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On Interply friction in prepreg forming simulations

Sidd K[1], Abhik Dutta[2], Mats Landervik[3], Anders Bernhardsson[3], Malin Åkermo[2]

[1] : Volvo Car Corporation

[2] : KTH Royal Institute of Technology

[3] : DYNAmore Nordic AB

2021-10-28

Prepreg compression moulding

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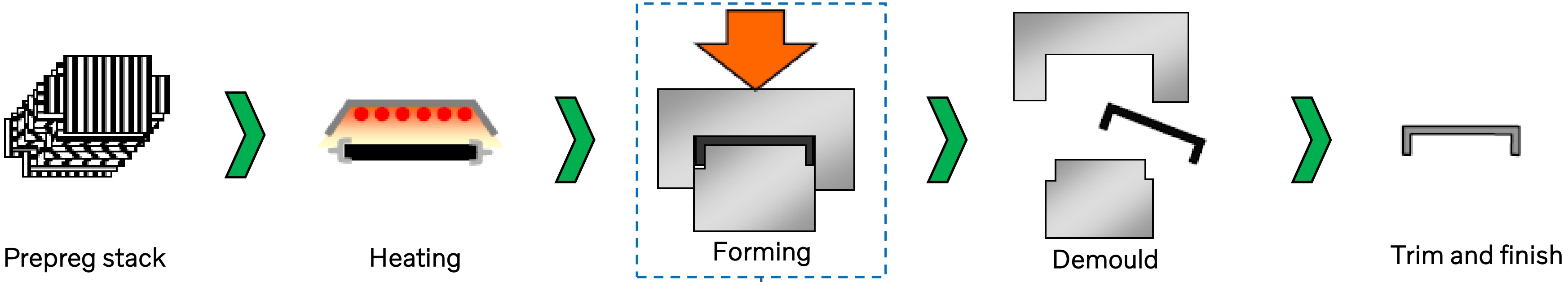
High level of automation

Higher volumes

Possible to co-process cheaper material systems. Eg, SMC

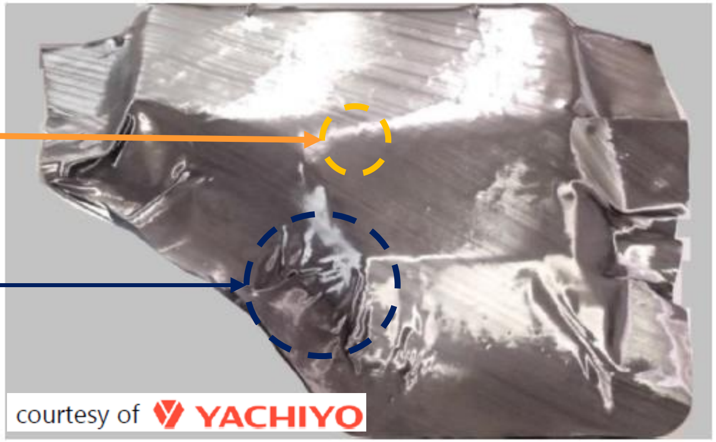


Courtesy of Mitsubishi Rayon

Defect

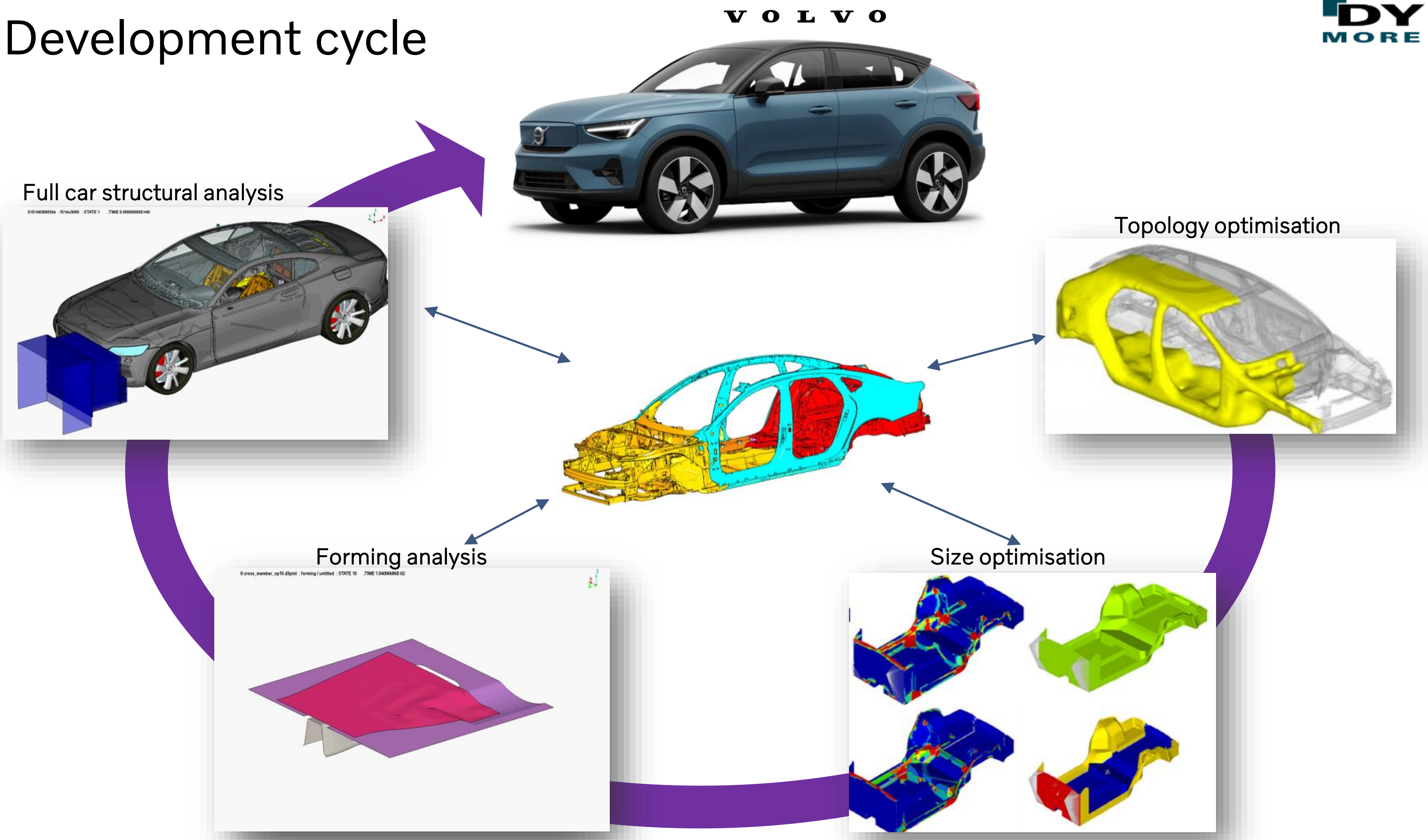
Fiber angle deviation

Wrinkles



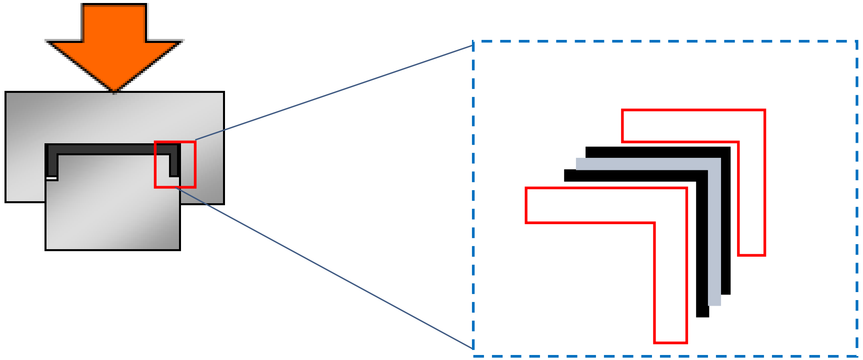
Process modelling is essential to predict and eliminate Forming induced defects

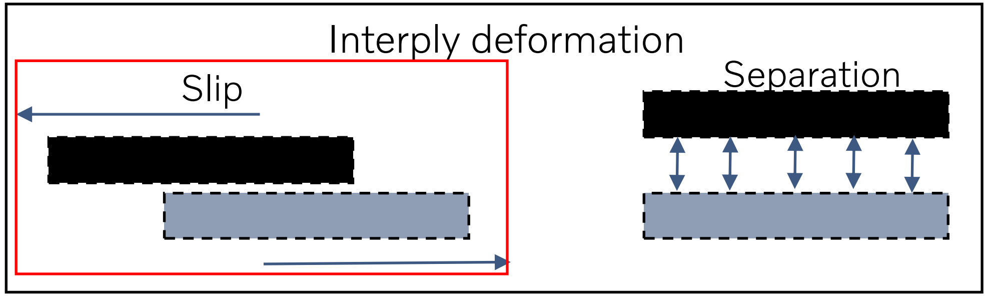
Development cycle

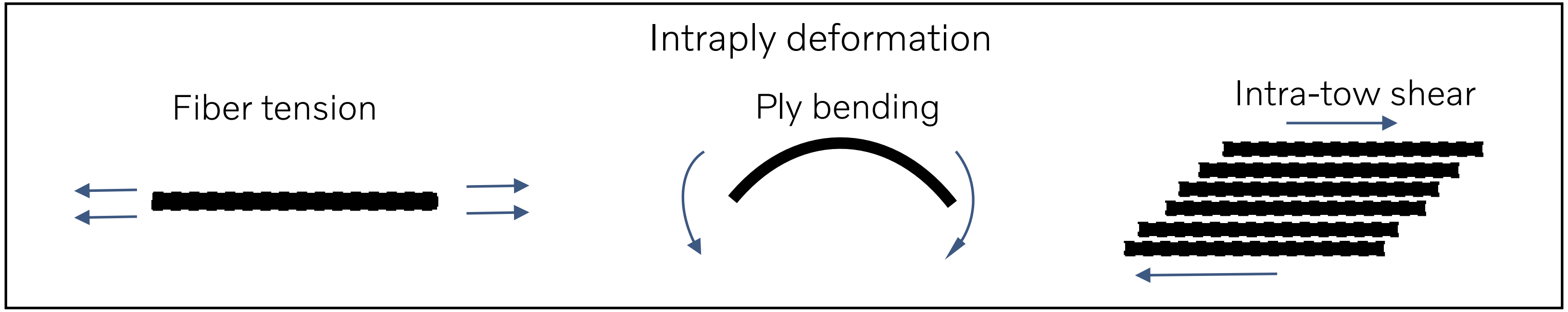


Deformation mechanism

Continuous fiber reinforced prepregs







Modelling Technique

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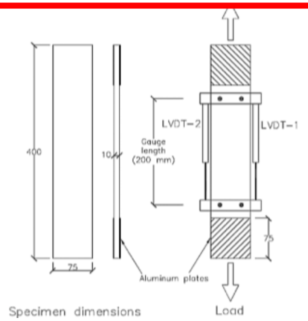
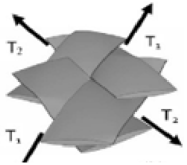
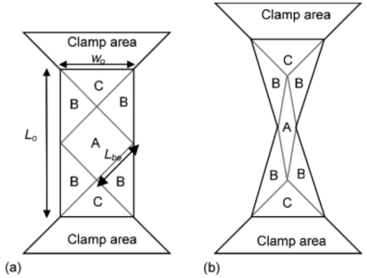
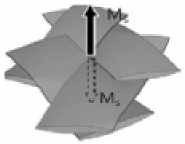
Intraply deformation modes



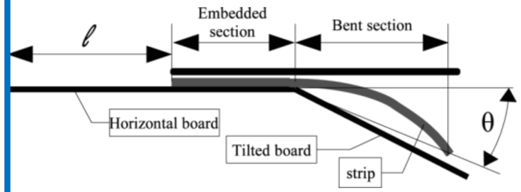


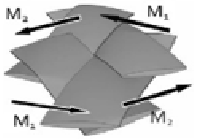
Axial tension





In- plane shear





Bending moments

$$\begin{Bmatrix}\sigma_{11}\\ \sigma_{22}\\ \sigma_{12}\\ m_{11}\\ m_{22}\\ m_{12}\end{Bmatrix} = \begin{pmatrix} f1 & 0 & 0 & 0 & 0 & 0\\ & f2 & 0 & 0 & 0 & 0\\ & & f12 & 0 & 0 & 0\\ & & & g1 & 0 & 0\\ & & & & g2 & 0\\ & & & & & g12\end{pmatrix} \begin{Bmatrix}\varepsilon_{11}\\ \varepsilon_{22}\\ \gamma_{12}\\ \kappa_{11}\\ \kappa_{22}\\ \kappa_{12}\end{Bmatrix}$$

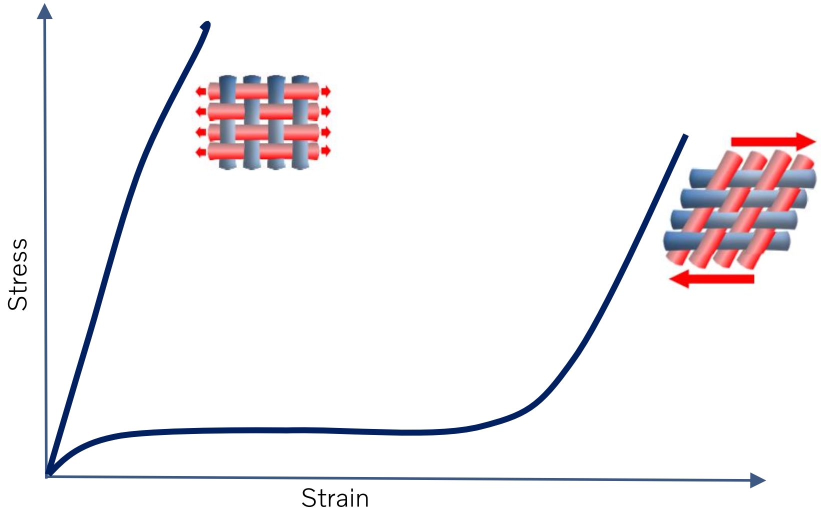
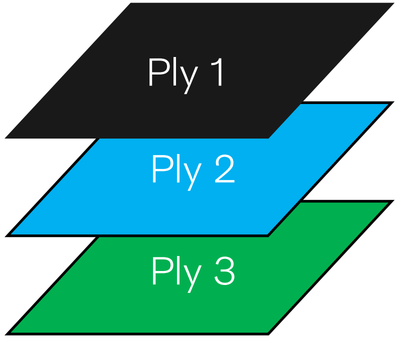


Image source: Zhang et al[6]

Modelled using *MAT_THERMOPLASTIC_COMPOSITE (249)

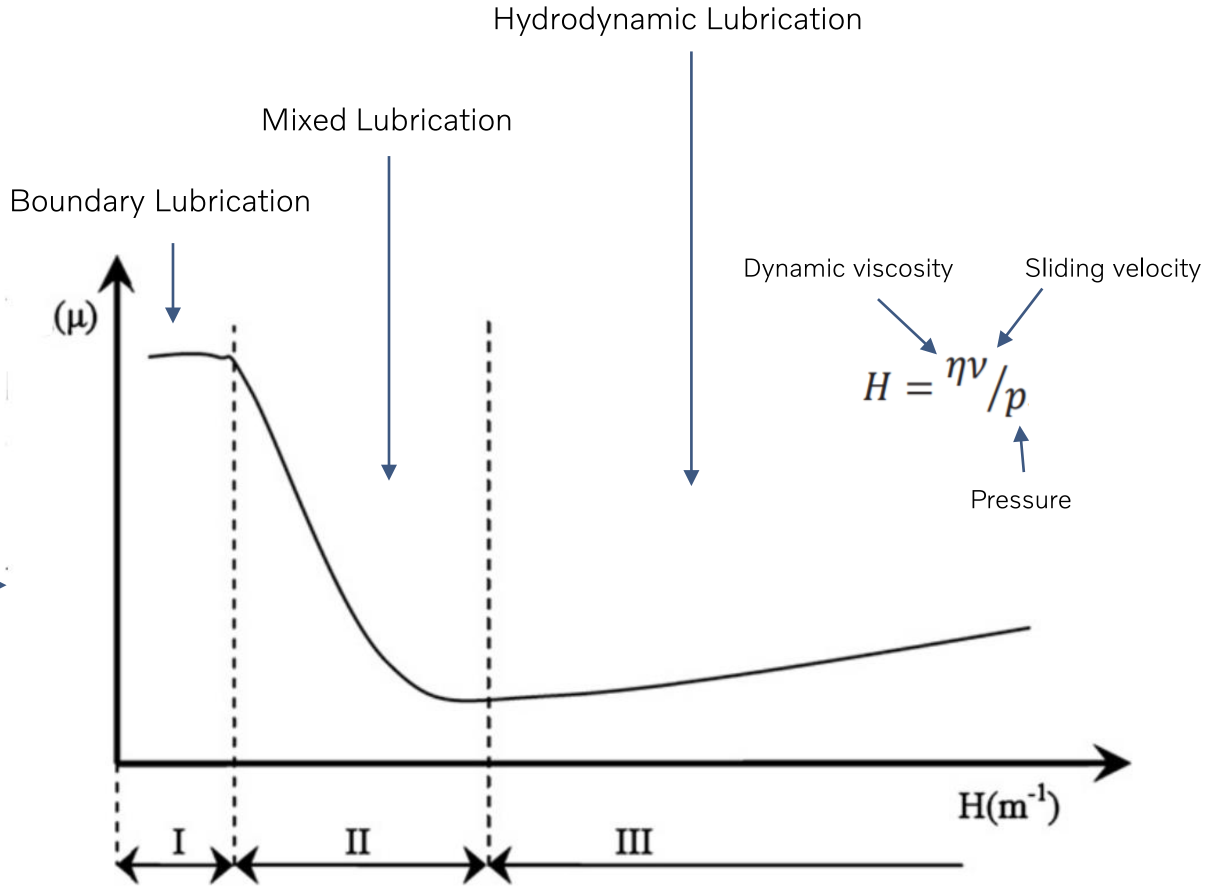
Interply friction: State of the art

Stacked shell model in contact



State of the art friction models capture dependency of

- Pressure
- Viscosity
- Slip rate



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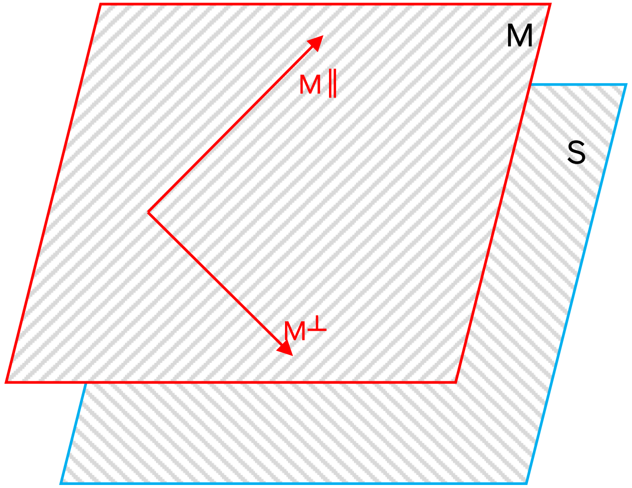
Interply friction

What about the effect of fiber orientations?

$M_{\parallel}$ is the primary material direction in Surface M
$S_{\parallel}$ is the primary material direction in Surface S



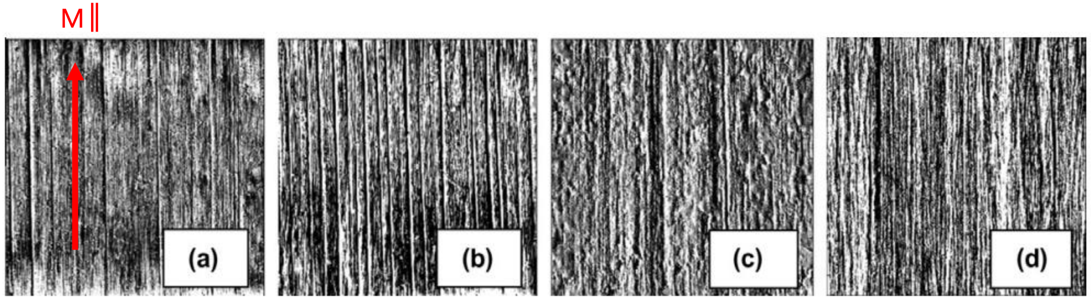


Image courtesy of Larberg et al[5] showning surface topologies of different prepregs at elevated temperatures

Interply friction has a dependency on fiber angles in consecutive layers!

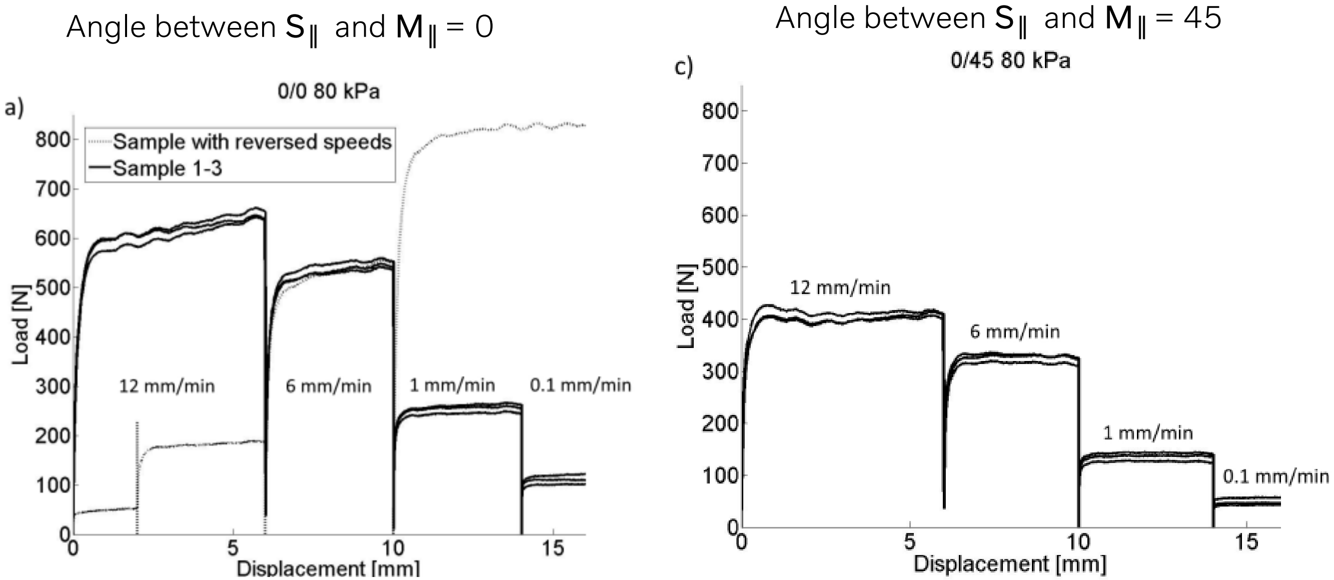


Image courtesy: Sjölander et al

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Orthotropic friction

*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ORTHO_FRICTION

Implemented by Thomas Borrvall, DYNAmore Nordic

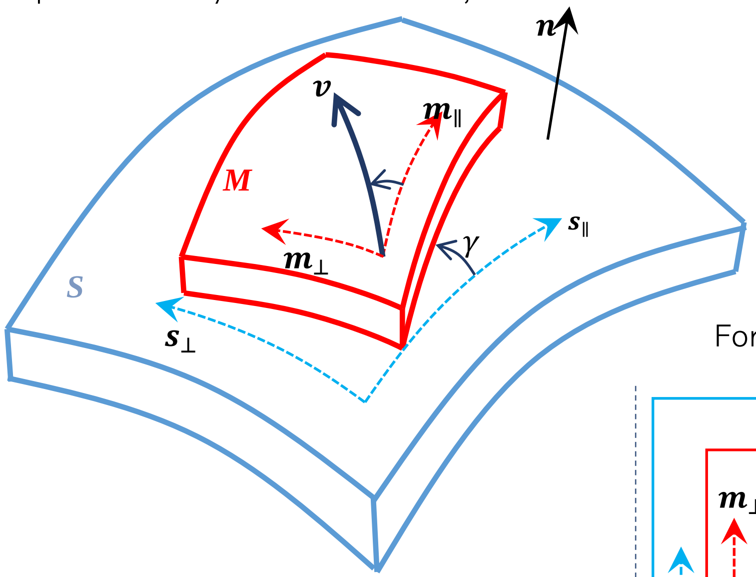
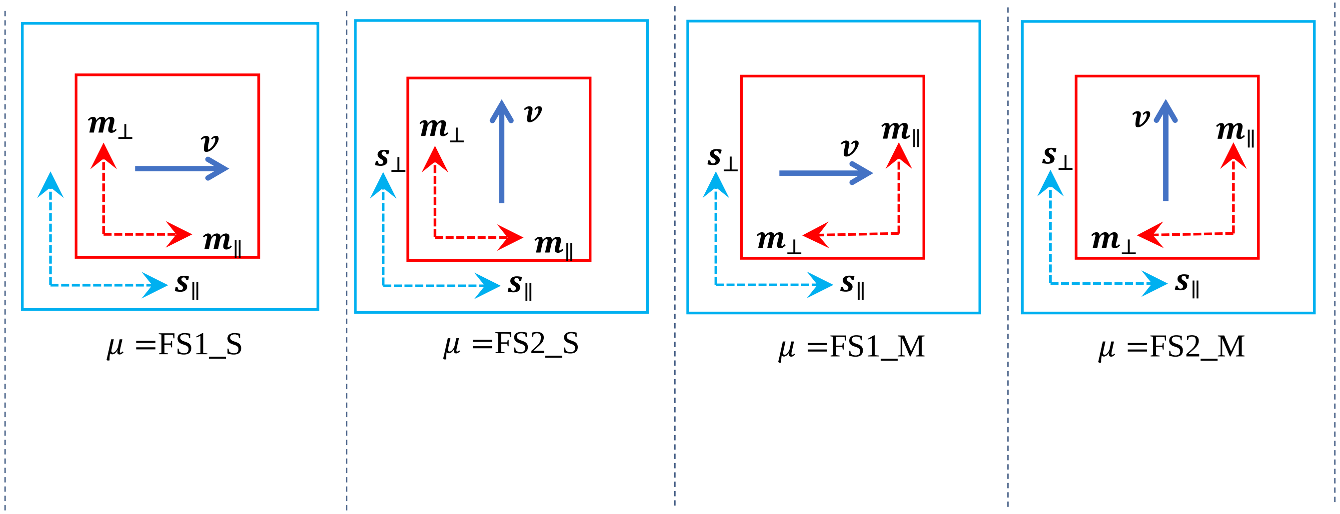


Image from User manual[1]

Parameters that affect Interply friction

- Difference in primary orientation of the consecutive layers (γ)
- Direction of sliding ($\boldsymbol{v}$)
- Slip rate
- Consolidation pressure

For a given pressure and slip rate, the orthotropy in friction is characterized by 4 values



In order to capture the effect of pressure and slip rate, each of these friction values can be represented by *DEFINE_TABLE_2D_TITLE

Material testing

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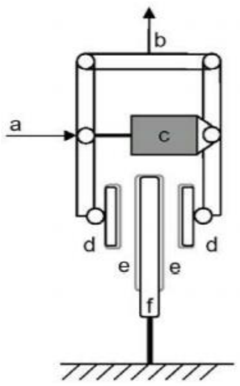
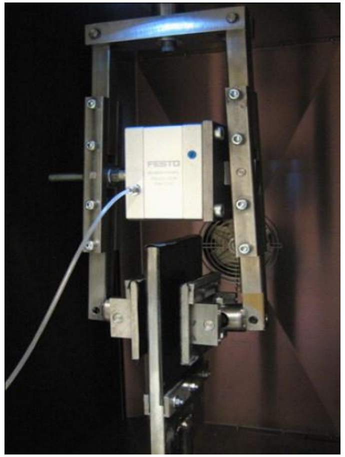
Friction testing rig at KTH



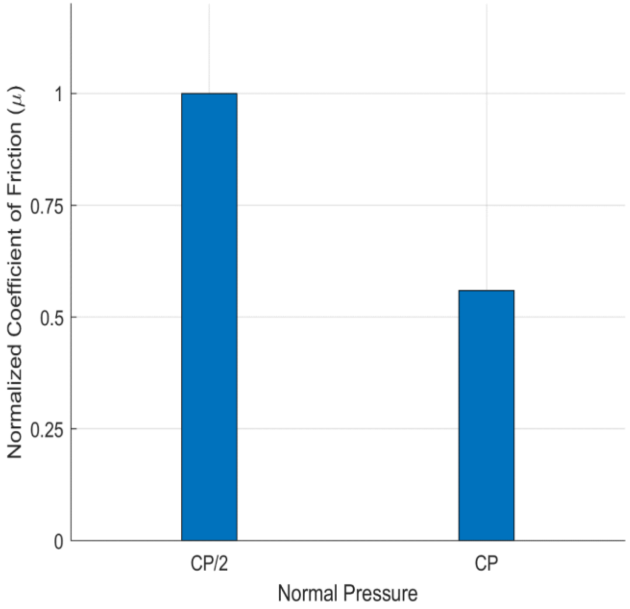


Courtesy of Larberg et al[5]

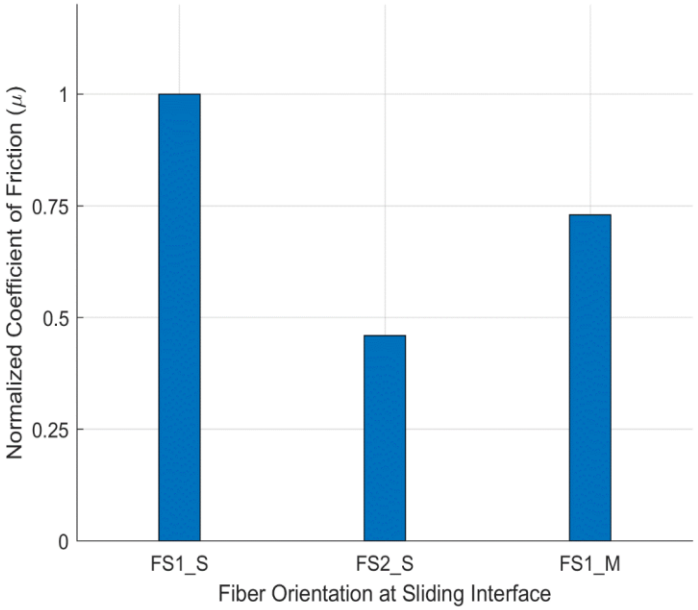
Test data

Normalised data

Effect of consolidation pressurre on co-efficient of friction

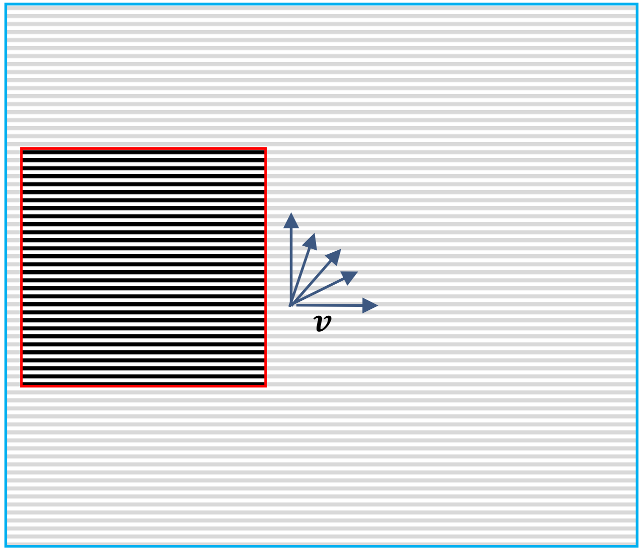


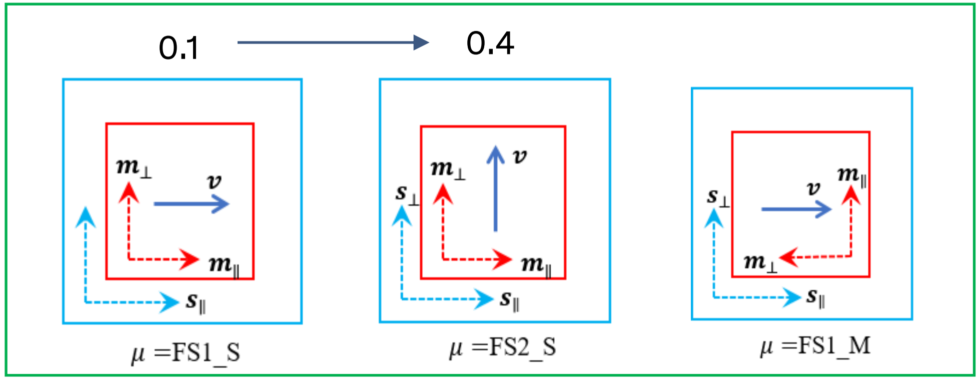
Effect of orientation difference $S_{\parallel}$ and $M_{\parallel}$ on co-efficient of friction

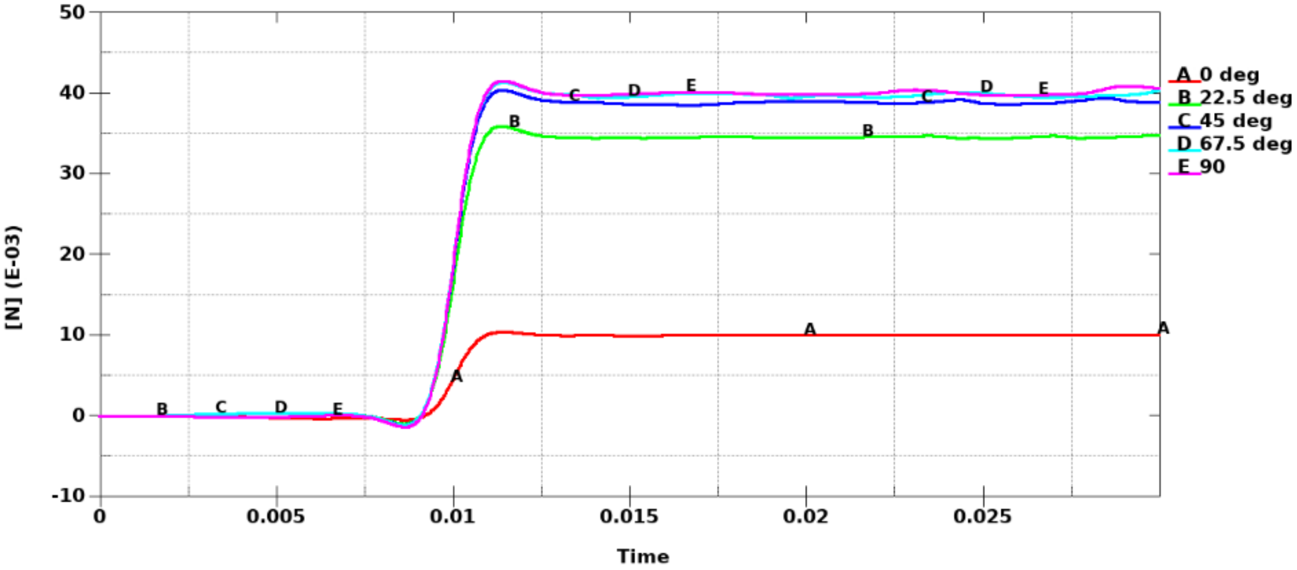


Example: Interply sliding

Angle between $S_{\parallel}$ and $M_{\parallel} = 0$







Changing the direction of sliding while keeping the pressure and speed constant.

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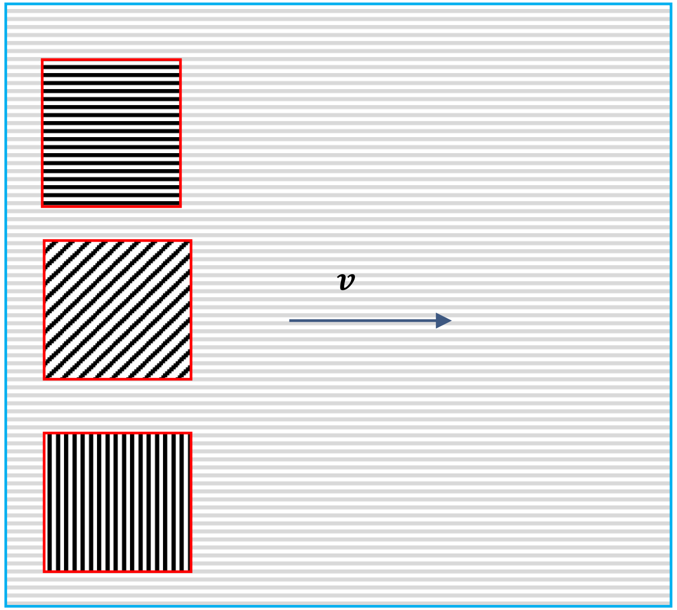
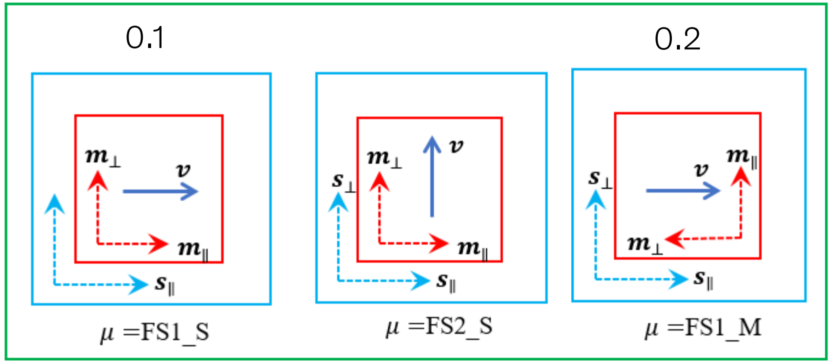
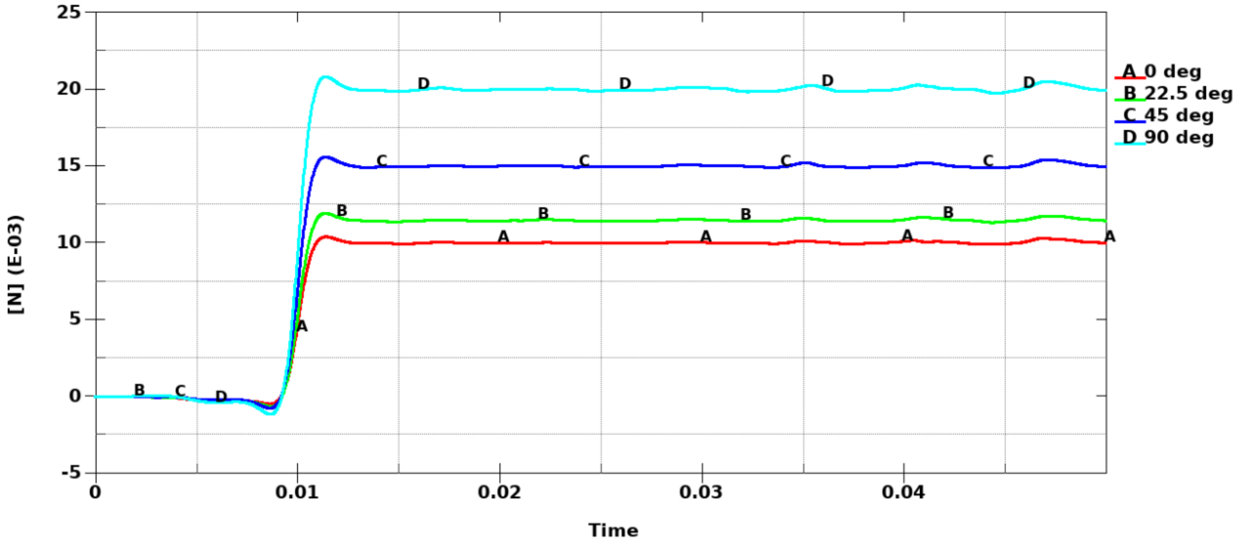
Example: Interply sliding

Angle between $S_{\parallel}$ and $M_{\parallel}$ varied from 0^0 to 90^0







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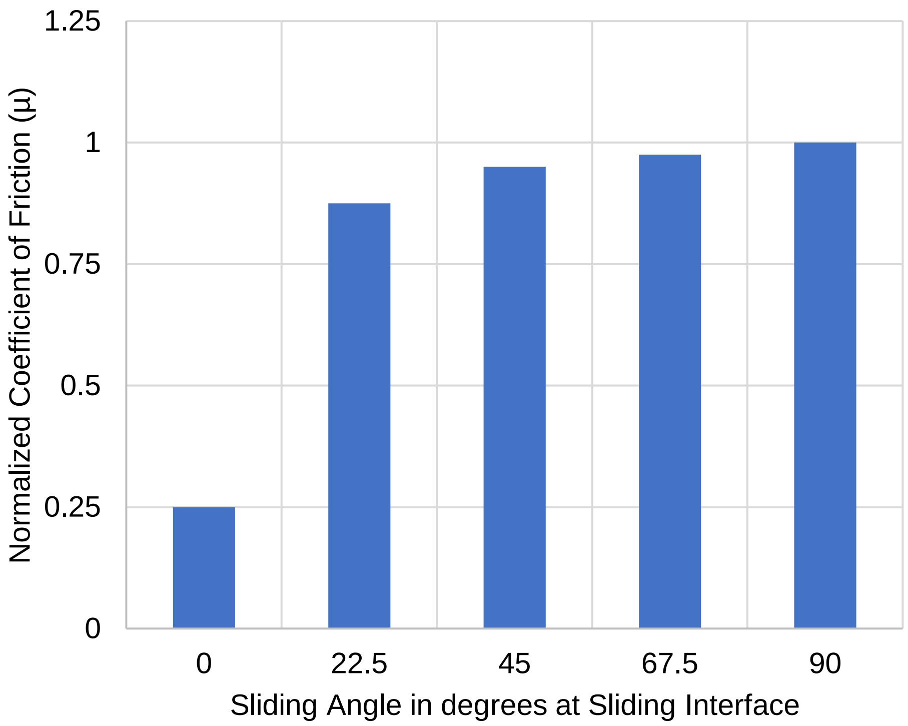
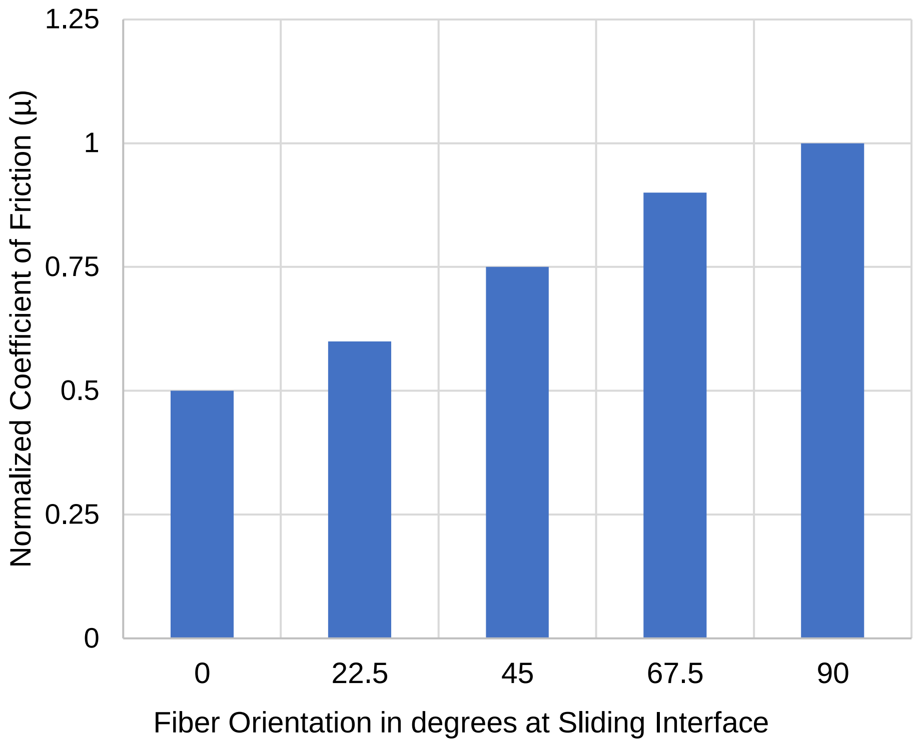
Interpolation

Elliptical interpolation for fixed angle between $S_{\parallel}$ and $M_{\parallel}$ with varying $\boldsymbol{v}$



Linear interpolation for varying angle between $S_{\parallel}$ and $M_{\parallel}$ with fixed $\boldsymbol{v}$



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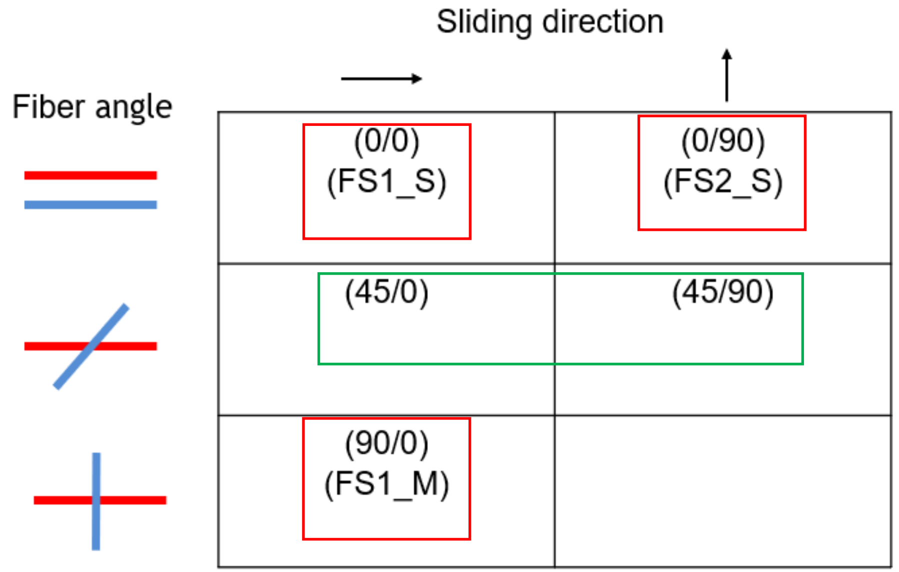
Correlation to physical tests

Normalised data

Experimentally obtained: Input values

Interpolated values



Sliding interface	Physical test	Simulation
(0/0)	1	1
(0/90)	0.47	0.47
(45/0)	0.72	0.87
(45/90)	0.63	0.61
(90/0)	0.74	0.74

Satisfactory correlation is observed for both defined and interpolated cases.

Virtual Demonstrator

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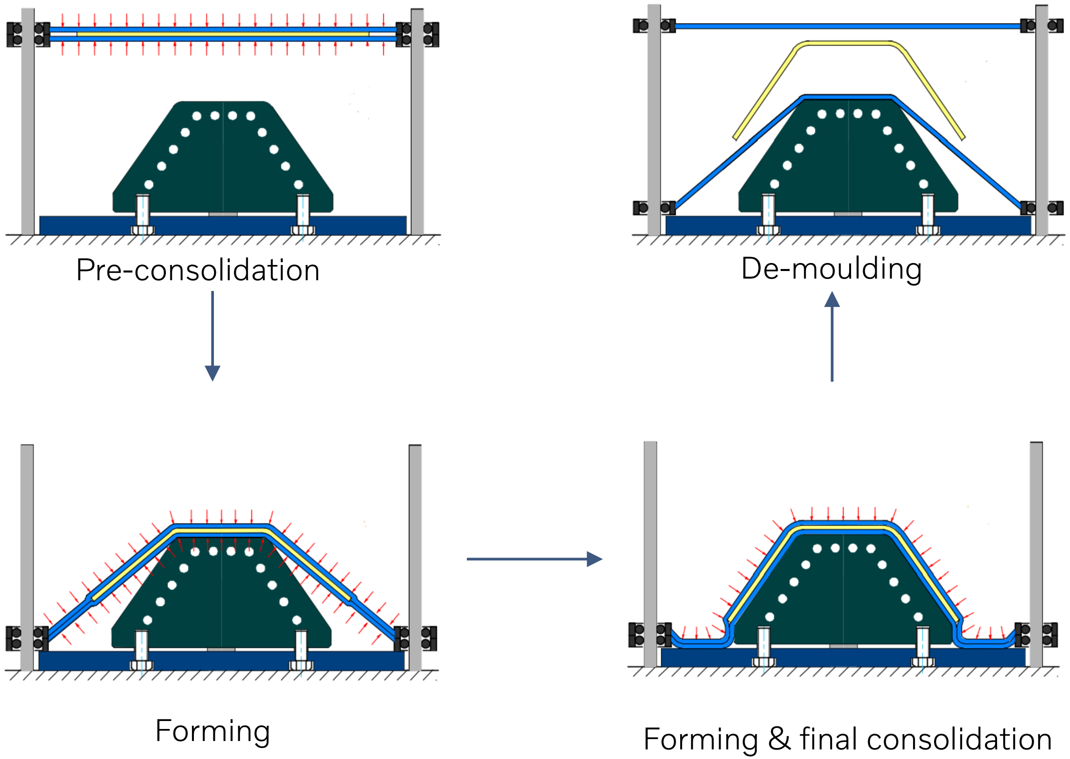
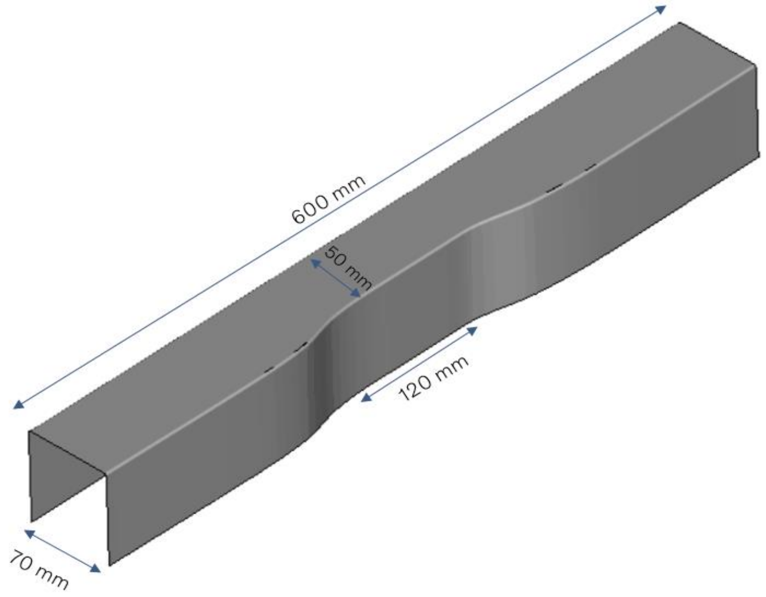
Virtual demonstrator

Process: Vaccuum assisted Diaphragm Forming



Demonstrator geometry



Joggled beam to trigger defects

Stacking sequence → UD plies → $(+45/-45/0/0)_s$

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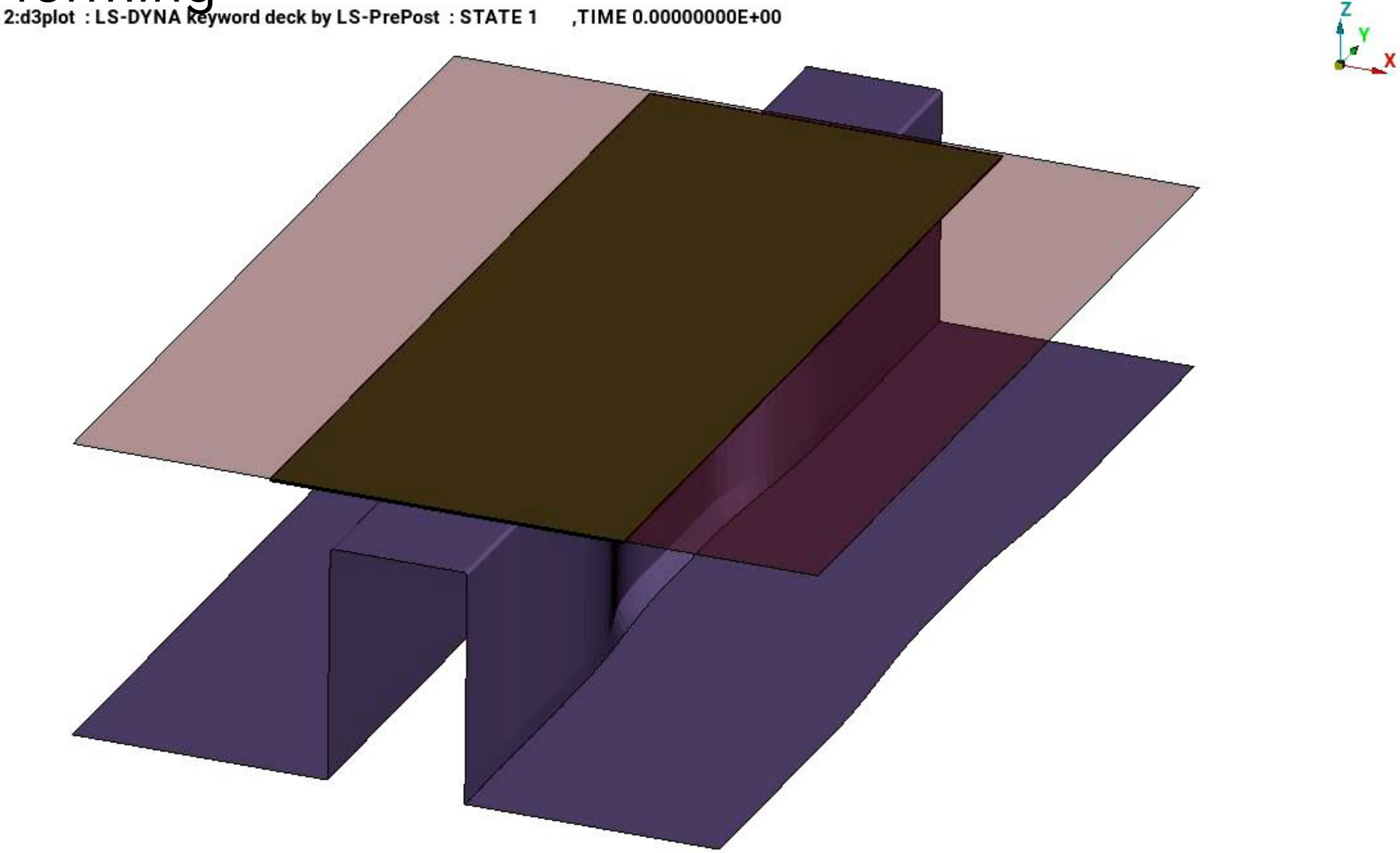
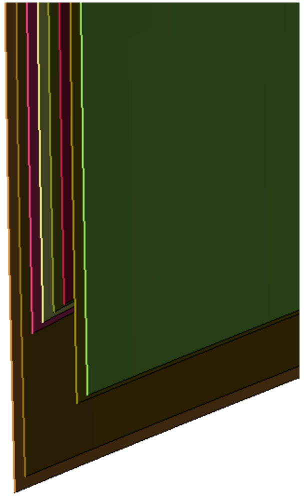
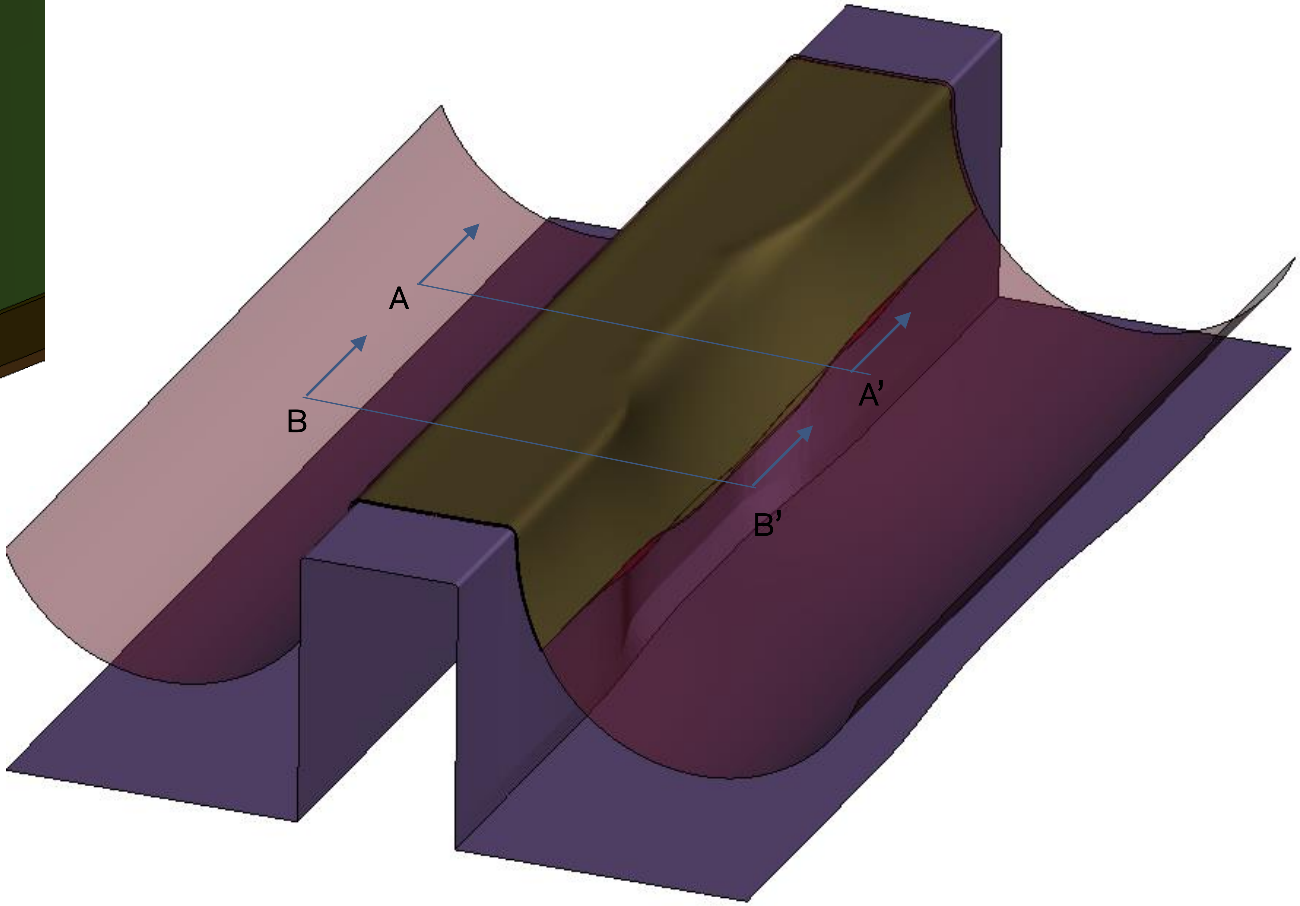
Diaphragm forming

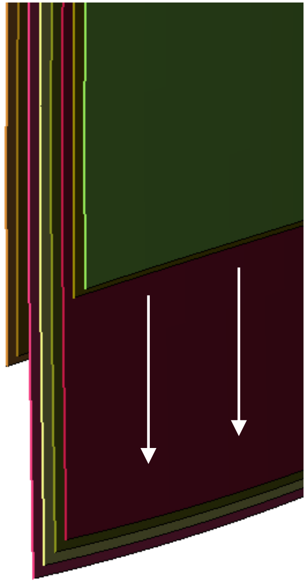


Diaphragm forming



Section A-A'





Section B-B'

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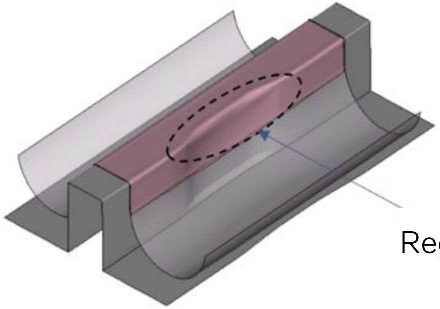
Demonstrator : Contact benchmark

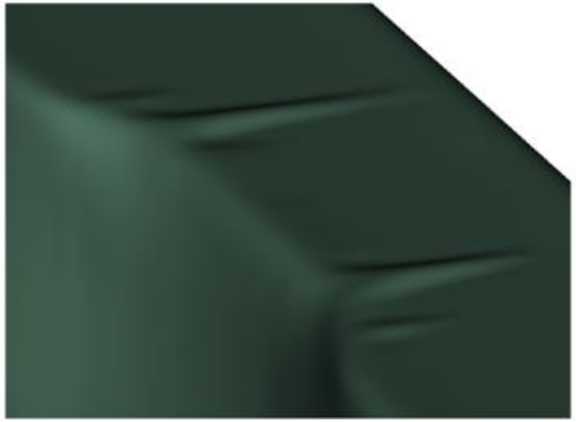


Region of interest

*CONTACT_AUTOMATIC
_SURFACE_TO_SURFACE_MORTAR

No wrinkles

*CONTACT_AUTOMATIC
_SURFACE_TO_SURFACE_MORTAR
with pressure dependency

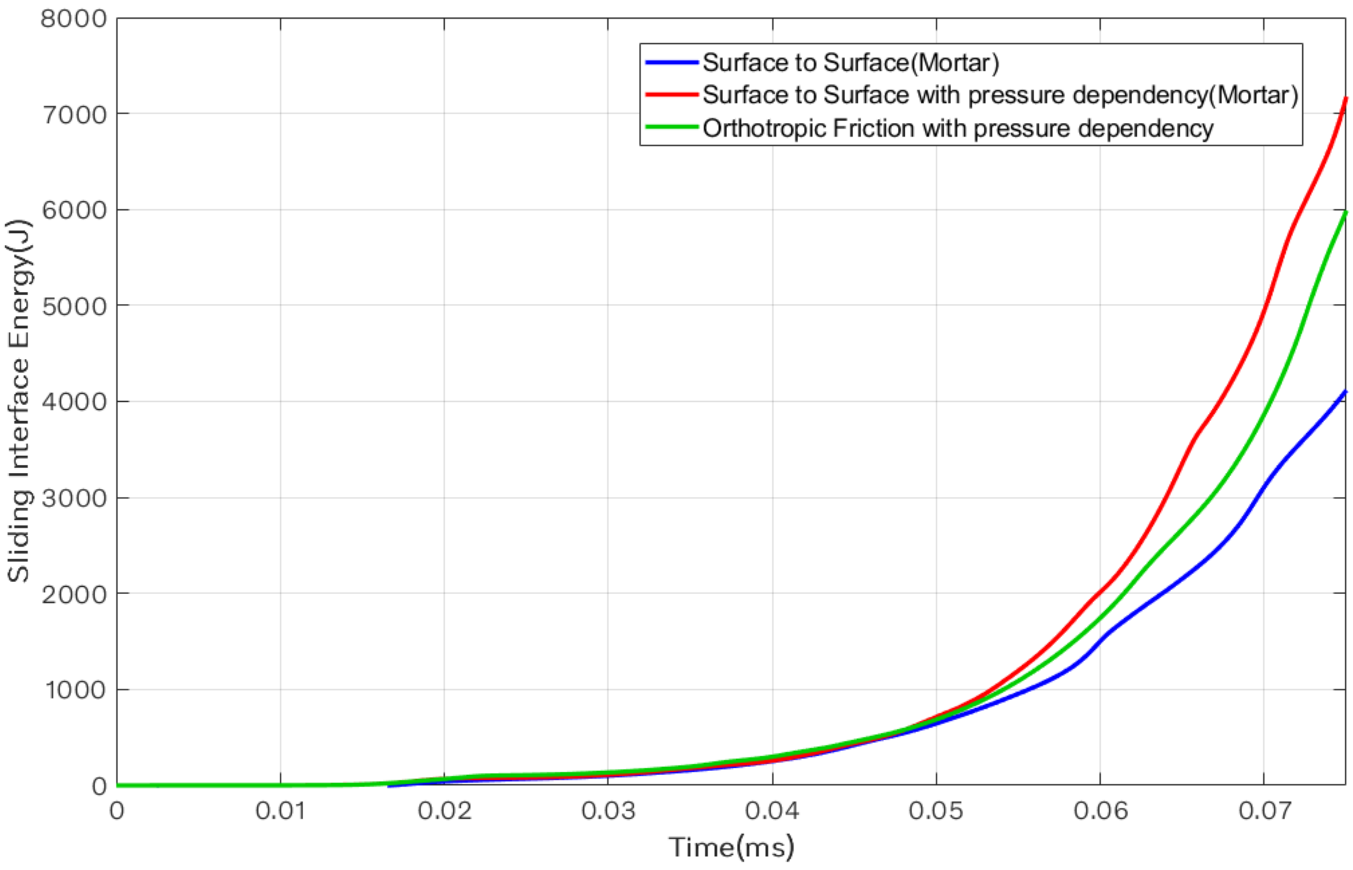


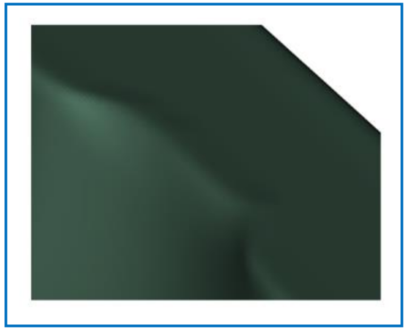
Large wrinkles

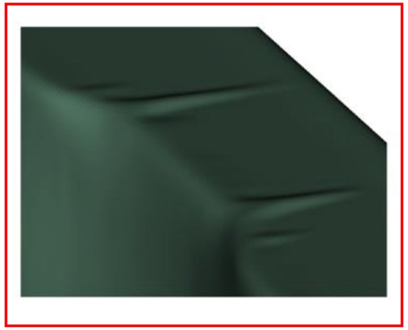
*CONTACT_AUTOMATIC
_SURFACE_TO_SURFACE_MORTAR_
ORTHO_FRICTION

Minor wrinkles

Sliding interface energies

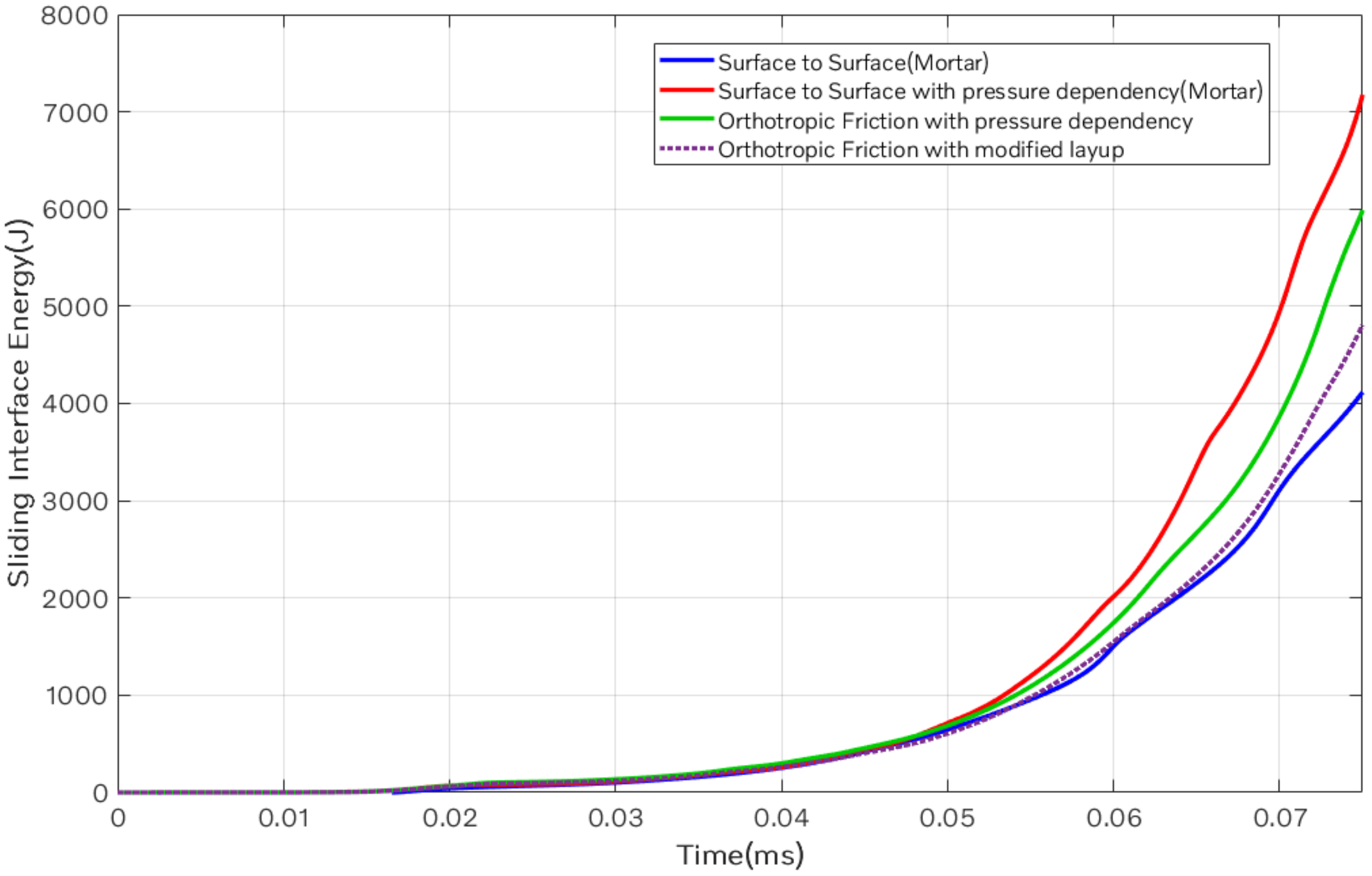






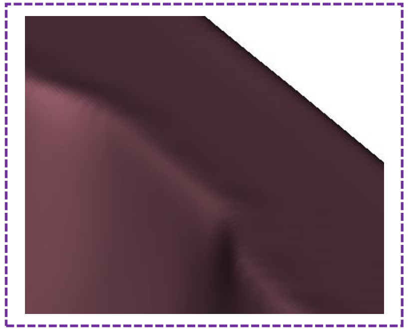
Sliding interface energies

Effect of changing stacking sequence



Lay-up: $(+45/-45/0/0)_s$

Lay-up: $(0/90/0/90)_s$



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Summary

- Orthotropic friction with pressure dependence is implemented in a Mortar contact in LS-Dyna
- The model is evaluated against physical tests and shows satisfactory correlation
- Virtual trials show were used to compare different contact formulations.

Next steps

- Investigate effects of different prepreg architectures
- Correlation to physical tests on a Body-in-white component.

Thank you!

References

[1] LS-DYNA® KEYWORD USER'S MANUAL, VOLUME I, 05/06/21 (r:13750), LS-DYNA Dev, LIVERMORE SOFTWARE TECHNOLOGY (LST), AN ANSYS COMPANY.

[2] Sjölander J: PhD dissertation, “Improving Forming of Aerospace Composite Components through Process Modelling”, KTH 2018, ISBN 978-91-7729-881-6.

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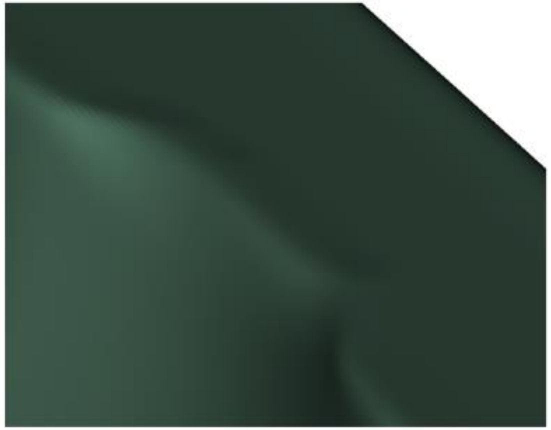
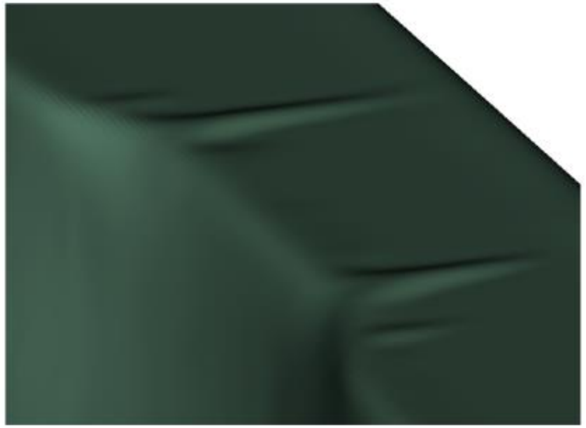
[7] Hallander P. Towards defect free forming of multi-stacked composite aerospace components using tailored interlayer properties [Internet] [PhD dissertation]. [Stockholm]; 2016. (TRITA-AVE). Available from: http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-185694



A
No-out of plane wrinkle



B
Large wrinkle

C
Minor wrinkle