HIGH RATE PROCESS for THERMOPLASTIC based COMPOSITE PARTS
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: \( \text{grad} \ P = \mu \Delta u \)

- **Viscosity of Thermoplastic Polymers (\(\mu\))**: 250 – 1000 Pa.s
  - To reduce viscosity: Two main technologies are developing
    - **Reactive Precursors**: monomers/oligomers (TP), with in-situ polymerization
      - Process: control of polymerization
    - **High Fluidity Polymers**: low viscosity TP (non evolutive)
      - melt viscosity \( 10 < \mu < 100 \) Pa.s

- **Permeability of fibrous Preforms (K)**
  - 10\(^{-13}\) to 10\(^{-11}\) m\(^2\) / Vf = 50%
  - Permeability control by fabric architecture
    - Warp-weft fabrics (Plain, Twill, …)
    - Unidirectional (UD)
    - Non Crimped Fabric (NCF)

- TS: OK with \( \mu < 0.01 \) Pa.s
- With TP polymer: \( \mu > 100 \) Pa.s!
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)
  - \( \eta \): 20 → 75 Pa.s (100 Pa.s)

### Polypropylene
- PPS Ryton® (Solvay) \( \eta \): 75 → 150 Pa.s

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

- ‘SCCER Mobility’ Sept. 11th, 2018 (Zurich, CH)
3. - Materials : TP Polymers & Reinforcement Structures

- **Fibers**  Glass / Carbon ....

- **Reinforcement**  Preforms
  Non woven - UD - Plain / Twill / Satin

- **NCF (Non Crimp Fabric)**

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

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

**Permeability (K)**  \( K : f° Vf, P \)

**Interfaces / Surface treatment (sizing)**
- during process : surface energies / wetting (\( \theta \))
- after consolidation : fibre/matrix adhesion (\( \tau \)) / toughness (\( Gc \))

-> Reinforcement compatibility with TP Polymers and Process !

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*Property of Solvay*
4.- Indirect Processes: Stamping / Overmolding

- Stamping / Overmolding
  - Infra-red oven
  - Finishing
  - Hot Press

- Semi-finished material manufacturing
- Semi-finished products
- Joining (e.g. welding)
- Parts of components
- Manufacturing (e.g. thermoforming)

- 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).

Thermal profile along pultrusion line is critical

Continuous process: fast impregnation is required

**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 \(T_1\) *(-> 400°C)*
  Injection & Compression
  Cooling \(T_0\) *(-> 150-200°C)*

  \[
  \begin{align*}
  T_1 & > T_m \text{ (melting)} \\
  T_0 & < T_c \text{ (crystallization)}
  \end{align*}
  \]

  **Global cycle time target ~5 - 10 min.**

- **FHNW :** C. Dransfeld, J. Studer \(\rightarrow\) 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)

\[ \Delta T \text{ insert / melt} (\Delta T < 150°C) \]

Time (Pressure)

\[ \Delta T = 195°C \text{ (T moule: 100°C) } \]
\[ \Delta T = 145°C \text{ (T moule: 150°C) } \]

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

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

Adhésion (N) vs. T Moule °C

\[ L \]

\[ F \]

Gray - Base material (75% GR TPC sheet)

Red - Over molding (50% GR PA66 or 50% GR PPA)
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

Perspectives

- Composite Parts : Integration of functions . Active/Connected systems.
Thank you for your attention!