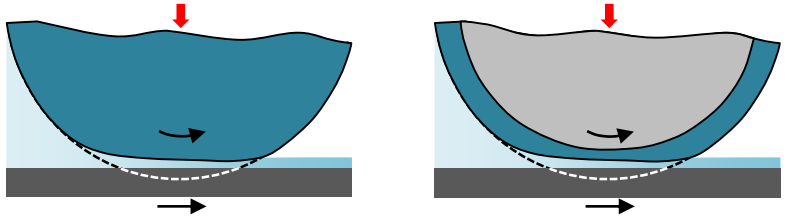


Solution

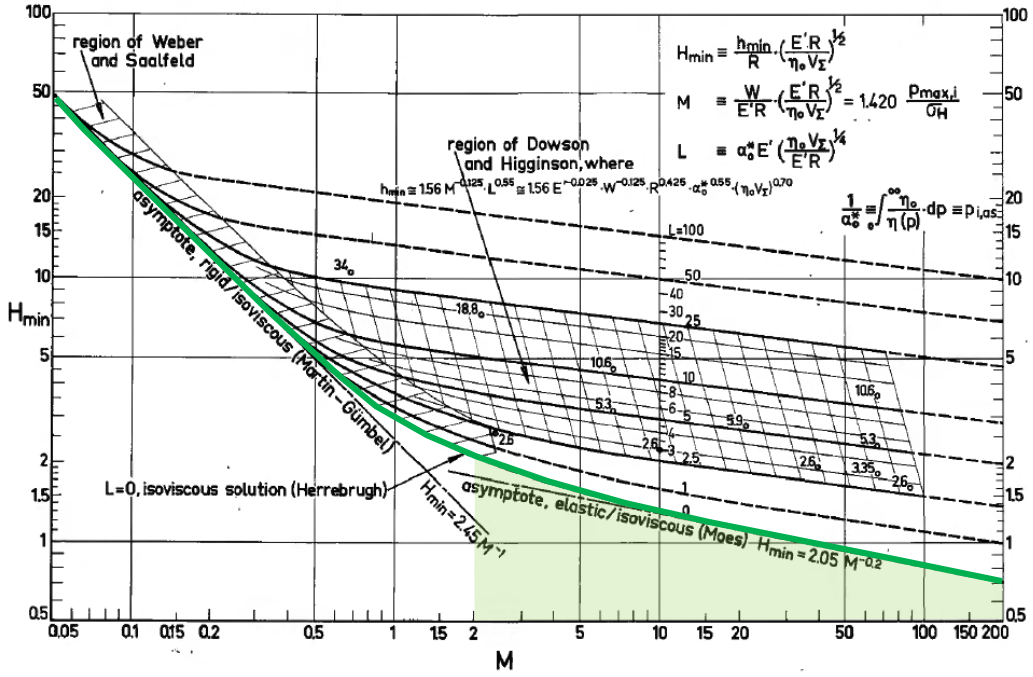


Model based on: Habchi, W. *Finite element modeling of elastohydrodynamic lubrication problems*. (John Wiley & Sons, 2018).

Modelling | EHL literature



- Three dimensionless variables to describe all EHL solutions
  - Load variable: $M = \frac{W}{E'R}\sqrt{\frac{E'R}{\eta U}}$
  - Height variable: $\mathrm{H} = \frac{h}{R}\sqrt{\frac{E'R}{\eta U}}$
  - Viscosity variable: $L = \alpha E' \left(\frac{\eta U}{E'R}\right)^{\frac{1}{4}}$
- Delft / Blok diagram (1966)

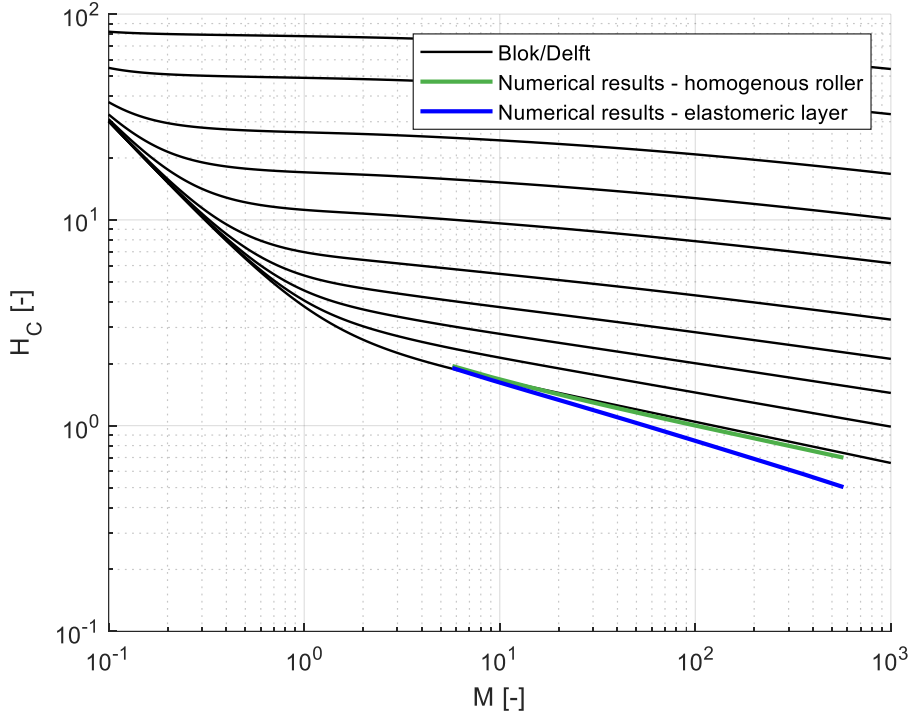


Moes, H. *Lubrication and Beyond*. (2000).

Modelling | numerical results

- Delft / Blok diagram
- Results model for
  - Homogeneous roller
  - Roller with elastomeric layer

$$M = \frac{W}{E'R}\sqrt{\frac{E'R}{\eta U}} \qquad \mathrm{H} = \frac{h}{R}\sqrt{\frac{E'R}{\eta U}}$$



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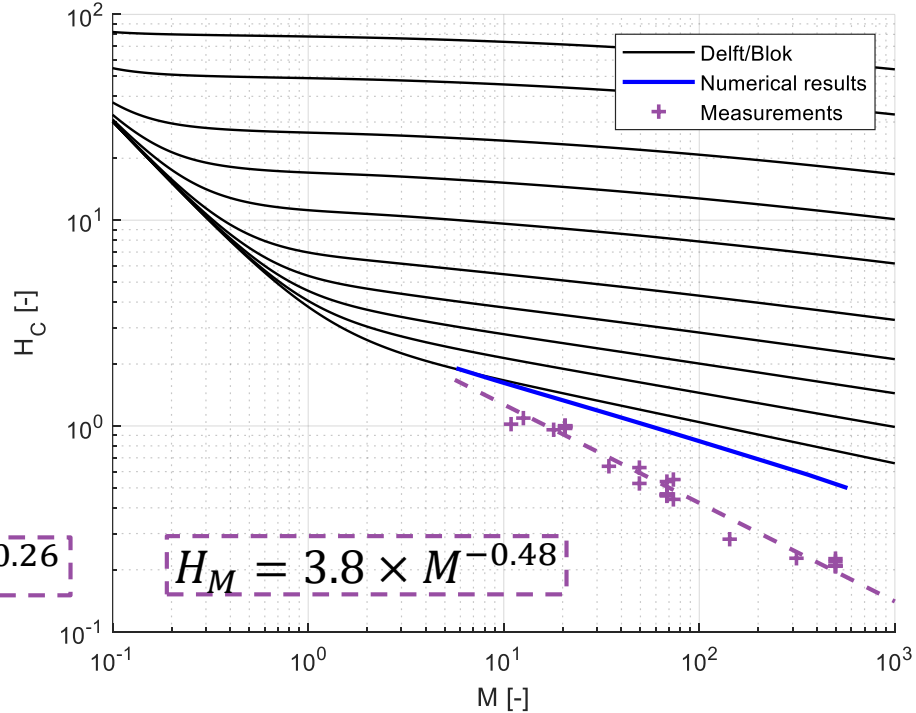
Experimental results | Delft / Blok diagram

- Variation of
  - Imprint equipment
  - Viscosity: η
  - Velocity: U
  - Load: W

$$M = \frac{W}{E'R}\sqrt{\frac{E'R}{\eta U}} \qquad \mathrm{H} = \frac{h}{R}\sqrt{\frac{E'R}{\eta U}}$$

$$h_C = 3.8 \times (\eta U R)^{0.74}\,(W)^{-0.48}(E')^{-0.26}$$



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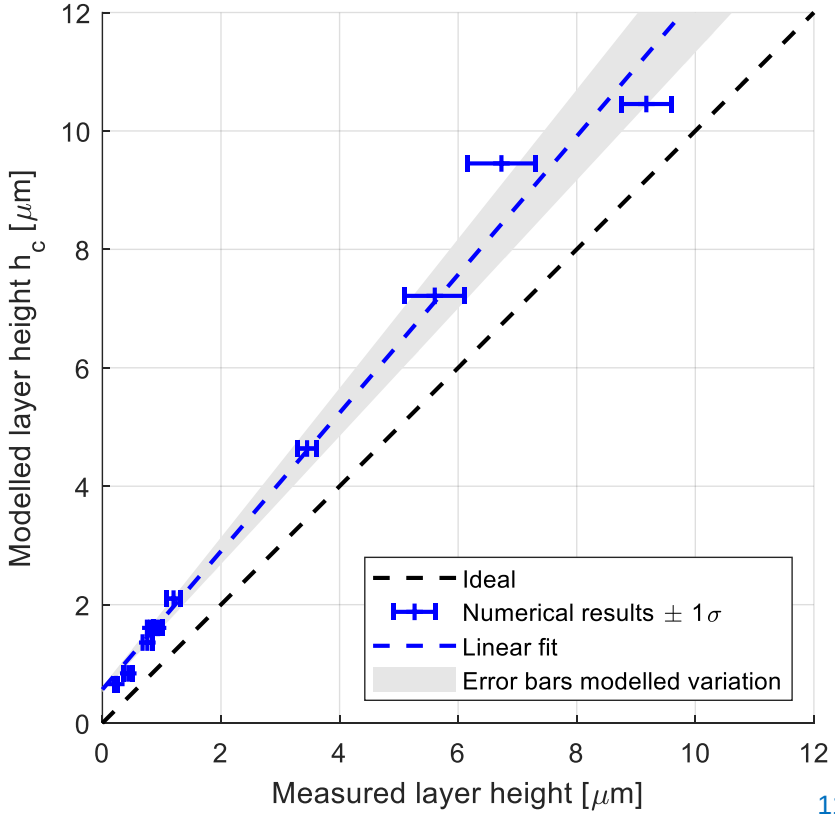
Experimental results | layer height graph h_c

- Modelled variation over process parameters
  - Elastic modulus E: $\pm$ 3 Shore A
  - Viscosity η: $\pm$ 5%
  - Load W: $\pm$ 3%
  - Elastomer thickness t: $\pm$ 0.5%
  - Velocity U: $\pm$ 0.5%



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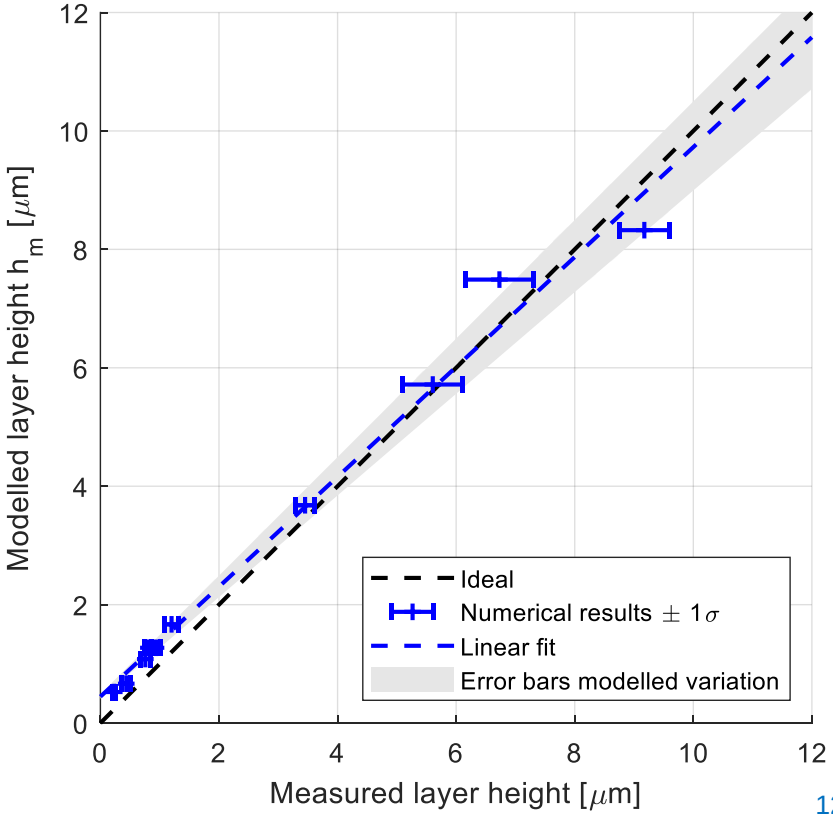
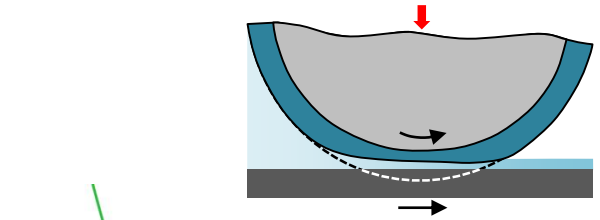
Experimental results | layer height graph h_m

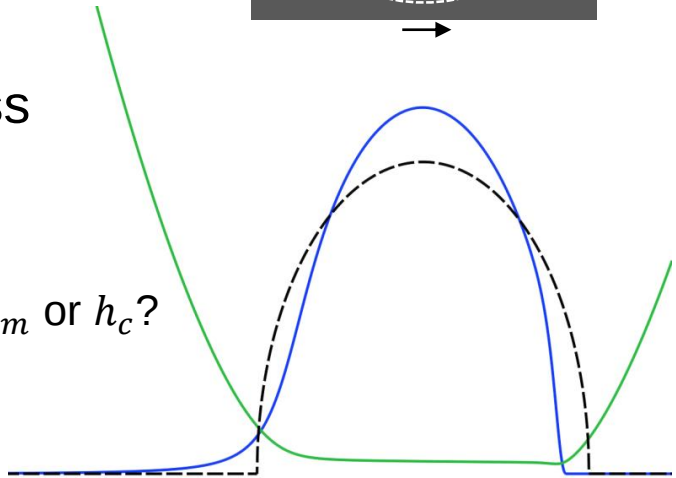
- Modelled variation over process parameters
  - Elastic modulus E: $\pm$ 3 Shore A
  - Viscosity η: $\pm$ 5%
  - Load W: $\pm$ 3%
  - Elastomer thickness t: $\pm$ 0.5%
  - Velocity U: $\pm$ 0.5%



Conclusion & next steps

- Development of a numerical EHL model
  - Useful to study the layer thickness in R2P imprinting
- Empirical formula to predict the layer thickness
  - Based on EHL theory & dimensionless numbers
- Next steps
  - Determine the correct layer height from the model: h_m or h_c?
  - Extension of the model
    - Flexible stamp
    - Textures





$$h_C = 3.8 \times (\eta UR)^{0.74} (W)^{-0.48} (E')^{-0.26}$$

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Acknowledgments

This research was carried out within the ELANIA RVO project

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