SOLVAY

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HIGH RATE PROCESS for THERMOPLASTIC based COMPOSITE PARTS

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09/2018

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

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Outline

1. - TP Composites : High Production Rate/ Low Cost Process ?

2. - Key Problem : fast Impregnation / fast Consolidation !

3. - Materials : TP Polymers & Reinforcement Fibrous Structures

4. - Direct process : Pultrusion TP

5. - Direct process : Resin Transfer Molding (RTM) -> C-RTM TP

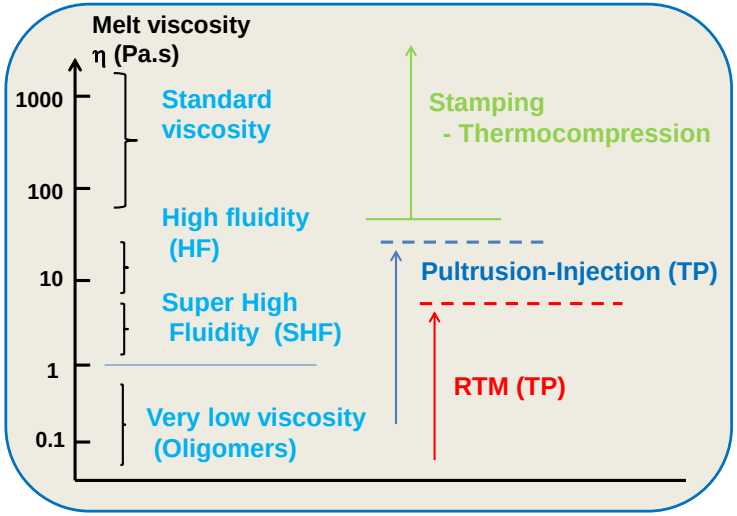
6. - Overmolding / Assembly

7. - Conclusion & Perspectives

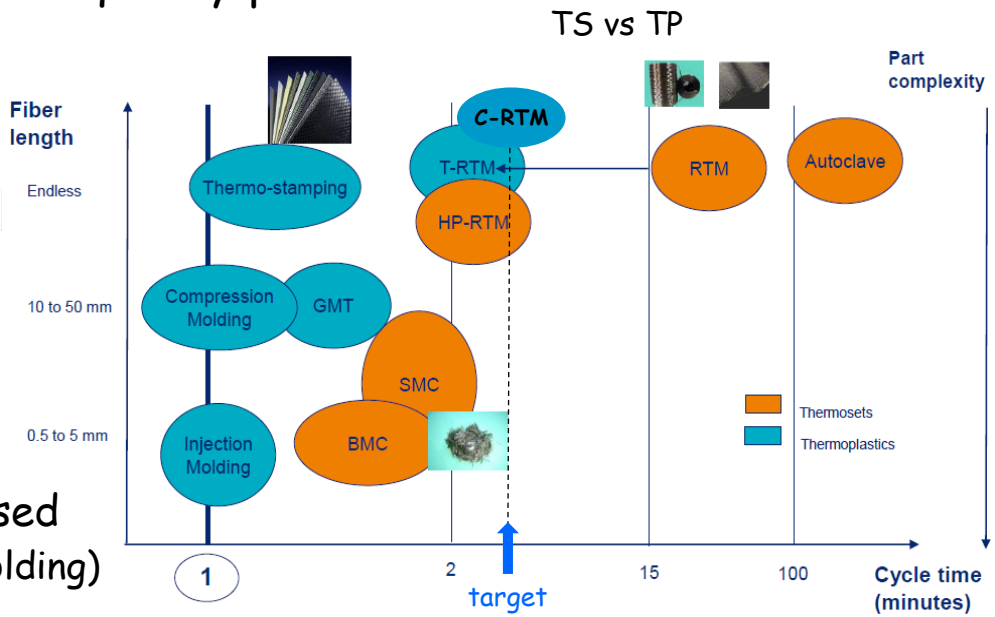
1.-TP Composites : High Rate Production & Cost Controlled Process

❑ TP Composites : main processing ways

- **Indirect** (from semi-products) : TRL 7-8
  - Pre-preg / Plates -> Stamping, Overmolding
  - Tapes (UD) -> Filament winding/Tape placement
- **Direct** (raw materials) : TRL 3-4
  - Pultrusion (profiles)
  - Injection in closed mold/LCM (RTM)



❖ **Process issue** : **low cycle time** for high production rate and cost control, with high mechanical performances and good quality parts.



Today : combination of thermo-stamping and overmolding

New developments : direct process, based on plastic technology (melt injection + overmolding)

2.- Key Problem : Fast Impregnation & Fast Consolidation

❑ Direct Composite Processing : Preform Impregnation

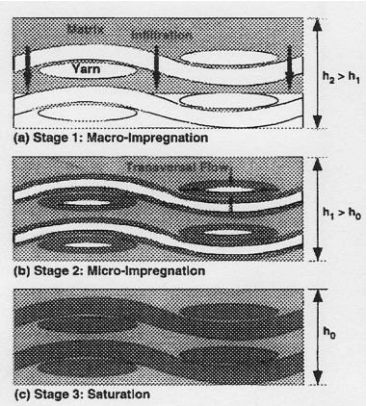
Inter + Intra meshes -> viscosity and capillarity forces

Darcy's law : $Q = \frac{K.A.\Delta P}{\mu.\Delta L}$

Stokes : grad P = μ Δu

TS : OK with μ < 0.01 Pa.s
With TP polymer : μ > 100 Pa.s !

Double scale porosity



❖ Viscosity of Thermoplastic Polymers (μ) 250 – 1000 Pa.s

- To reduce viscosity : Two main technologies are developping

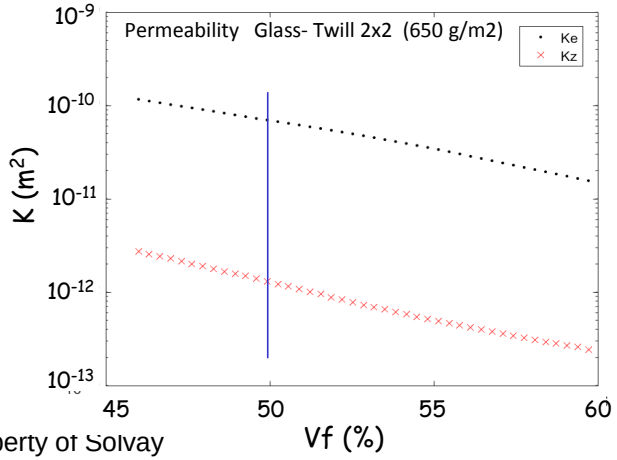
❖ **Reactive Precursors :**
monomers/oligomers (TP),
with in-situ polymerization
Process : control of polymerization
- restricted to PA6/capro

❖ **High Fluidity Polymers :**
low viscosity TP (non evolutive)
- melt viscosity 10 < μ < 100 Pa.s
Process : require low viscosity (< 25 Pa.s)
& high permeability preform (> 5. 10^{-10} m^2)

❖ Permeability of fibrous Preforms (K)

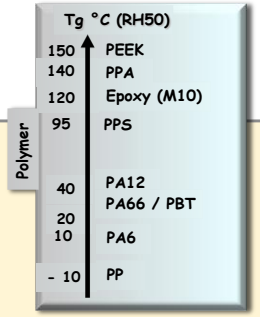
10^{-13} to 10^{-11} m2 / Vf = 50%

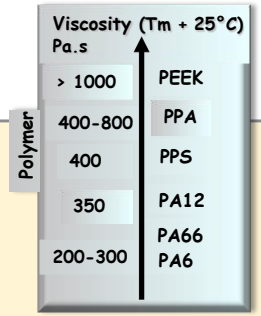
- **Permeability control by fabric architecture**
  Warp-weft fabrics (Plain, Twill, …)
  Unidirectional (UD)
  Non Crimped Fabric (NCF)



3.- Materials : TP Polymers & Reinforcement Structures

❑ TP Polymer Requirements :





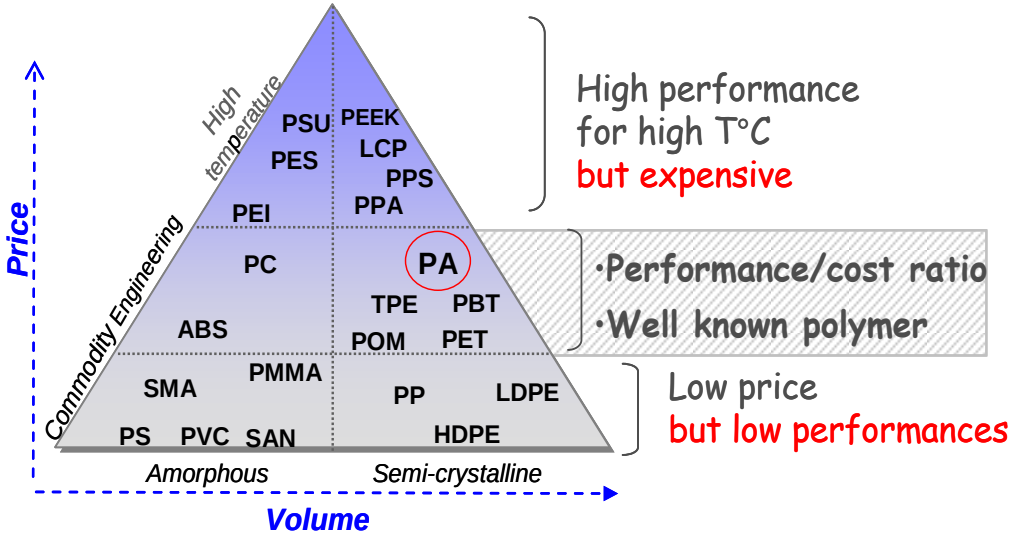
- **Thermoplastic** : High modulus & toughness
  High Tg (vitreous transition)

TP : Engineering Polymers (PA, PBT, PET)

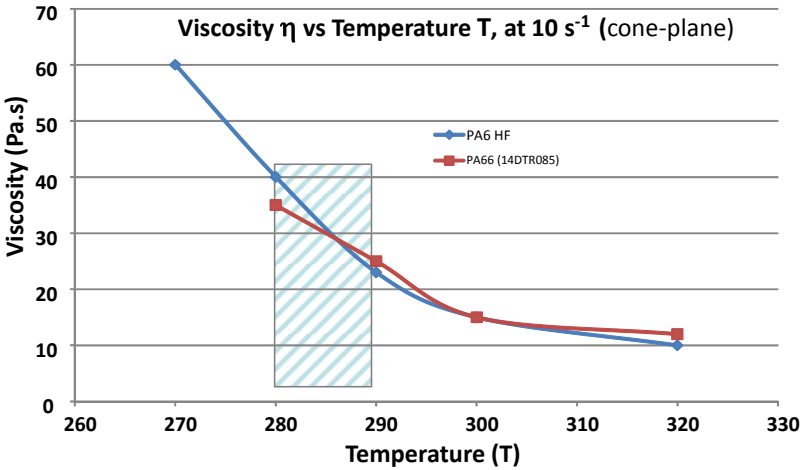
-> High Performances Polymers (PPA, PPS, PEAK, PEEK)

Ratio mechanical performance/cost (Semi-Crystalline, High modulus, High Tg)

Problem : high viscosity (melt)/ high temperature/ thermal shrinkage.



- **Polyamide** PA6, PA66 Evolite® (Solvay)
  η : 20 -> 75 Pa.s (100 Pa.s)



High fluidity TP : compromise between viscosity (η) and mechanical properties (E, Gc).

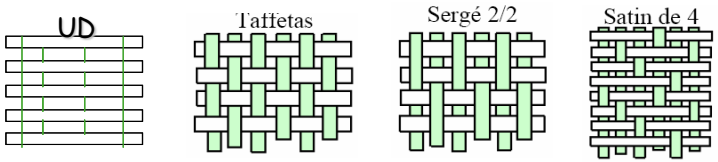
- **PPS** Ryton® (Solvay) η : 75 -> 150 Pa.s

3.- Materials : TP Polymers & Reinforcement Structures

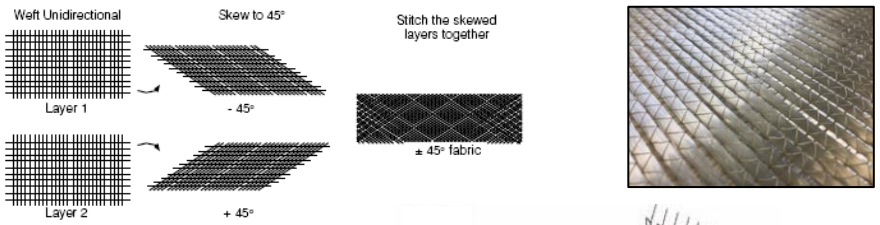
- **Fibers** Glass / Carbon ….

- **Reinforcement** **Preforms**

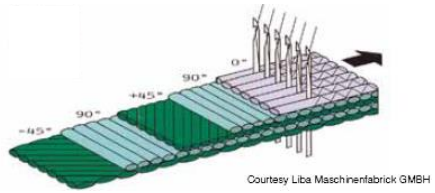
Non woven - UD - Plain / Twill / Satin



NCF (Non Crimp Fabric)



HT Stitching



- **Multi-scale** : dual size distribution of porosity/ high flow channels.

EPFL/LPAC : V. Michaud, D. Salvatori
-> high flow channels (RTM preforms).

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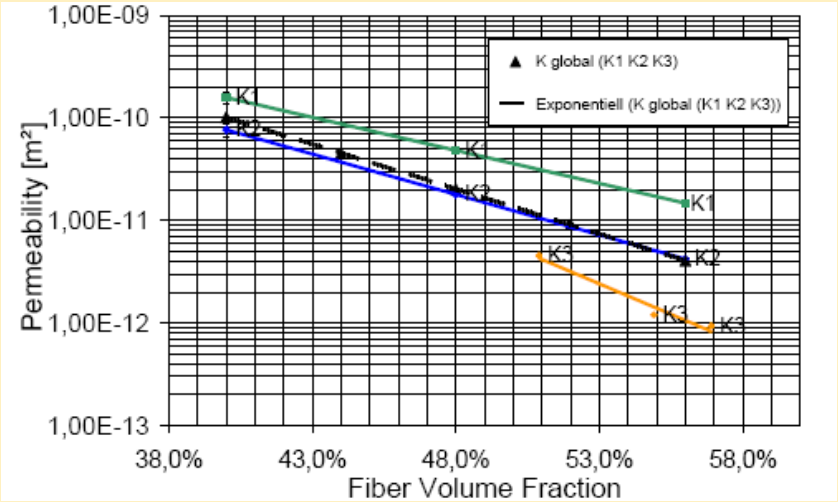
Permeability (K) K : f° Vf, P



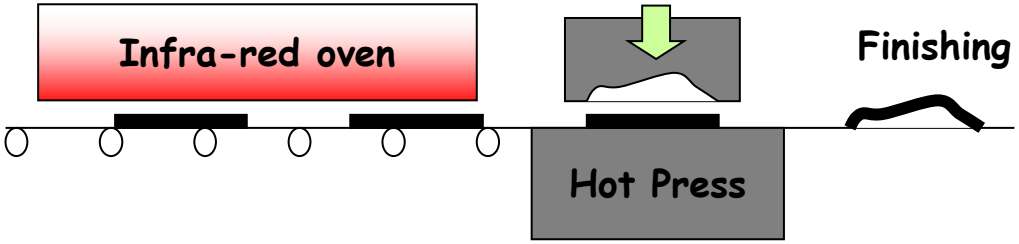
Interfaces / Surface treatment (sizing)

- during process : surface energies / wetting (θ)
- after consolidation : fibre/matrix adhesion (τ) / toughness (Gc)

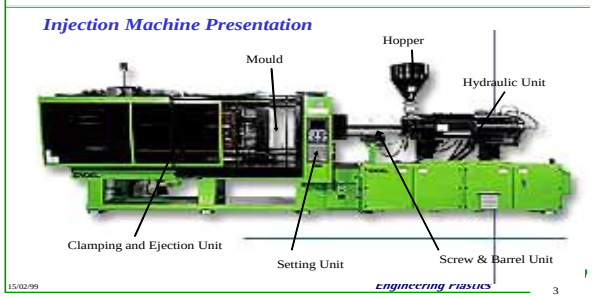
-> Reinforcement compatibility with TP Polymers and Process !

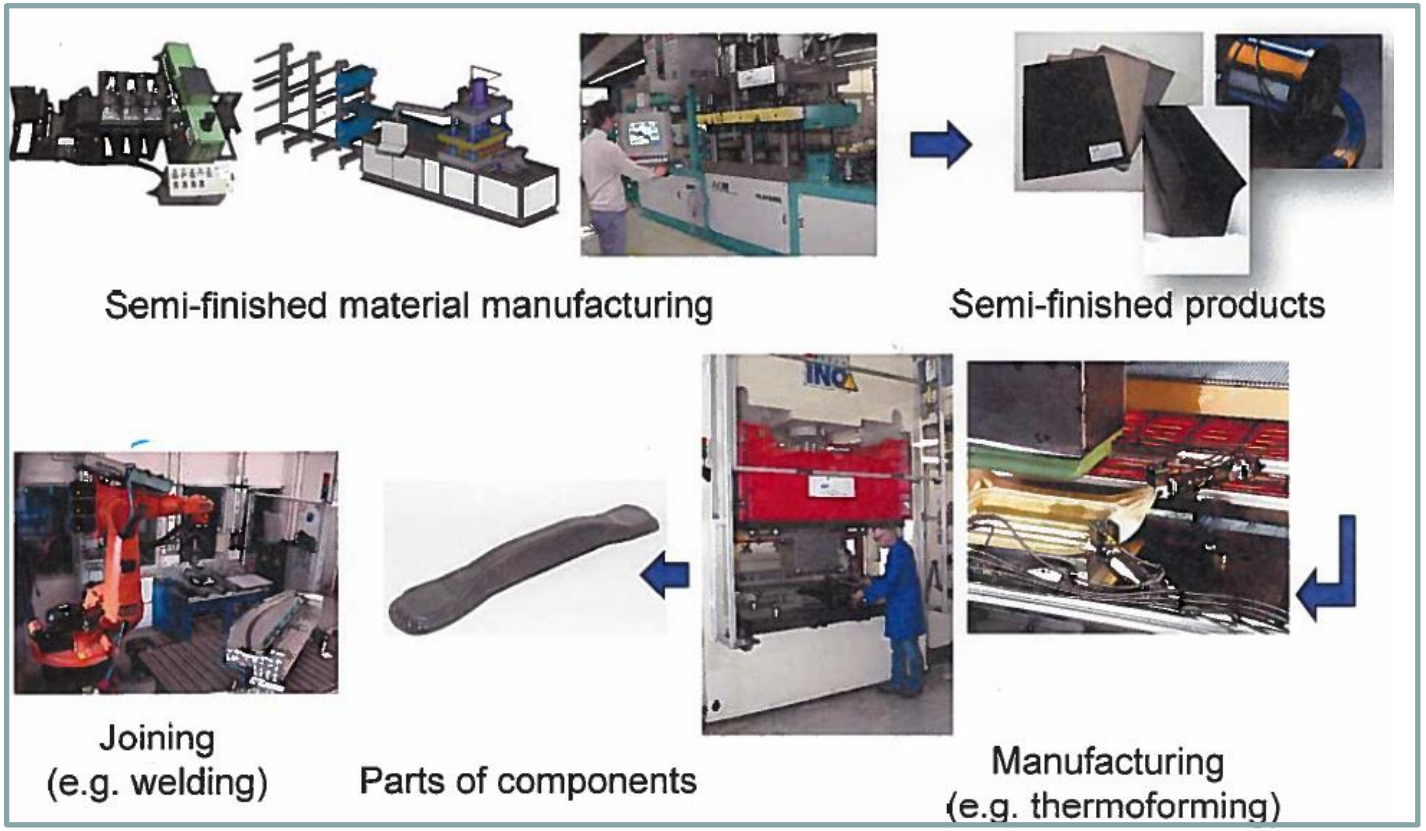
4.- Indirect Processes : Stamping / Overmolding

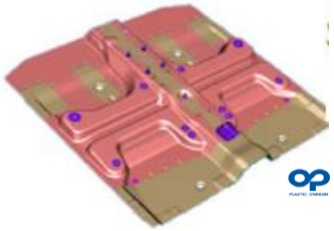
❑ Stamping / Overmolding



Overmolding







Camisma's

Steering-wheel
Solvay-Hacoma

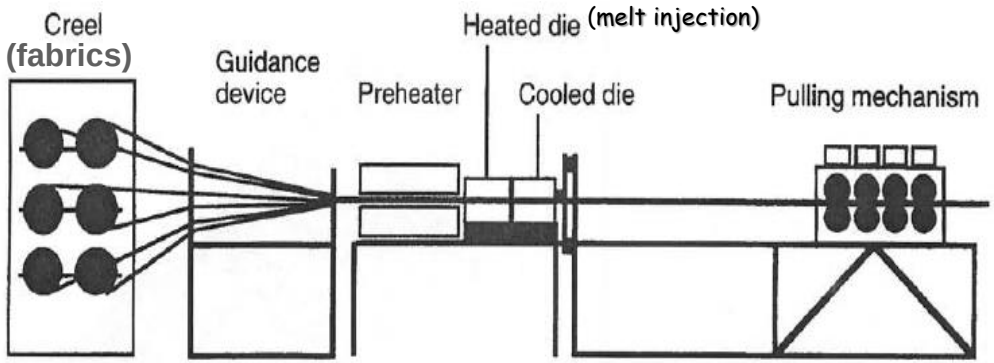
5.- Direct Process : Pultrusion-Injection TP

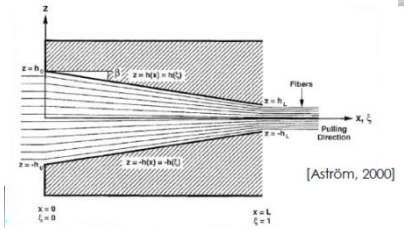
❑ Pultrusion-Injection TP : Tapes / Profiles

UD -> Fabric

- Injection : low viscosity polymer, or melt precursor
- Consolidation : cooling down, or polymerization

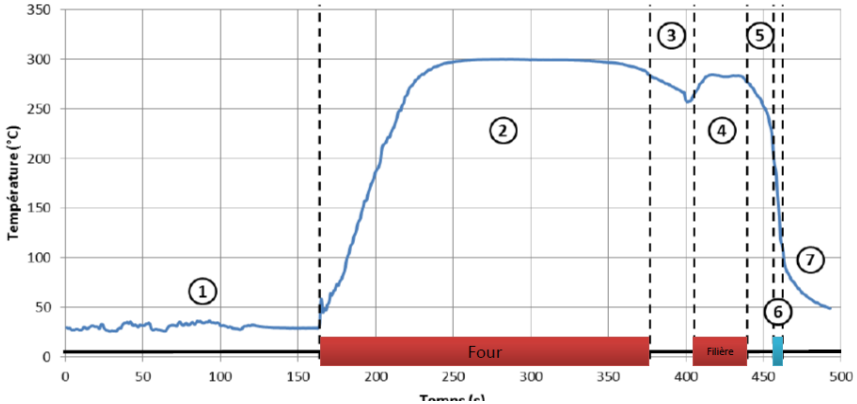
Low viscosity is required for high pulling rate (> 5 m/min).



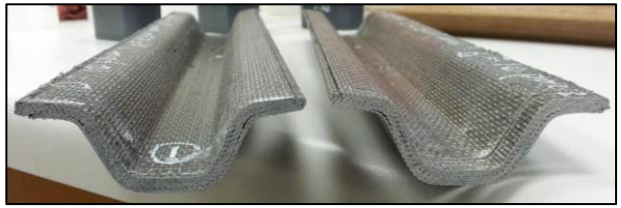


Continuous process : fast impregnation is required

Thermal profile along pultrusion line is critical



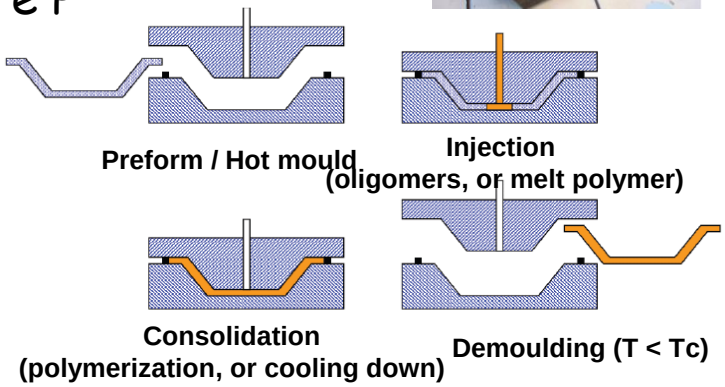
OMEGA profile (stiffner)
Pulling speed : 3 – 5 m/min



5.- Direct Process : RTM -> Injection-Compression TP

❑ RTM TP : 3D Preform

- Injection : melt polymer *(or precursor)*
- Impregnation : in-plane resin flow under Pressure P
- Consolidation : cooling down *(or polymerization)*
- Demolding (T< Tc)



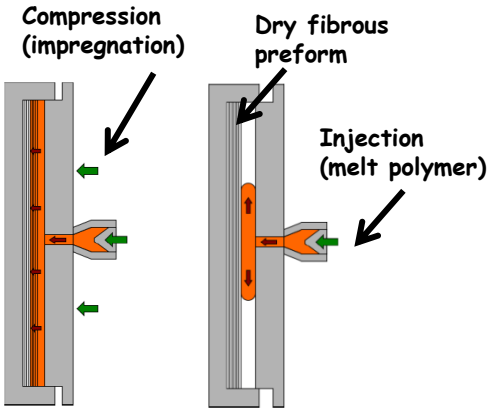
To obtain good impregnation (low pressure P) :

-> low viscosity (< 0.1-10 Pa.s) + wettability
and high permeability (K > 0.5 10^{-10} m^2).

❑ Compression-RTM TP : injection-compression TP

Heating T1 (-> 400°C)
Injection & Compression
Cooling T0 (-> 150-200°C)

T1 > Tm (melting)
T0 < Tc (crystallization)



Global cycle time target ~5 -10 min.

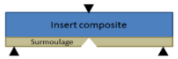
-> FHNW : C. Dransfeld, J. Studer -> Compression-Injection modelling.

6.- Net shape Composite Parts : Overmolding / Assembly

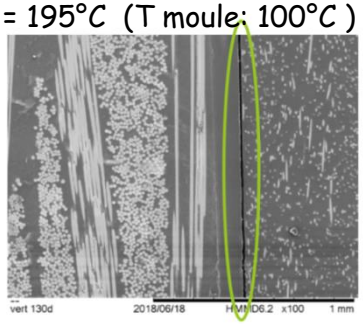
❑ Net shape part : TP composite insert / overmolding

Injection molding : melt (PA6) / insert (PA6/Glass)

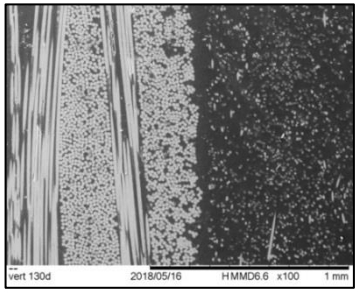
- Tprocess (T >Tg + 100°C)
- ΔT insert /melt (ΔT < 150°C)
- Time (Pressure)

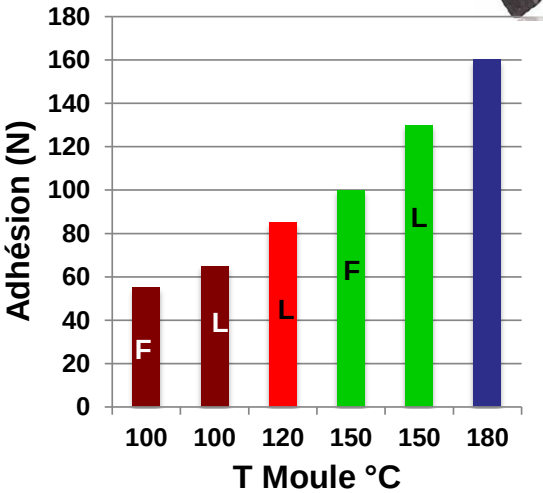


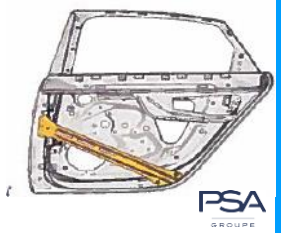
ΔT = 195°C (T moule: 100°C)



ΔT = 145°C (T moule: 150°C)

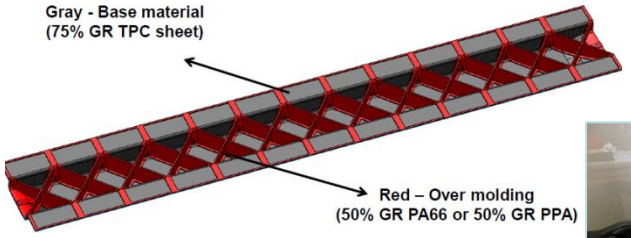


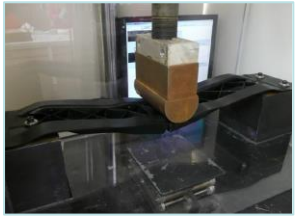


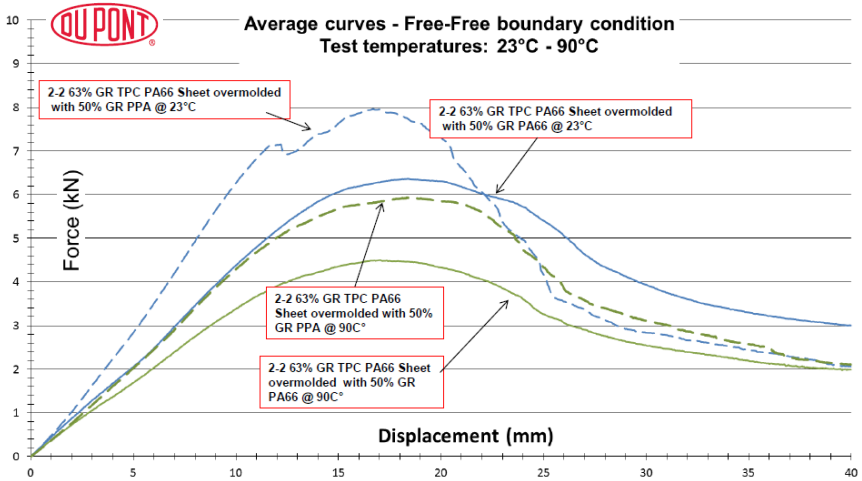


❑ Overmolding with High Perf. Polymer (50% short GF) :

- Aliphatic PA (PA66) *medium Tg*
- Semi-aromatic PA (PPA) *high Tg*







7.- Conclusion & Perspectives

High rate process with cost control have to be developed to propose TP Composites in large markets (automotive, …) : 30,000 -> 100,000 parts/y

❑ Tailored Raw Materials

- **Polymers (TP) -> low viscosity** : 25 -> 100 Pa.s (PA, PPS …)/ or precursors (0.1 Pa.s)
  -> high Tg : >80°C (semi-crystalline)
- **Fibrous structures (Glass /Carbon) -> high permeability K** (longitudinal,transverse)

NB : improvement required on **fiber sizing** *(compatibility with both process & polymer)*

❑ Direct process to develop : from raw materials (granulates / fabrics)

- **Fast Impregnation : high flow strategies**
- **Injection-Compression TP : cycle time and cost control**

Modelling to develop -> Optimization

❑ Perspectives

- **Process** : High rate process technologies (injection molding press / fast heating and cooling technologies).
- **Composite Parts** : Integration of functions . Active/Connected systems.

Thank you for your attention!