Brightlands Materials Center

COMSOL CONFERENCE 2018 LAUSANNE

Multiphysics modelling of photo-polymerization in DLP printing process and validation

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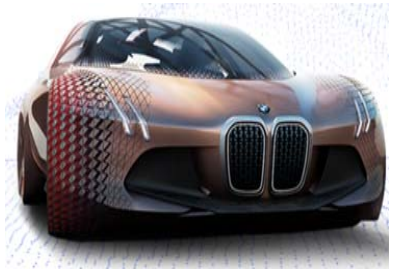
Brightlands Materials Center

- **Public-private partnership** initiative founded March 19, 2015 by TNO and the Province of Limburg.
- Focusing on **sustainable** innovations in **polymers**.
- Three programs driven by **application challenges**, together with universities and industry partners.

Sustainable Buildings

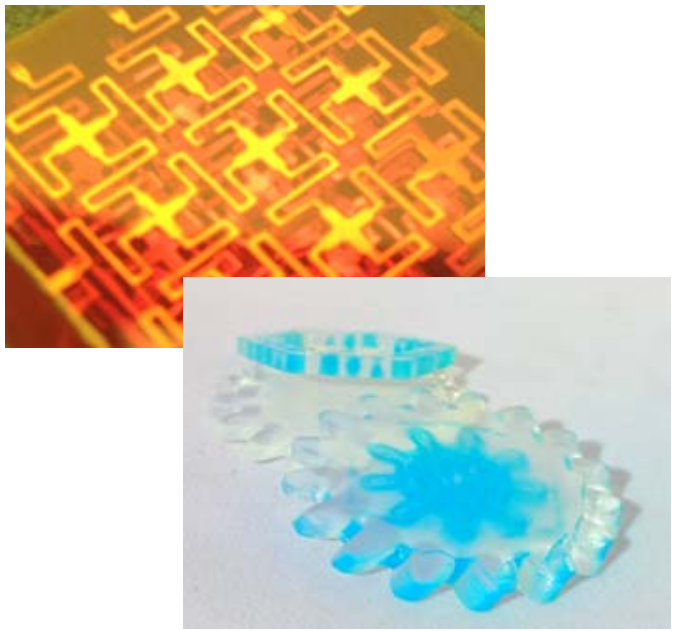
Additive Manufacturing

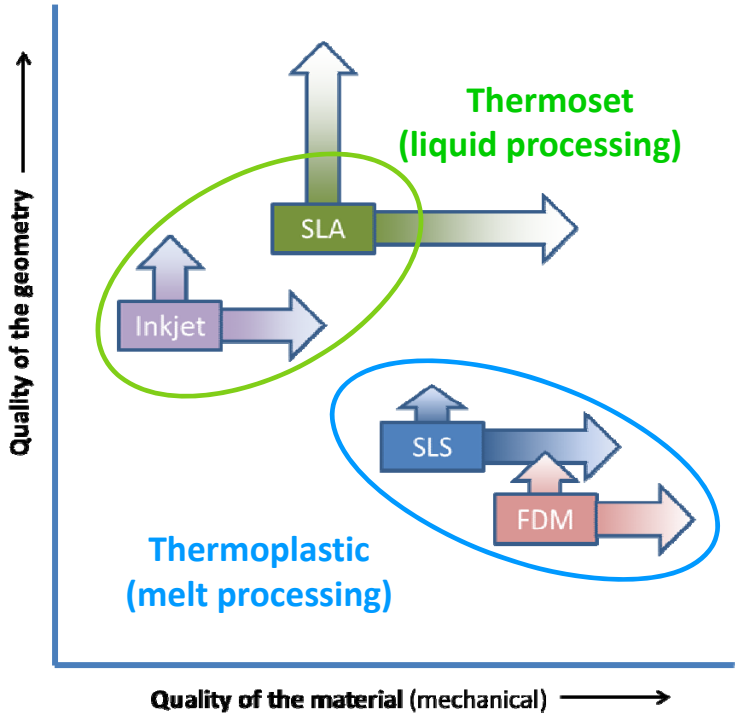


Lightweight Automotive

Additive Manufacturing Program – Focus

Multi-material photopolymer
for new (responsive) functionalities





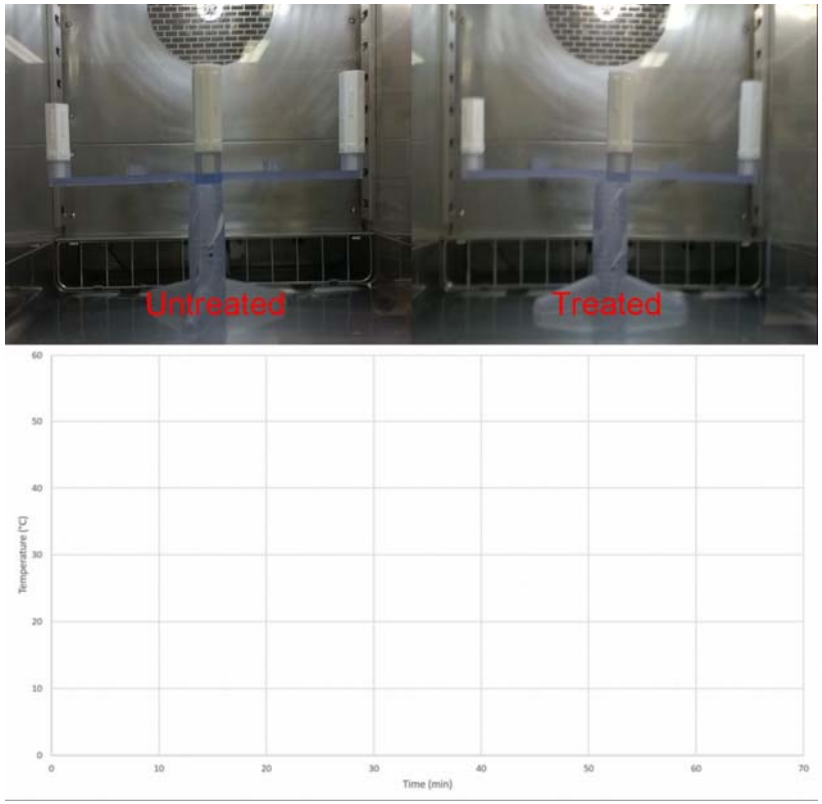
polymers with continuous fibers
for reinforcement and sensing

Materials Challenges

- Quality: warpage and residual stress, …
- Stability: structural performance at high temperature and long term behavior, …
- Multi-material, 4D printing and etc.

Warpage in products

Thermal stability



Objective

*To use **modeling and simulation** in order to link **materials** and **process** for further control in **SLA/DLP printing***

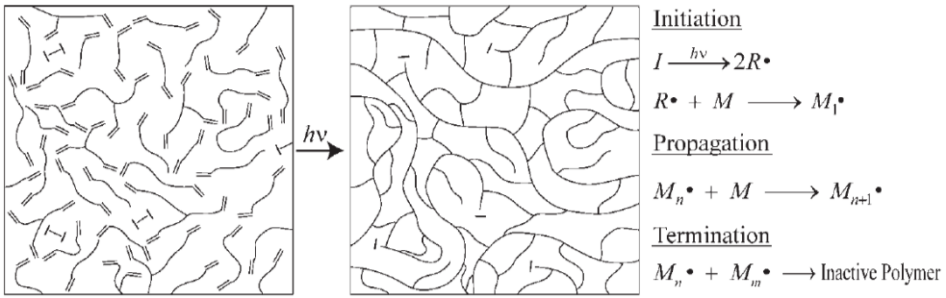
- Models are needed to understand and improve:

  Process conditions to meet or contribute to the object specifications

  *Material compositions t*o meet or contribute to the object specifications

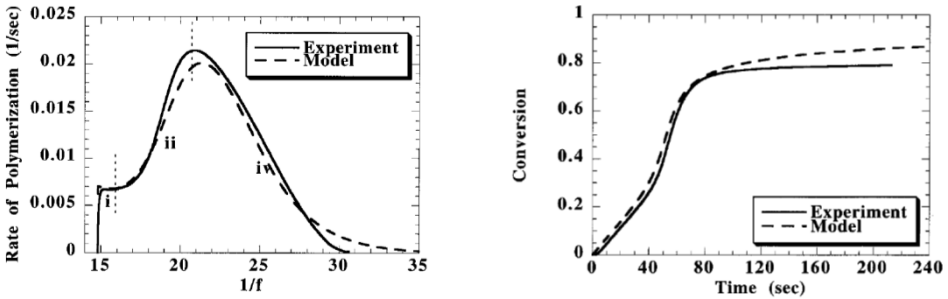
Photo-polymerization in SLA/DLP

- SLA: Stereolithography Apparatus; DLP: Digital Light Printing
- The photo-polymerization is the core of SLA/DLP technology.



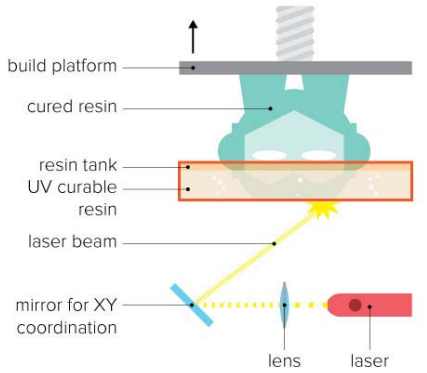
C.N. Bowman and C.J. Kloxin, 2008

- The double-bond conversion can be used to present the reaction.



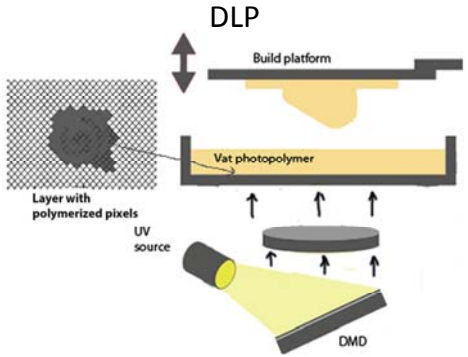
M.D. Goodner H.R. Lee and C.N. Bowman, 1997

SLA



©http://rookieelectronics.com/3d-printing-technologies-types/

DLP



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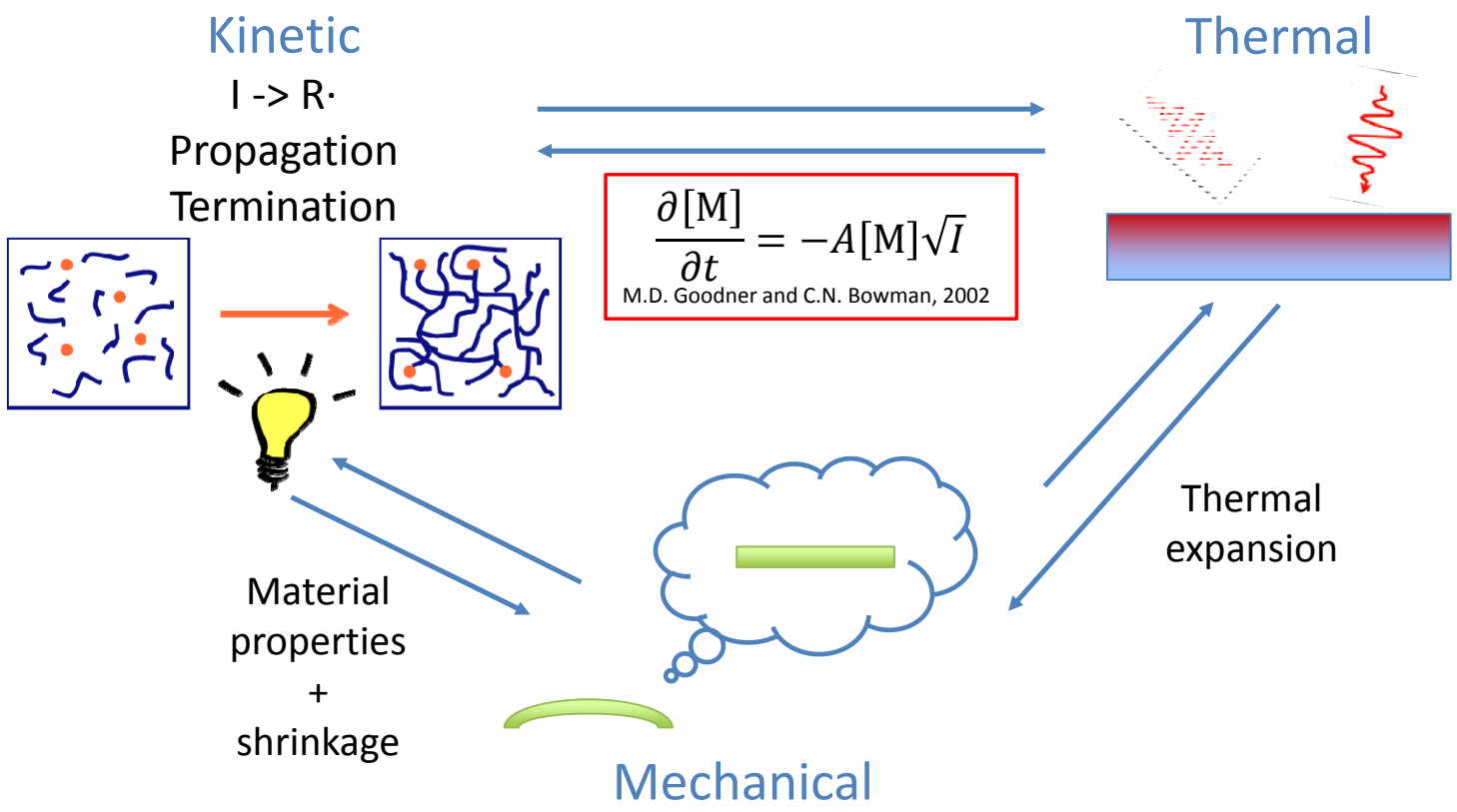
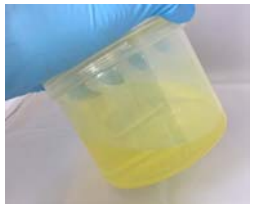
Multiphysics Modelling



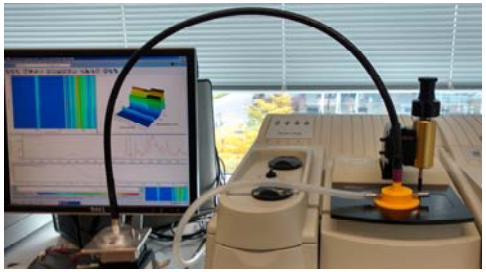
- Heat Transfer in Solids *(ht)*
  - Domains
    - Solid 1
    - Initial Values 1
    - Heat Transfer in Solids - Material
    - Heat Source - Light
    - Heat Source - Reaction
- Solid Mechanics *(solid)*
  - Domains
    - Linear Elastic Material 1
    - Initial Values 1
    - Linear Elastic Material - Material
- Photopolymerization, no diffusion *(dode)*
  - Domains
    - Distributed ODE 1
    - Initial Values 1
- Beer-Lamber Law *(cdeq)*
  - Domains
    - Convection-Diffusion Equation 1
    - Initial Values 1
- Multiphysics
  - Thermal Expansion 1 *(te1)*
  - Temperature Coupling 1 *(tc1)*
  - Thermal Expansion 2 *(te2)*

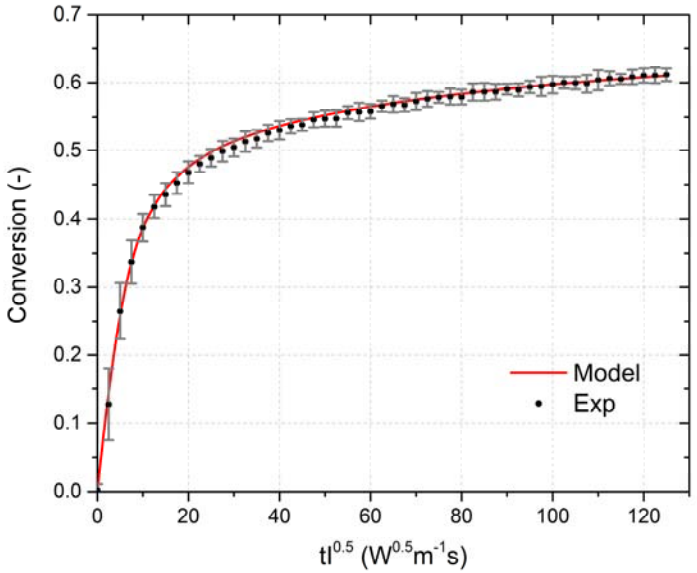
Material Characterization



- Parameters of the kinetics model are obtained based on the experiments.

In-situ FTIR

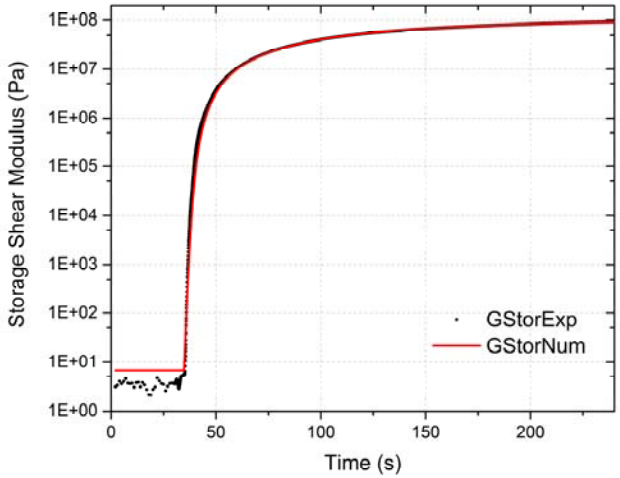




Material Contents

	Property	Variable	Value	Unit	Property group
☑	Density	rho	rho_t	kg/m³	Basic
☑	Heat capacity at constant pressure	Cp	Cp_t	J/(kg·K)	Basic
☑	Thermal conductivity	k_iso ; ki...	k_t	W/(m·K)	Basic
☑	Coefficient of thermal expansion	alpha_is...	alpha_t	1/K	Basic
☑	Bulk modulus	K	Km_t	N/m²	Bulk modulus and shear modu...
☑	Shear modulus	G	Gm_t	N/m²	Bulk modulus and shear modu...
	Poisson's ratio	nu	nu_t	1	Basic
	Young's modulus	E	Em_t	Pa	Basic

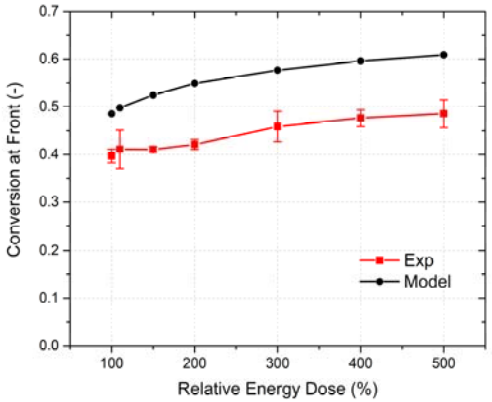
Rheometer

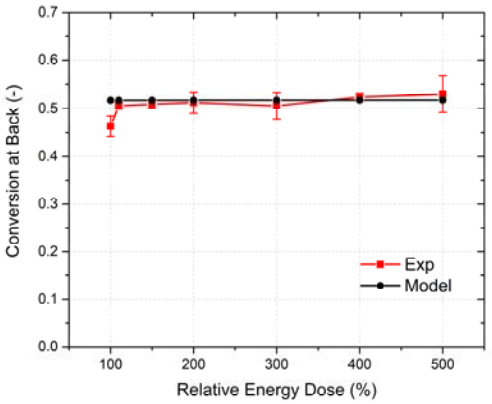


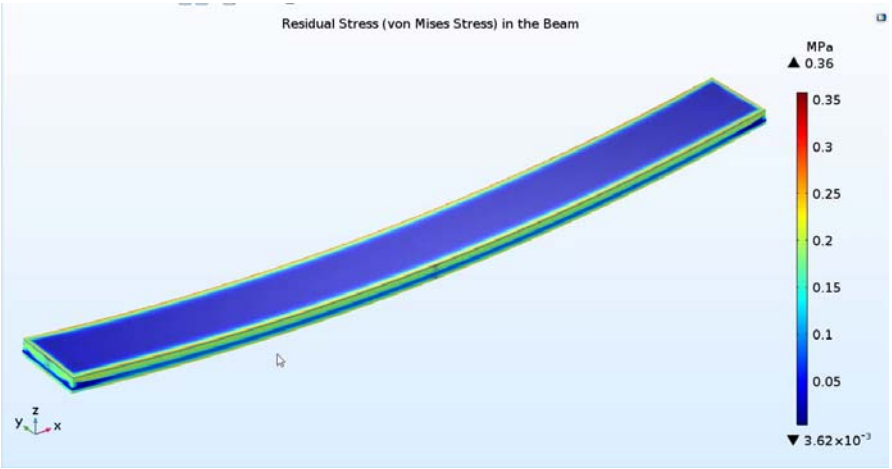
Experimental Validation

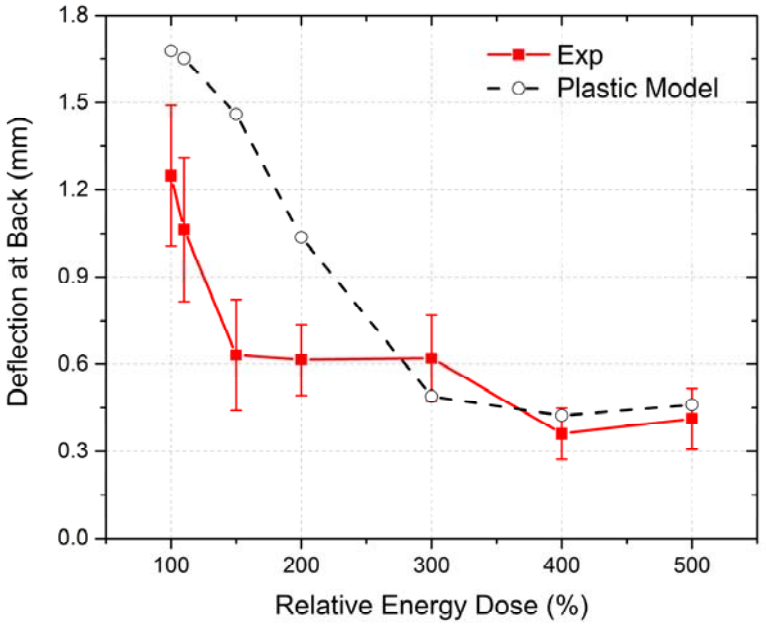
Adjust the exposure time of the **last layer**.

UV









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Conclusions and Outlook

- With COMSOL, a Multiphysics model was developed to investigate effects of **process conditions** and **material compositions** on **deformation** and **residual stress** of a **multi-layered DLP-printed** product.
- Required parameters can be obtained based on commercial-available experimental set-up. It gives a possibility for **standardization**.
- Validation showed a **good agreement** if a non-linear material model (plasticity) was adopted.
- We are
  - improving process conditions and new designs based on the developed model.
  - improving the accuracy and the computational cost of the model.
  - applying this model to other photo-polymers.
  - …

Thank you for your attention!

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