Keys for designing the most efficient and robust in-situ TP ATP.

Marta PEREZ[1], Angel LEON[1], Cyril DEDIEU[1], Clara ARGERICH[1], Brigitte DEFOORT[2], Jean Marc DUPILLIER[2], Éric SOCCARD[3], Anaïs BARASINSKI[1], Francisco CHINESTA[4].

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IC3 2018 - Arcachon , 4 Juin 2018

Framework

WOLF TP Project (FUI 16), Macothec (FUI 14)

(Winding and Optimization Laser Thermoplastic Placement)

CIFRE PhD with Ariane Group

Modelisation & Simulation of the process

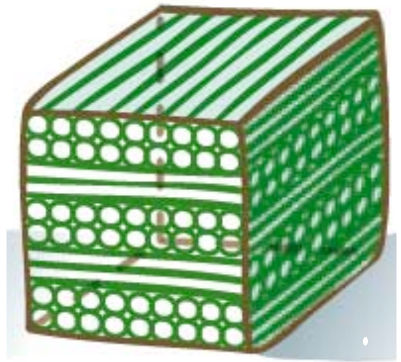
(Thermo-Mechanical - Micro Mechanical)

Applications

Need to manufacture complex form parts

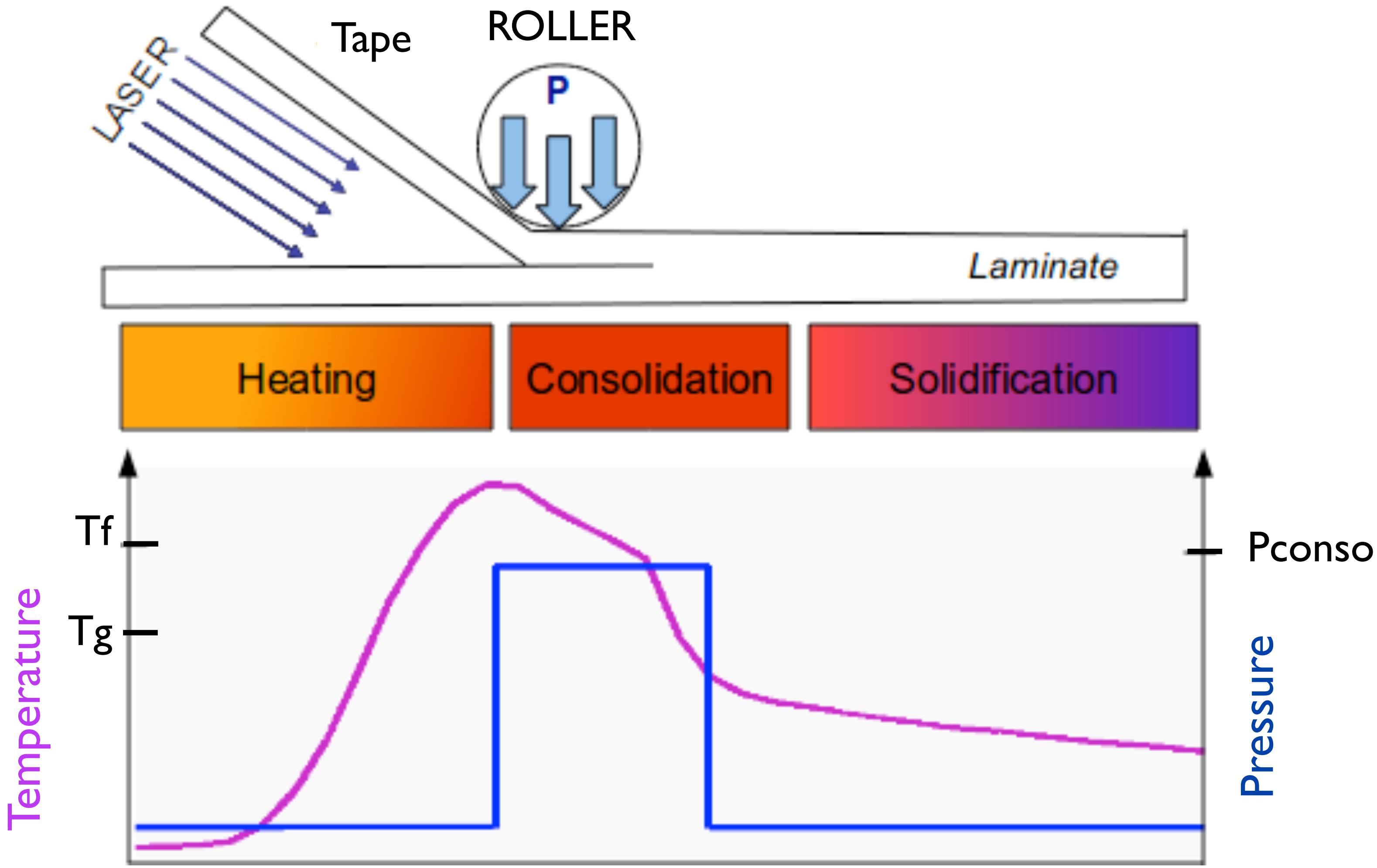
Laminated composite parts

Complex geometry



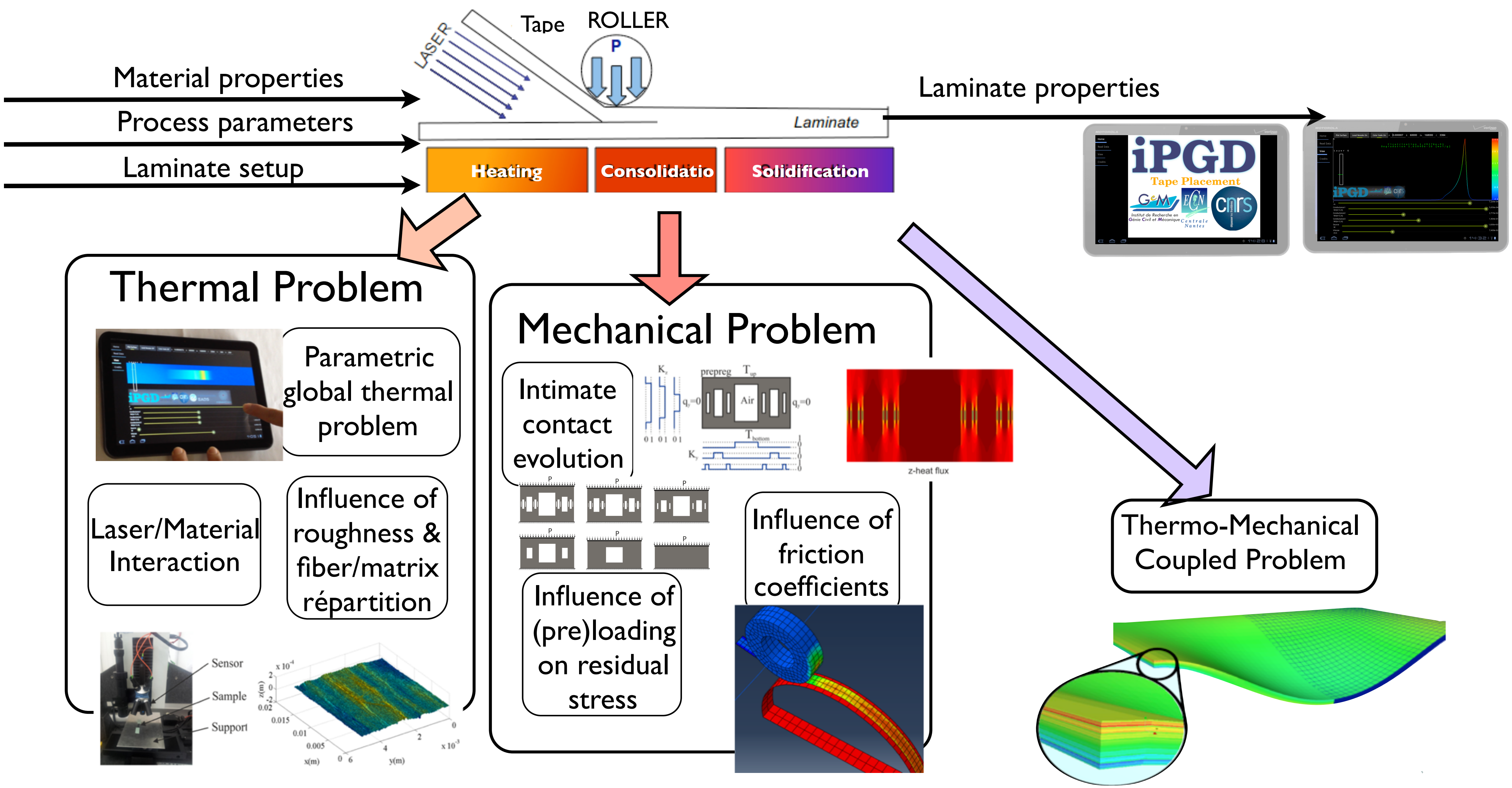
Identify the key parameters for efficient manufacturing

Comprehension ATP Process : Forming steps



Fusion Degradation	Adhesion	(re)Crystallisation Res Stress

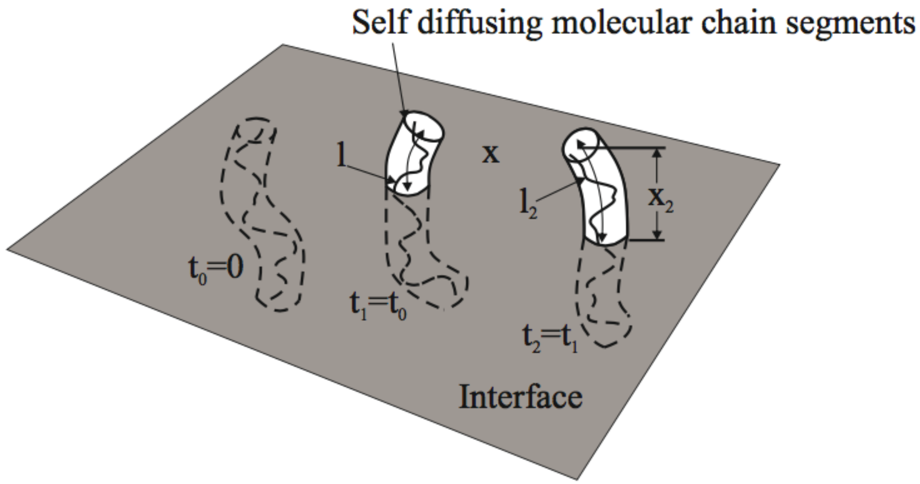
Automated Tape Placement - Overview



Also: Ray-Tracing 3D, Roller Compaction, Process variability,…

Framework Focus

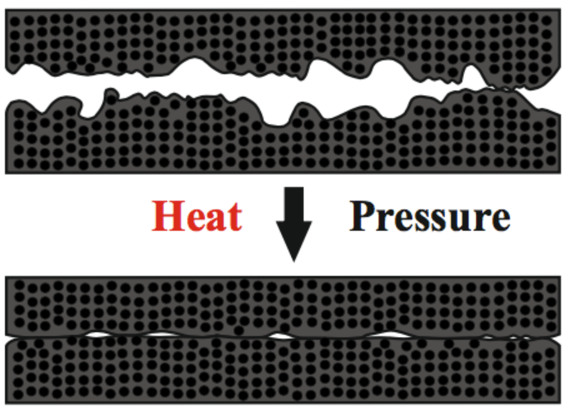
Healing



- Molecules diffuse across the interface
- Reptation theory depends on temperature

$$D_h = K(T) \cdot (t)^{1/4}$$

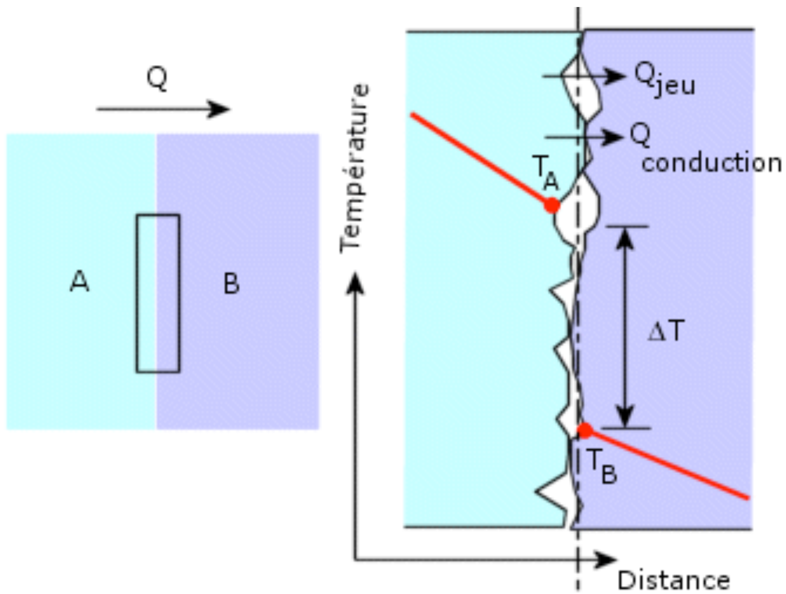
Intimate Contact

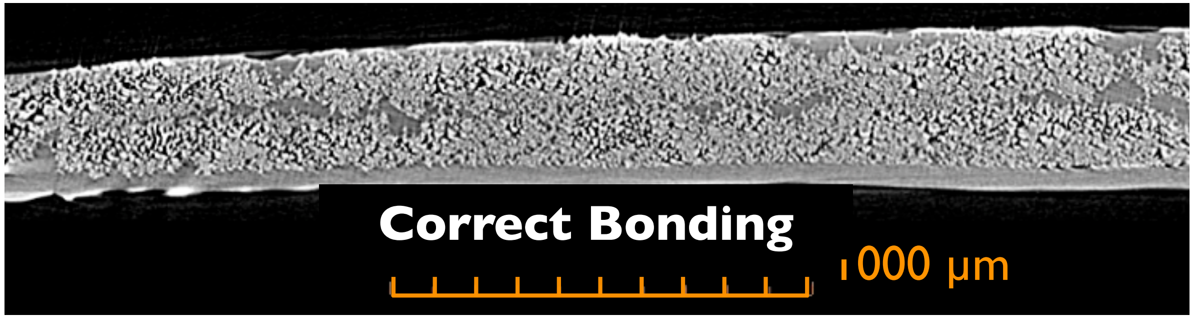


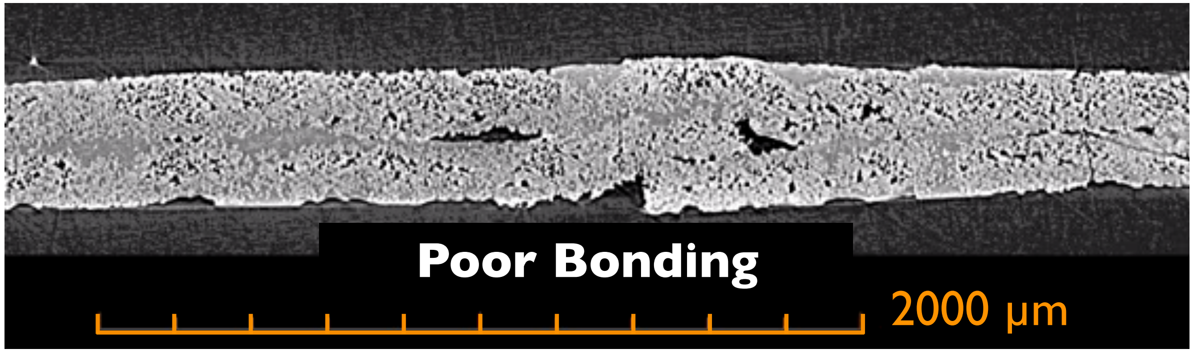
- Evolution of area in contact
- Viscosity depends on temperature

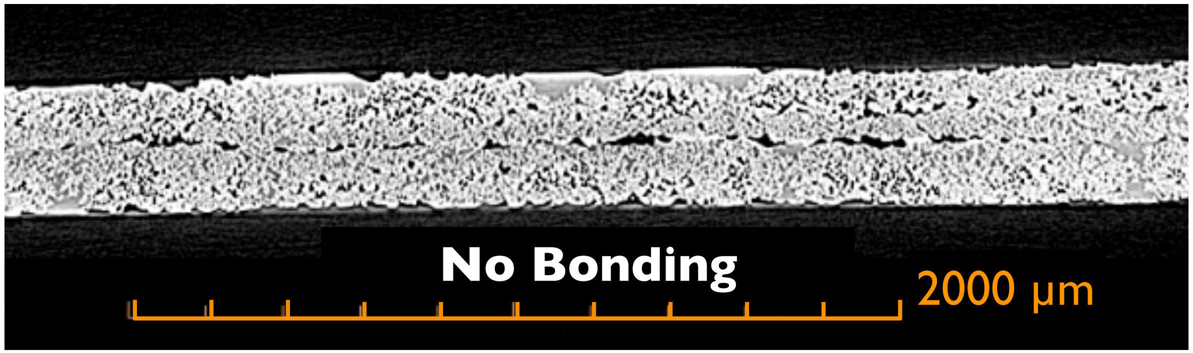
Main point to follow

Thermal contact resistance









Wavelet Representation

The interface can be represented in a set of basis that expresses the different levels (different scales) of the surface. Multilevel representation

$$V_m = V_0 \oplus W_1 \ldots W_{m-3} \oplus W_{m-2} \oplus W_{m-1} \oplus W_m$$

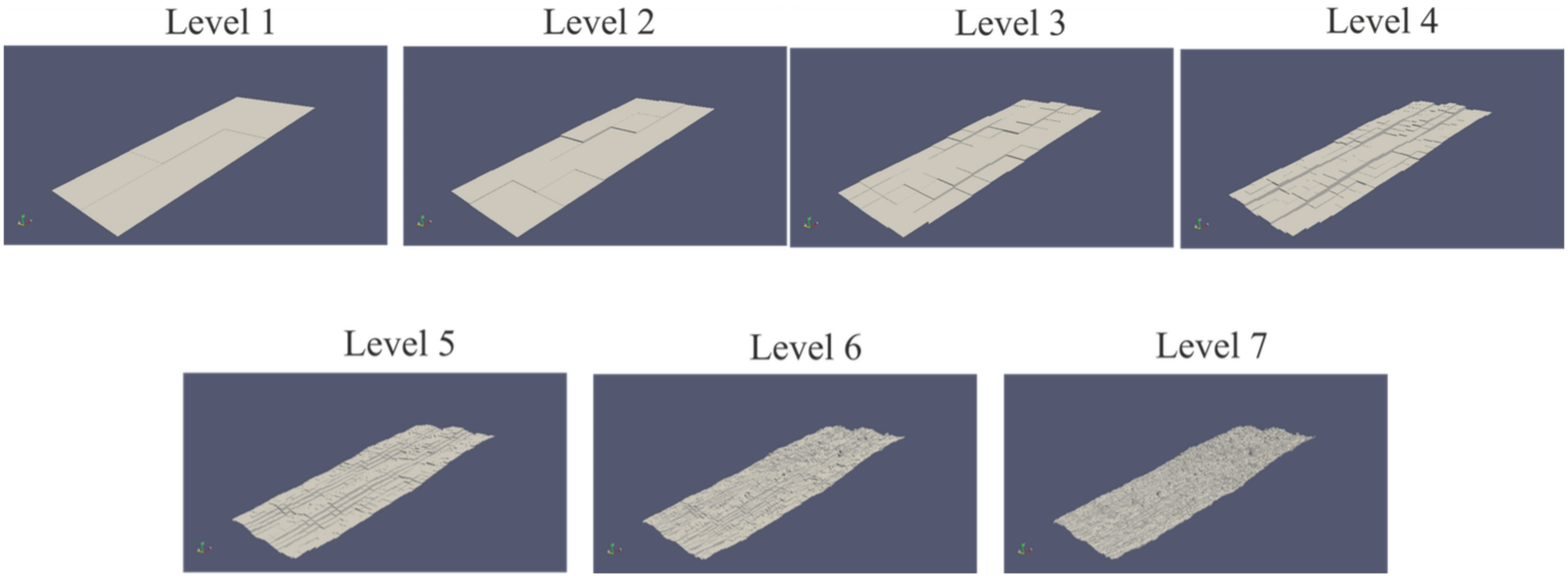
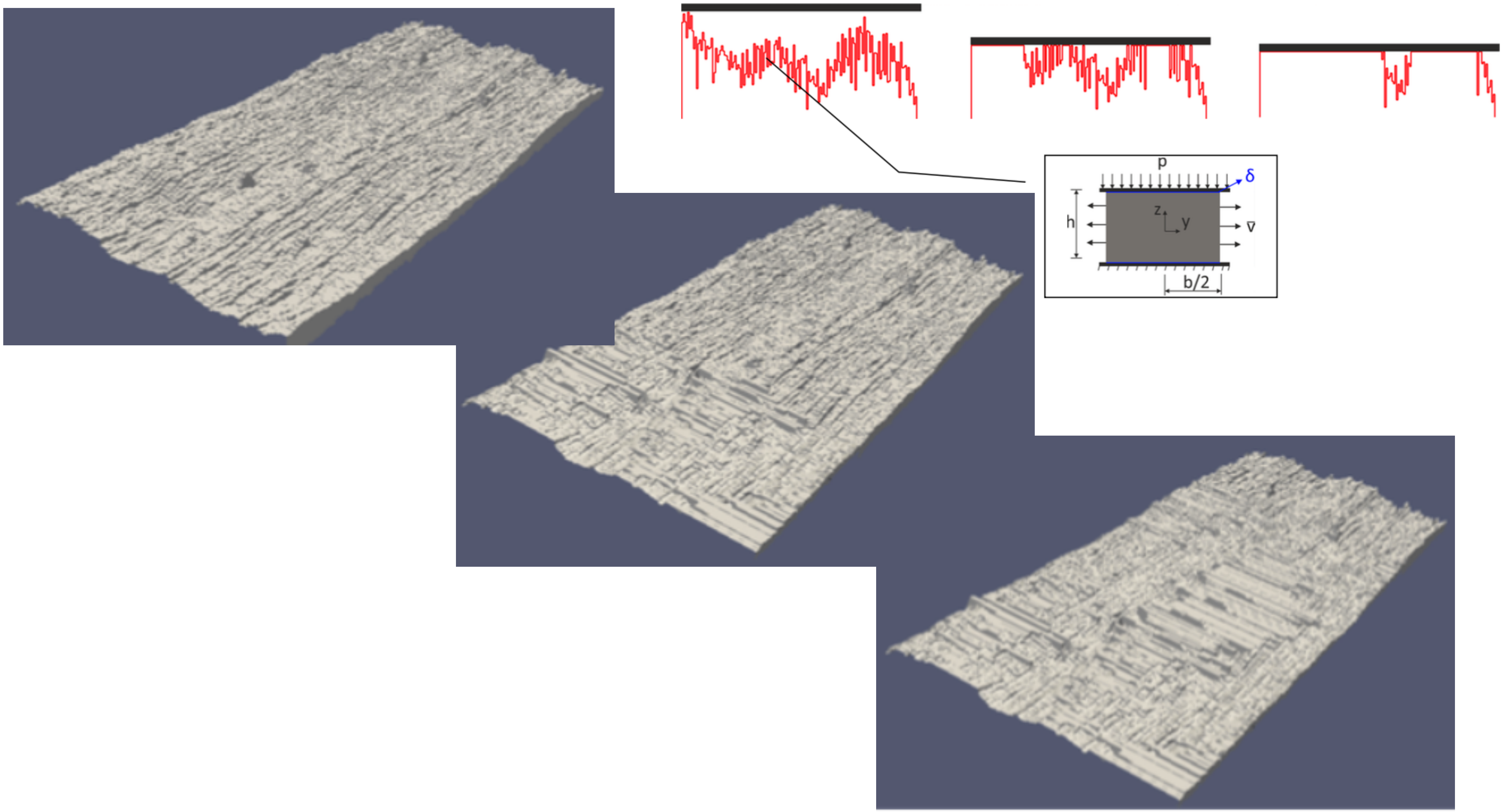


Figure 11: Interface expressed by wavelet basis at different levels

Orthogonal bases of compactly supported Wavelets I.Daubechies,. Communications on Pure and Applied Mathematics, 1988

Compression of the interface



We considered a squeeze flow for each asperity assuming lubrication hypothesis.

Compression of the interface

The temperature field is solved by applying PGD with different material conductivities, avoiding the distortion of the mesh.

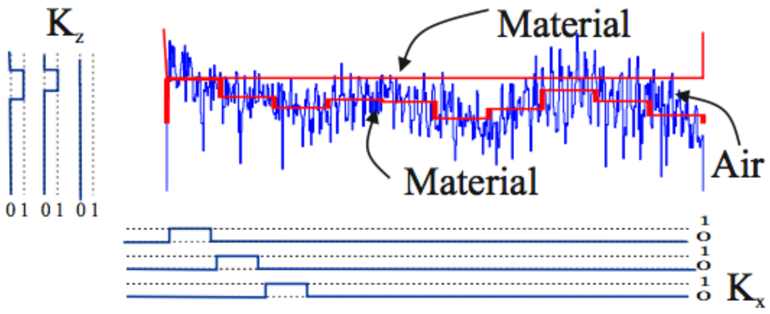
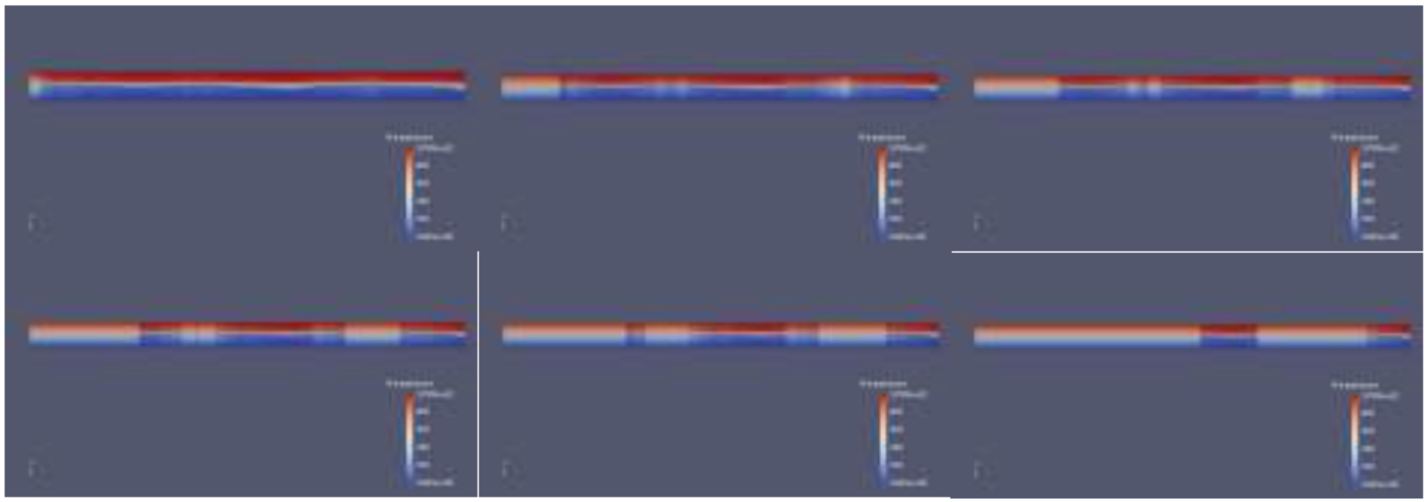


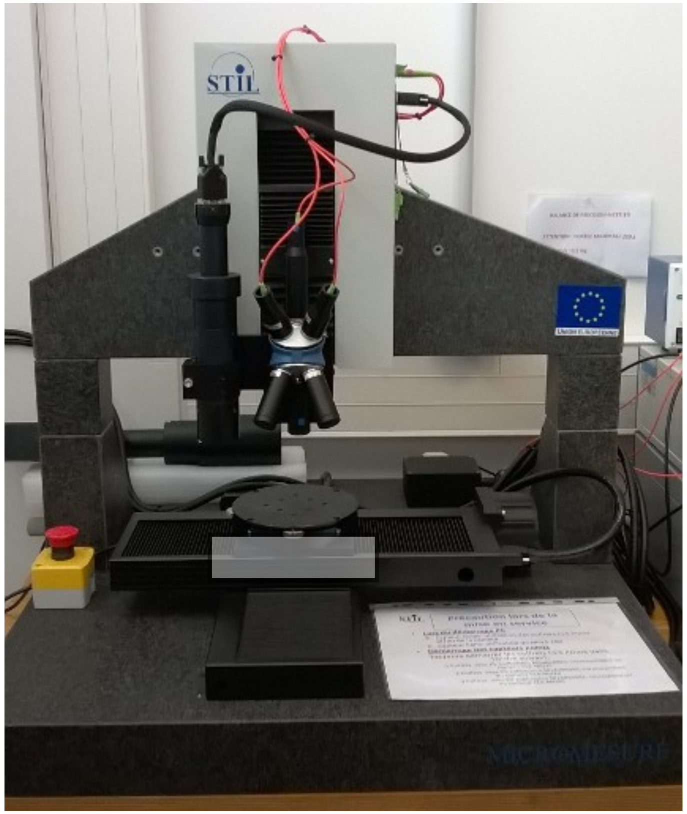
Figure 5: PGD material conductivities for representing the real geometry

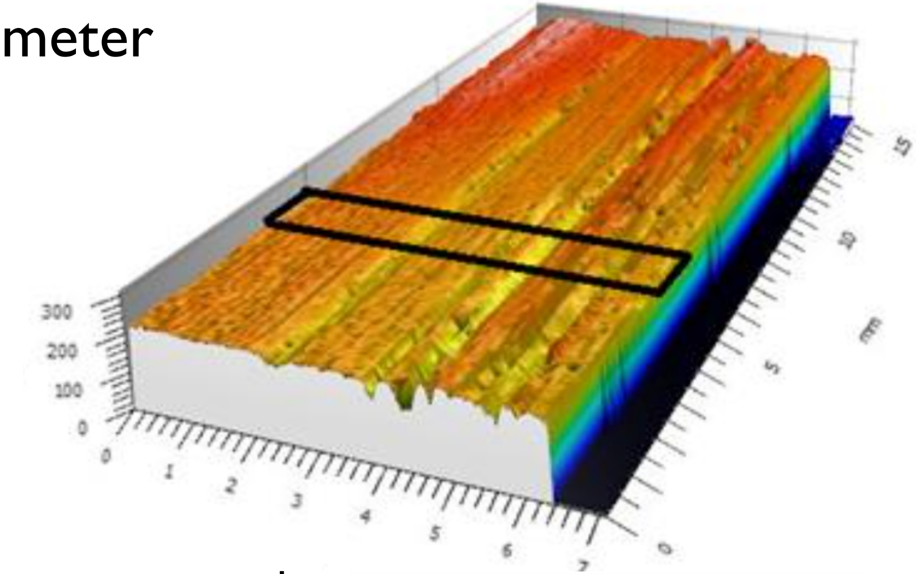
Evolution of the temperature. 30 times amplification in Z



Characterization of the interface

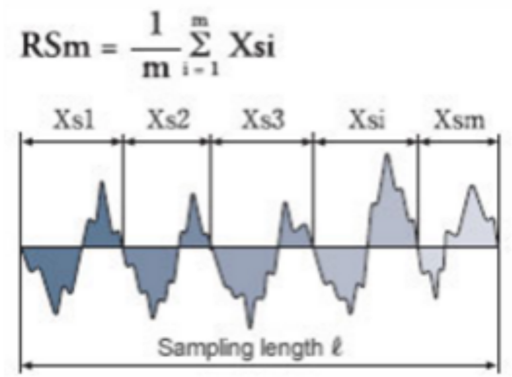
The surface is scanned by an optical profilometer





$$R_a = \frac{1}{N}\sum_{j=1}^{N} |r_j|$$

$$R_t = \left|\min_{1\le j\le N} r_j\right| + \left|\max_{1\le j\le N} r_j\right|$$

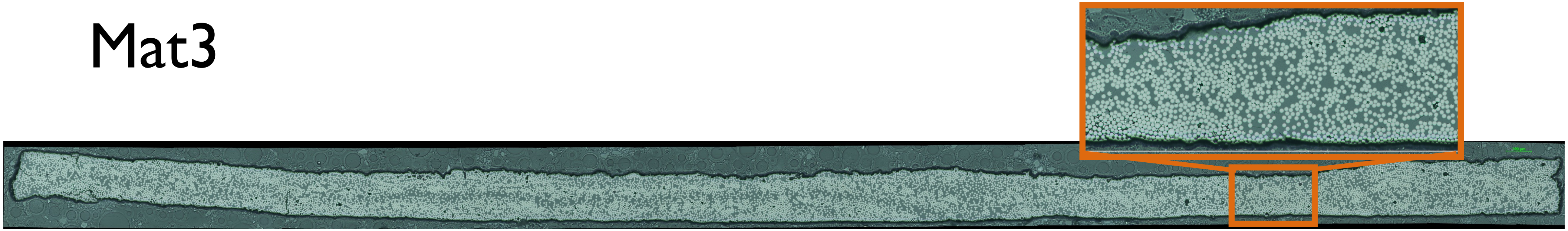


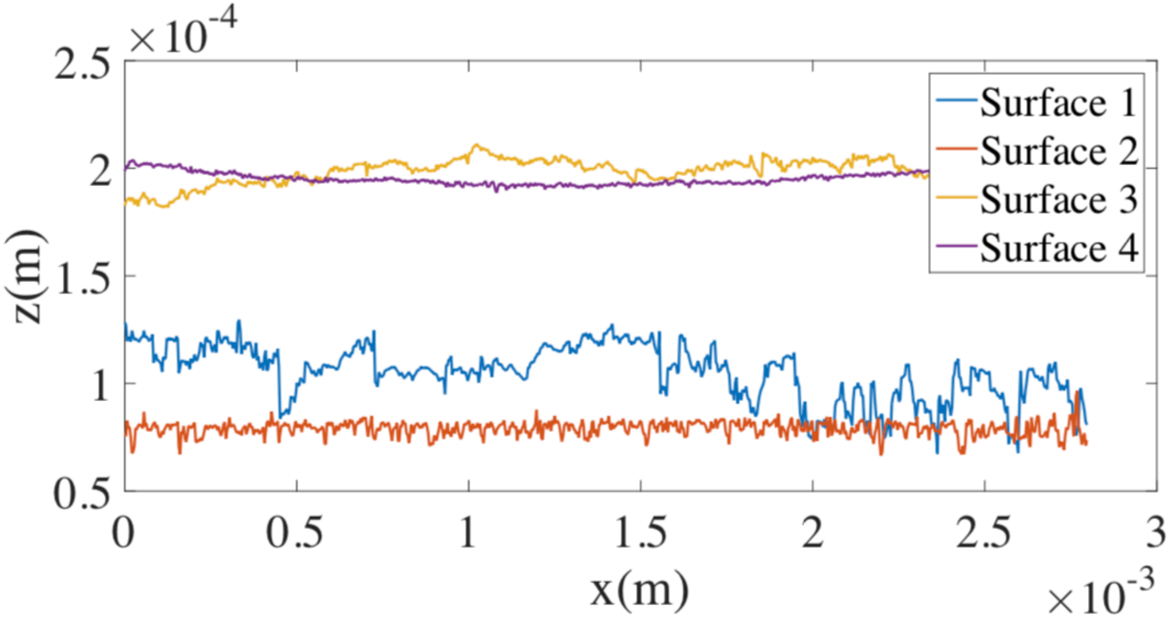
Material characterization : interface/impregnation/fibres repartition

Case study

Mat2

Mat3

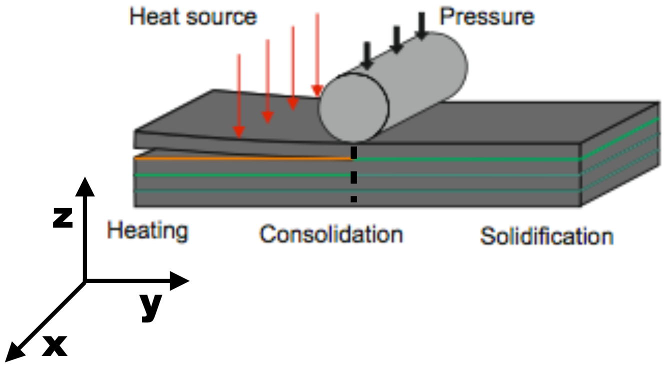


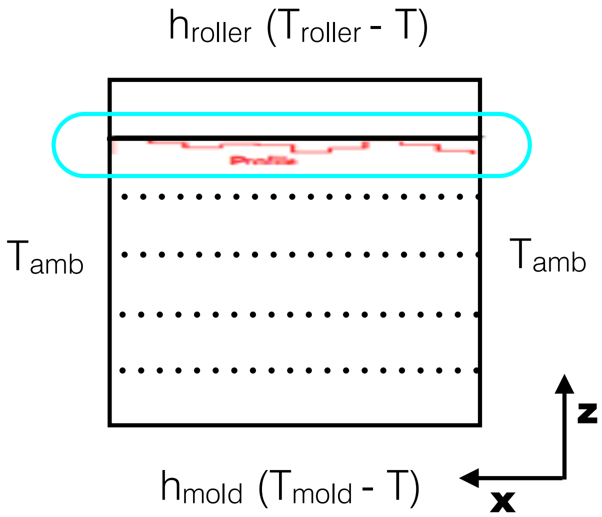


Surface	R_a	R_t	R_s
	$(10^{-6}m)$	$(10^{-6}m)$	$(10^{-6}m)$
S1	2.7	34.0	43
S2	2.1	25.3	13
S3	0.8	10.5	103
S4	0.4	4.5	57

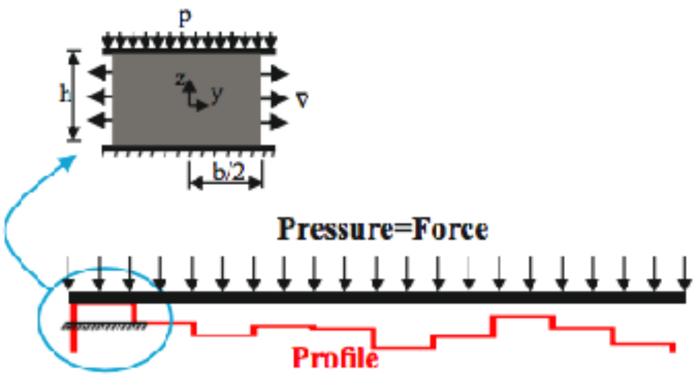
Micro-roughness (according to ISO 4287)

Compression during consolidation





Scheme of compression of the profile: each asperity as a squeeze flow assuming lubrification hypothesis

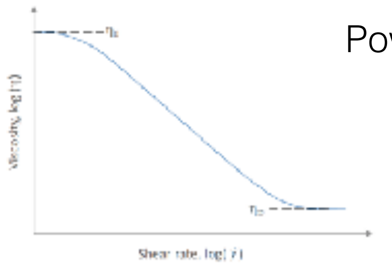


$$-\dot{h} = \frac{2nh^{2+\frac{1}{n}}}{\mu + 2n\mu}\Delta P$$

$$\mathbf{v} = \alpha^{-1+\frac{1}{n}} \frac{nh^{1+\frac{1}{n}}}{\mu + 2n\mu}\nabla P$$

Viscosity depends on temperature

$$\tau = \mu\ \dot{\gamma}$$

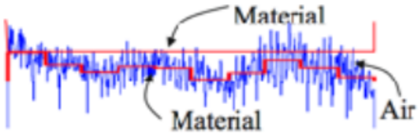


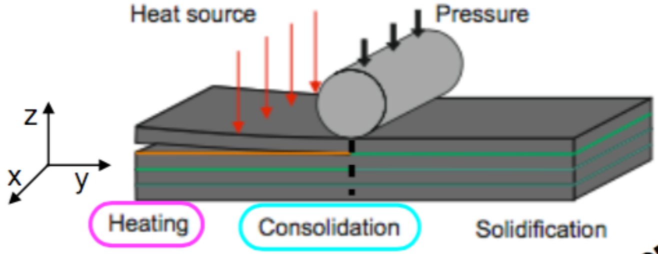
Power-law constitutive equation

$$\mu = K\ (\dot{\gamma}_{eq})^{n-1}$$

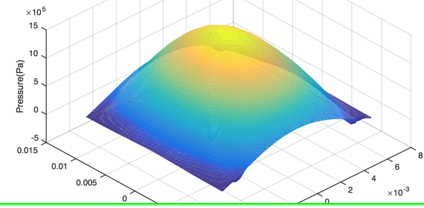
Dic Evolution Scheme

Surface profile: profilometer





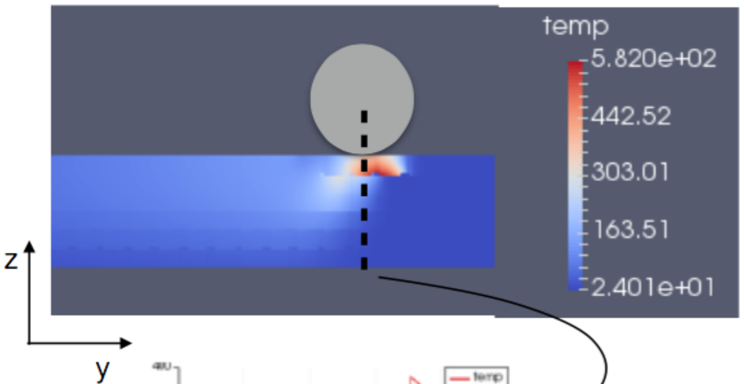
Roller Pressure

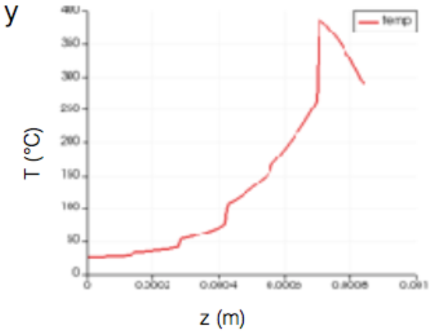


Input (profile)

Input

Initial temperature



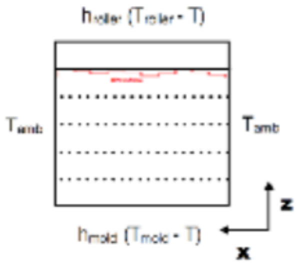


Input (T_0)

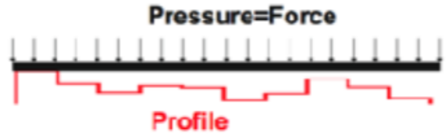
Evolution of DiC

Deformation depends on viscosity and the temperature depends on conductivity and deformation

Transient thermal problem



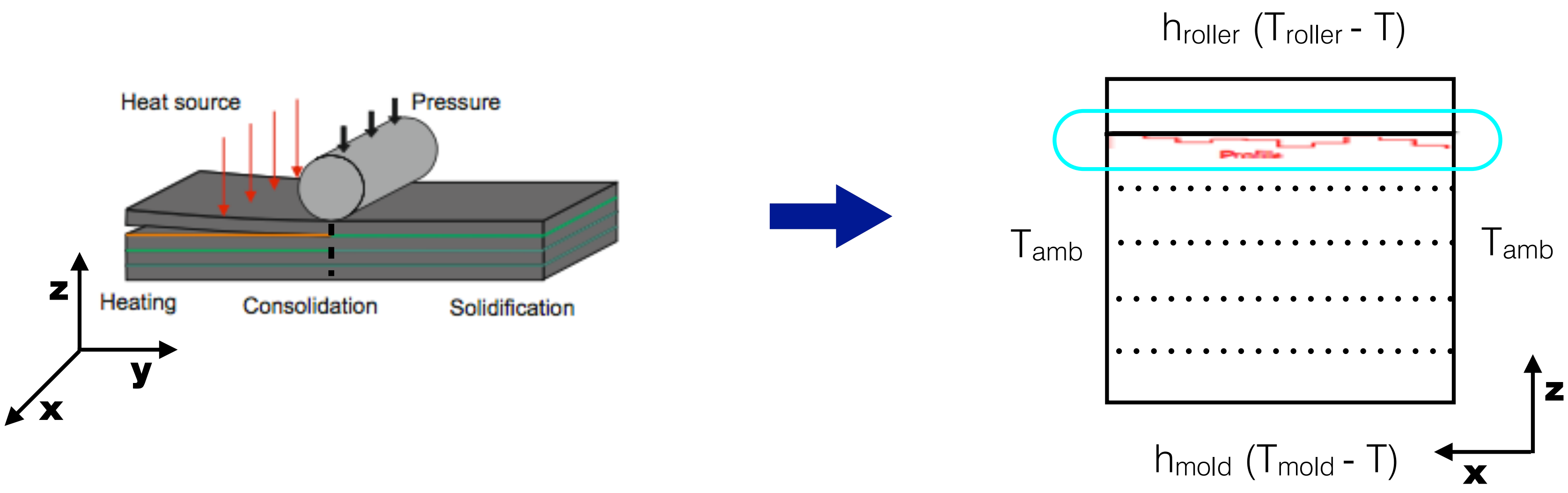
Compression: squeeze flow



$$\rho C_p \frac{\partial T}{\partial t} - \mathbf{K} \cdot \Delta T = 0$$

(Non-linear iteration)

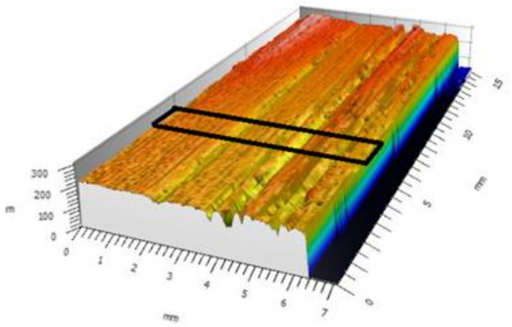
Compression during consolidation

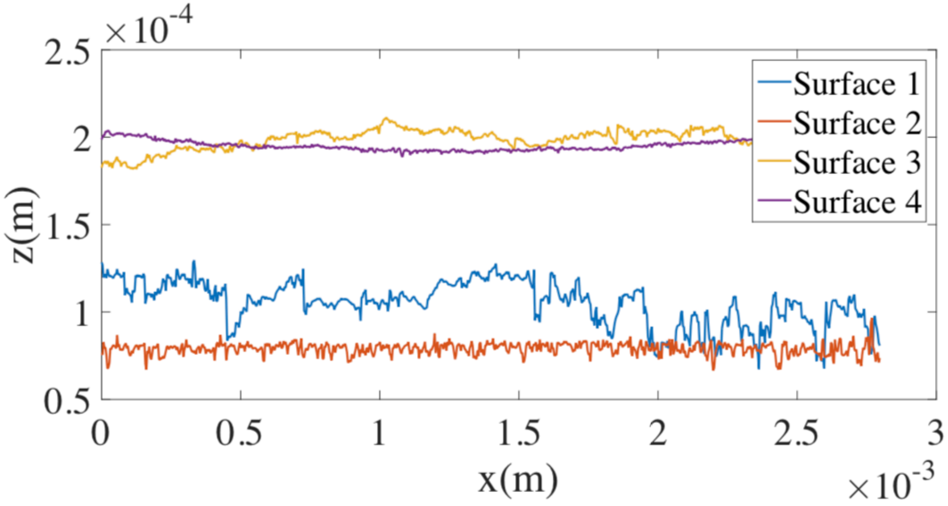


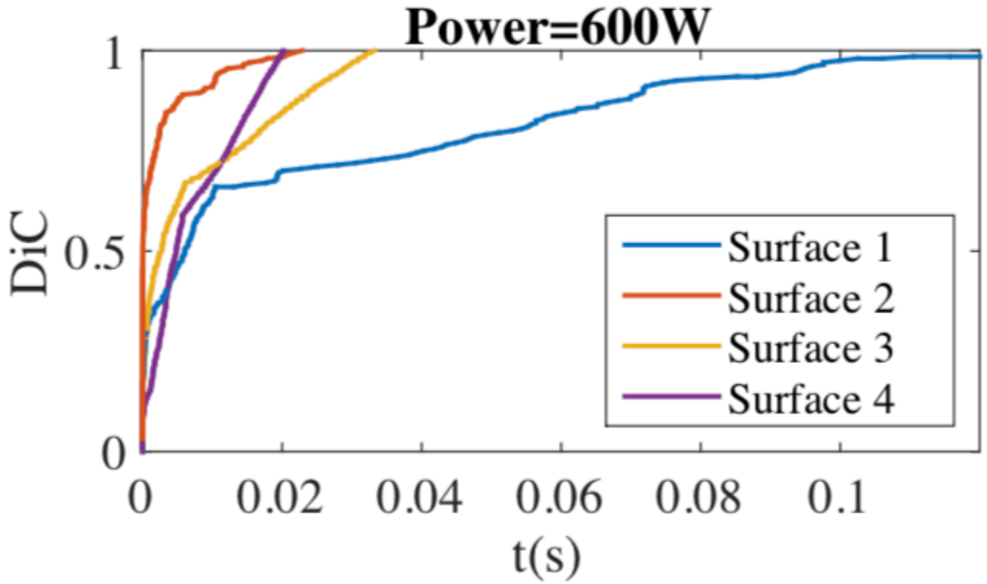
Simulation 'standard' parameters : Material, Process and Boundary conditions

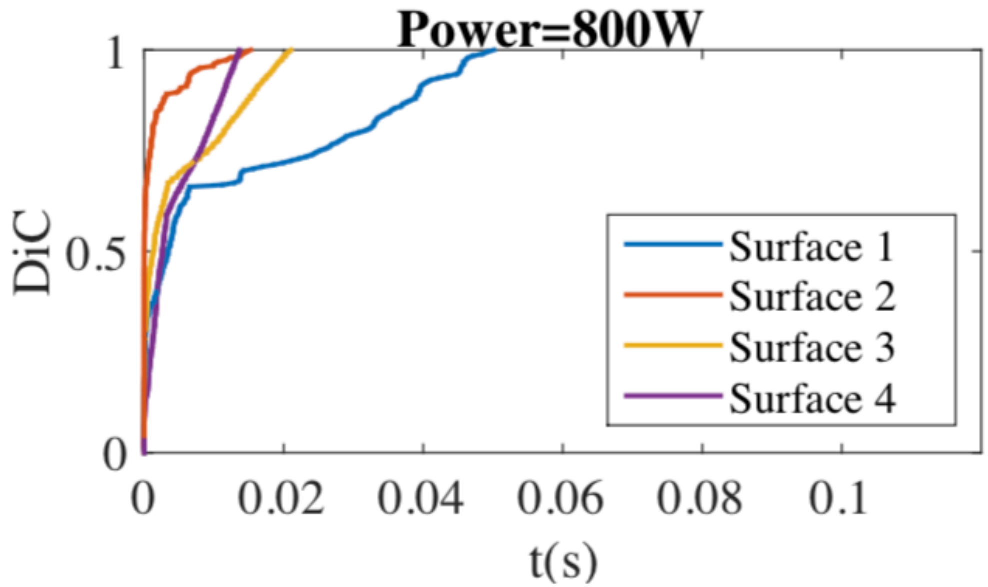
Parameters of simulation			
ρCp	$2.2\,10^6$	$\mathcal{F}$	$600\,N$
n	0.65	K_m	$0.5\,W/\,(m\,K)$
K_a	$0.024\,W/\,(mK)$	h_c	$4000\,K\,m^2/W$
h_{air}	$10\,K\,m^2/W$	h_{mould}	$2500\,K\,m^2/W$
h_{roller}	$2000\,K\,m^2/W$	V_{laser}	$0.1\,m/s$
m	6	T_{amb}	$25\,C$
T_{Mould}	$25\,C$	P_{laser}	$720\,W$

Case study - Dic evolution vs Power



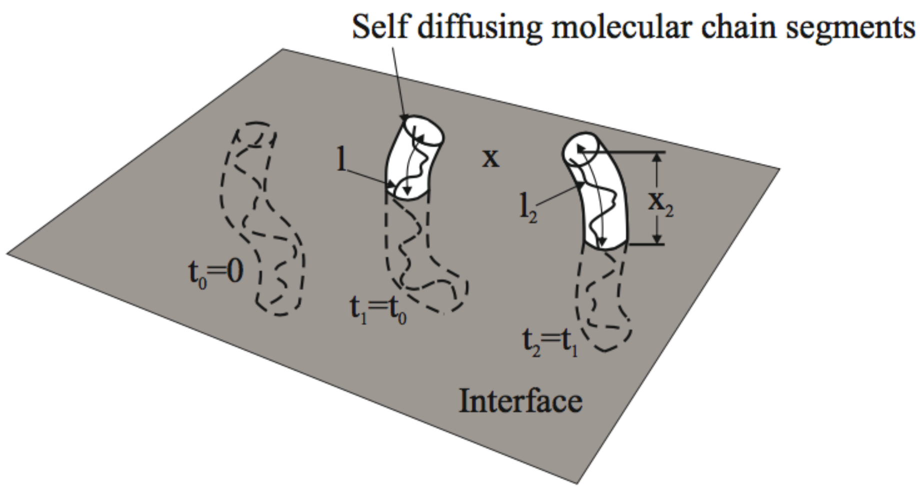






Physics needed

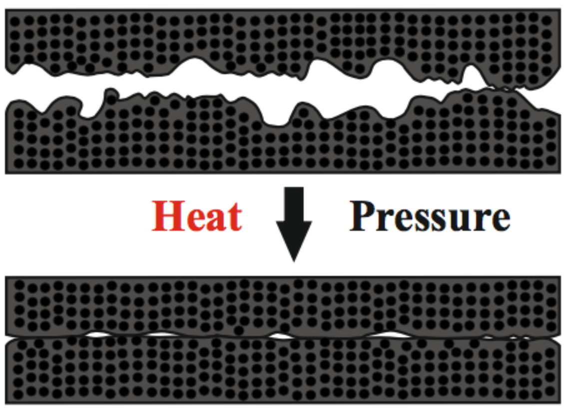
Healing



- Molecules diffuse across the interface
- Reptation theory depends on temperature

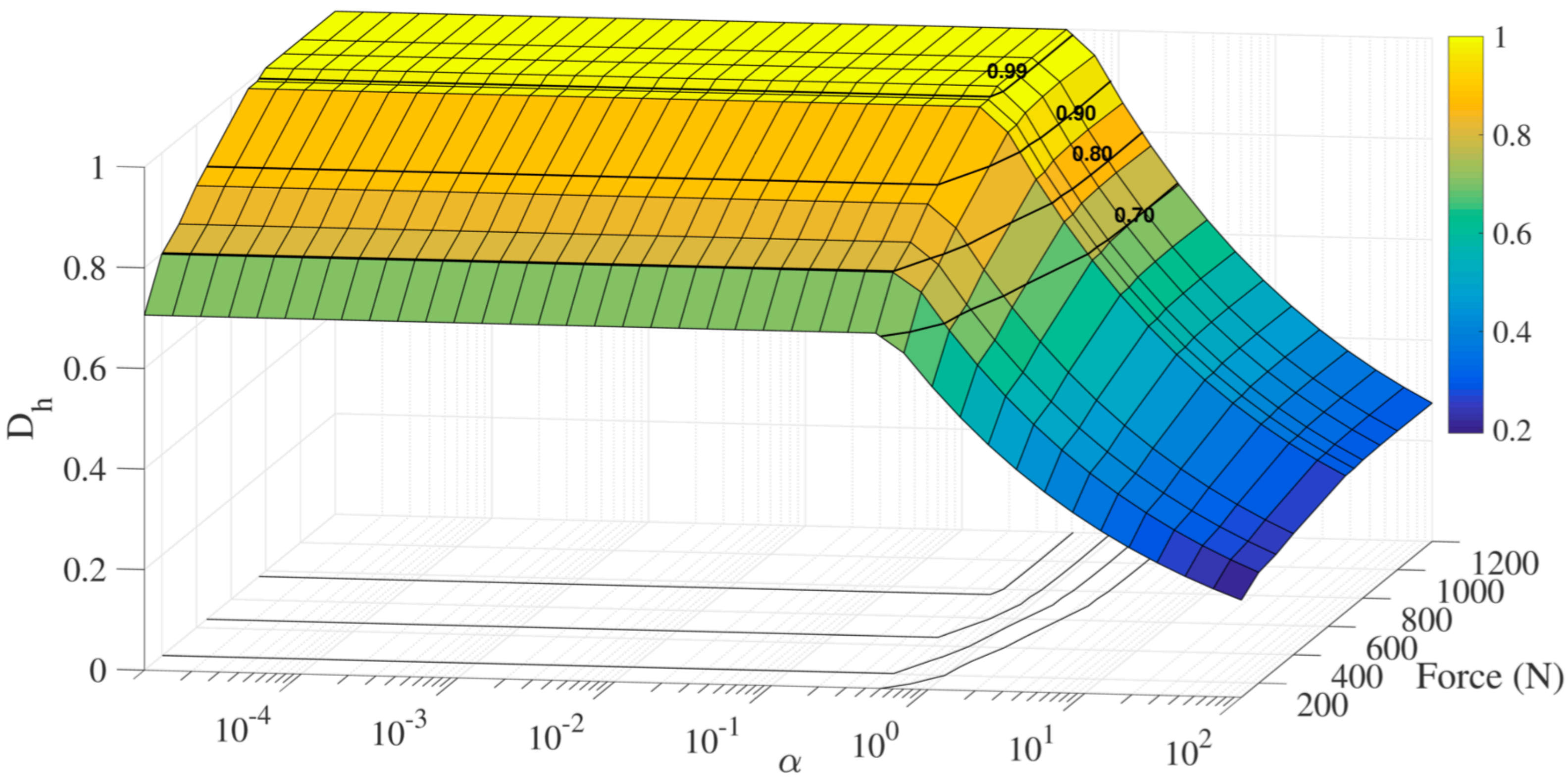
$$D_h = K(T) \cdot (t)^{1/4}$$

Intimate Contact



- Evolution of area in contact
- Viscosity depends on temperature

Case study - Dh evolution vs …

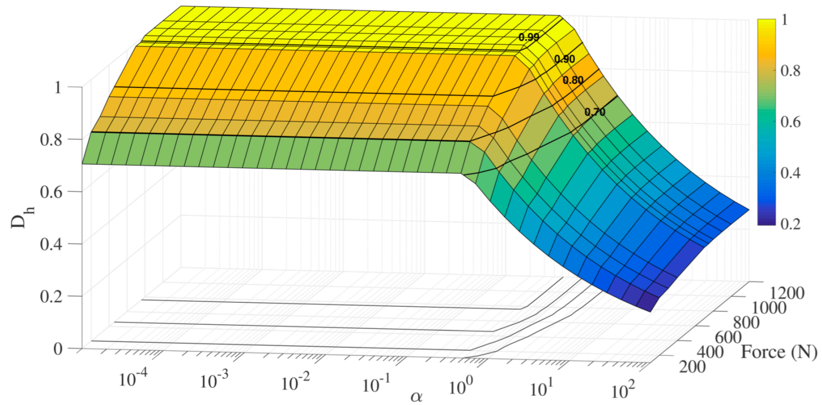


$$D_h(t) = \frac{\sigma}{\sigma_\infty} = \left(\int_0^t \frac{\mathrm{d}t}{t_w(T)} \right)^{1/4}$$

Degree of healing

$$t_w = \alpha_w \cdot t_{rep}^{PEEK}(T)$$

Case study - Dh evolution vs …



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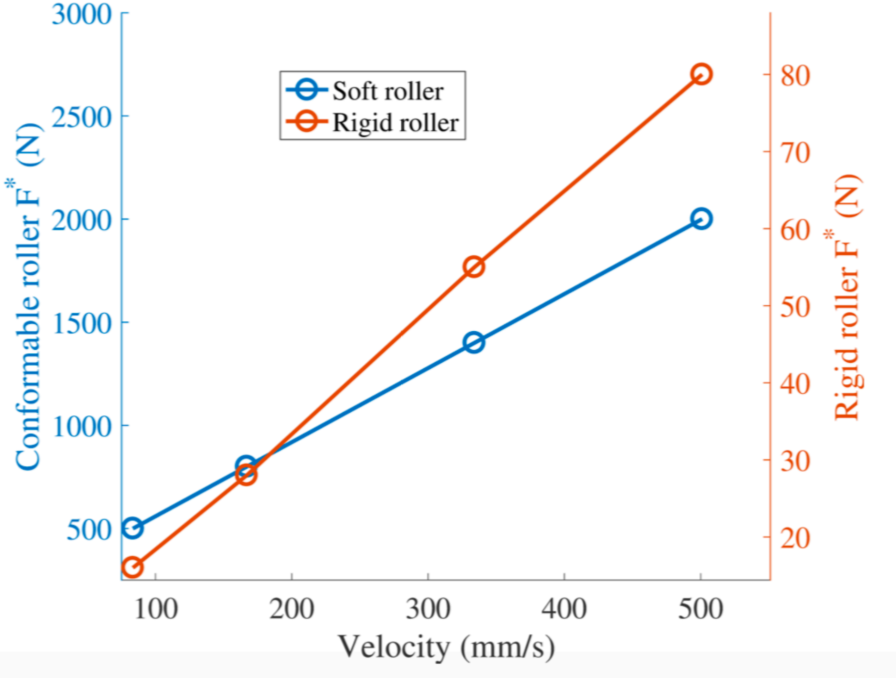
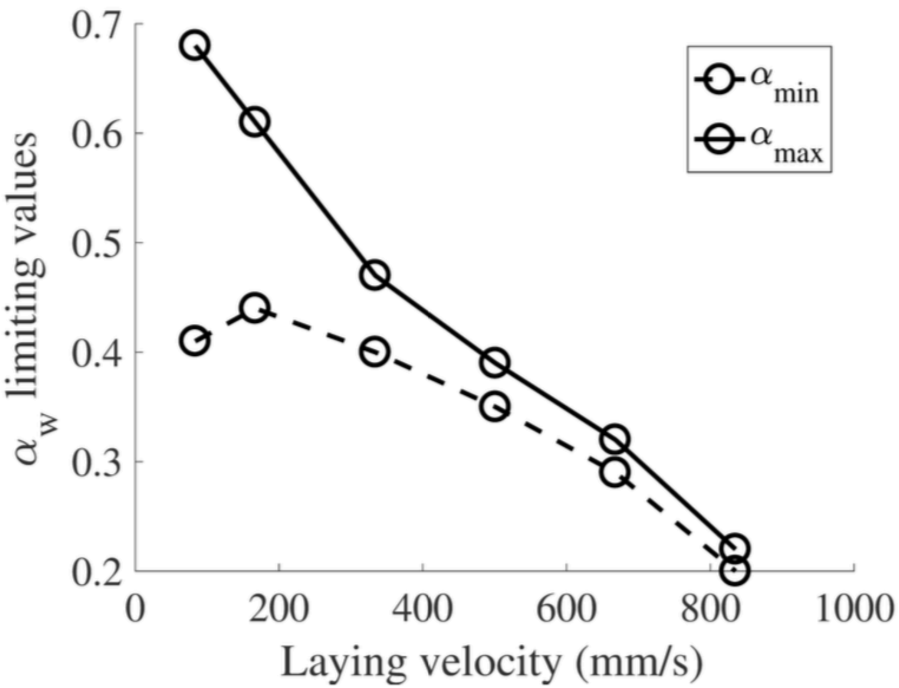




Conclusion & perspectives

This study aims at giving some key elements for quickly designing the most efficient and robust ATP Process.

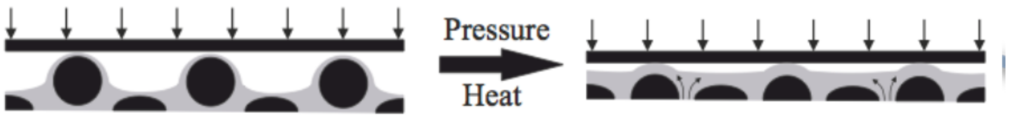
To do so, effort are gathered around the proposal of a modular simulation tool of the Process allowing a fine computation of the interply consolidation evolution.

A very fine modeling of the surface is compulsory to have a correct prediction of its evolution & further understanding of the needed desired prepreg features.

So, the interface is represented in a wavelet basis : allowing a multi-scale representation.

Today the compression of the real geometry is carried with lubrication hypothesis but the improvment of this point is actually in progress.

Actual work is also done improving the rheological modelisation of the interface during its compaction.



Conclusion & perspectives

We have shown in this presentation, some results regarding the effect of the initial surface roughness of the prepreg or the importance of the reptation time on the consolidation evolution.
Many others parameters (either material and/or process) could be explored.

Experimental validation and understanding are still in progress to specify the dreamed materials dedicated for ATP thermoplastic process that will allow to reach the dreamed in situ consolidation

The packaging of a modular simulation tool being also an action in progress.

Keys for designing the most efficient and robust in-situ TP ATP.

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