Composite Technology MSE 440

Processing methods

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Ecole Polytechnique Fédérale de Lausanne (EPFL),
CH-1015 Lausanne

Objectives

- Describe the main methods used to process polymer matrix composite materials.

- Justify the choice of a given process based on the materials selection, part complexity and production volume.

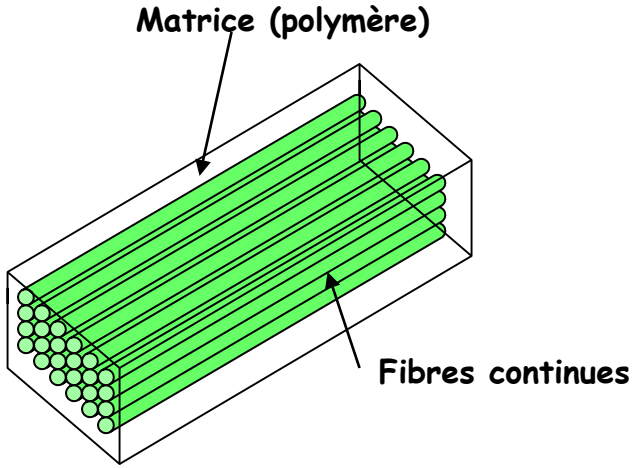
Composite processing

In general, the reinforcement is already under its definite form:
fiber, powder, potentially woven or assembled.
-> the matrix is the one that transforms during processing
-> Interface is also formed during processing.

Processing must ensure:

- to preserve the integrity of the reinforcement, its orientation, its architecture if needed.
- to provide a matrix that intimately bonds to the reinforcement, develops desired mechanical properties, and presents few defects.
- to be as cheap as possible, and as fast as possible to process for a given set of requirements.

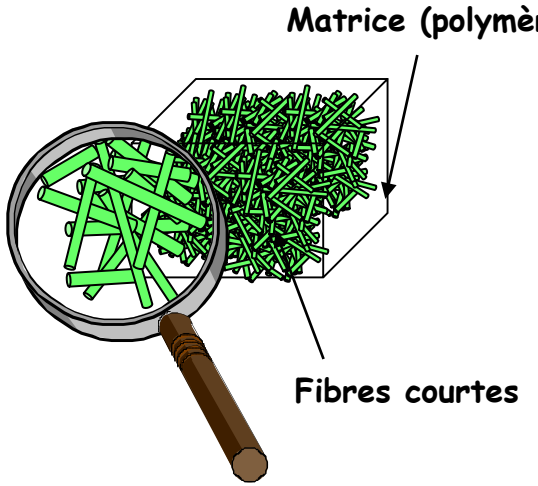
Form factor



- Fibres orientées
- Composites unidirectionnels (UD)
- Thermodurcis, thermoplastiques

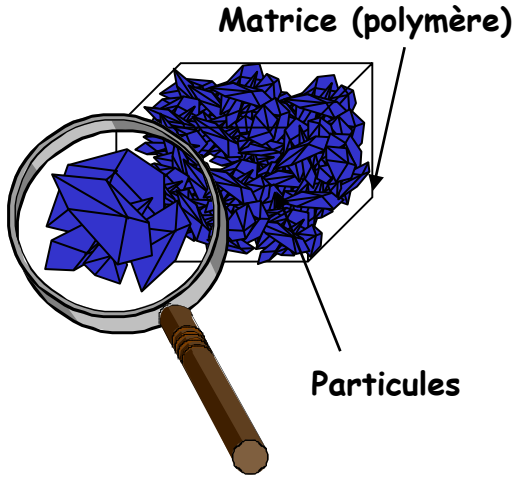
L/d >1000

Methods adapted to long fibers, fixed



- Distribution de fibres courtes (< 3mm)
- Surtout des matrices thermoplastiques

L/d entre 100 et 1000

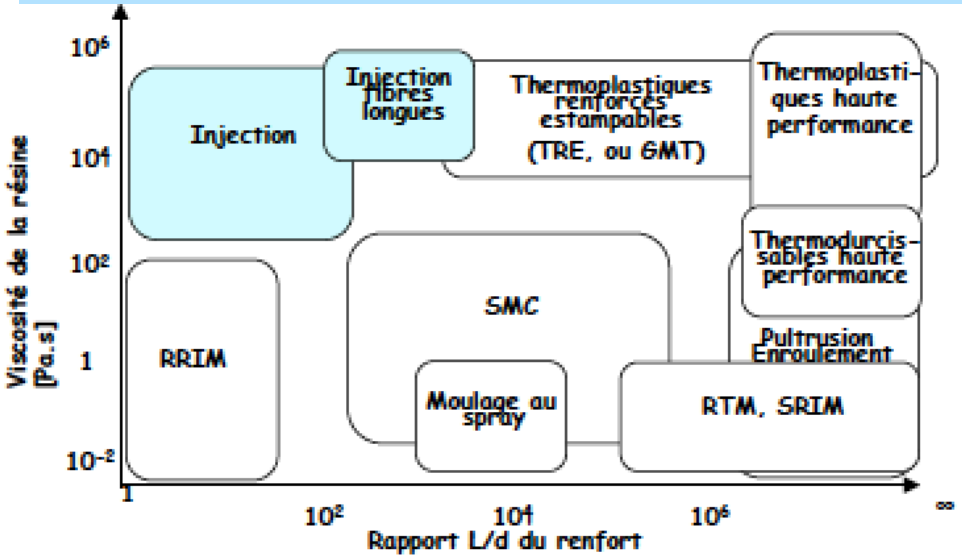


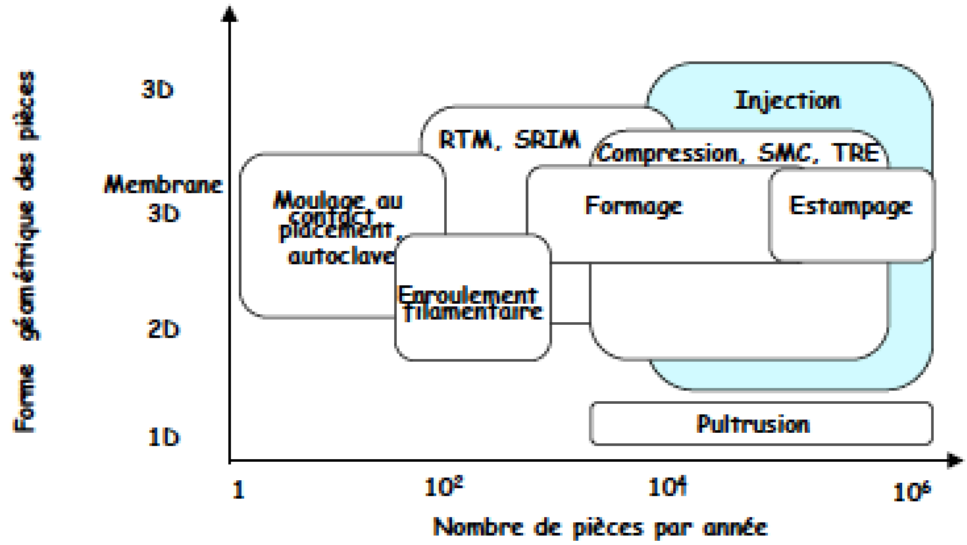
- Particules (1-400μm), silice, argile…
- Thermodurs et thermoplastiques

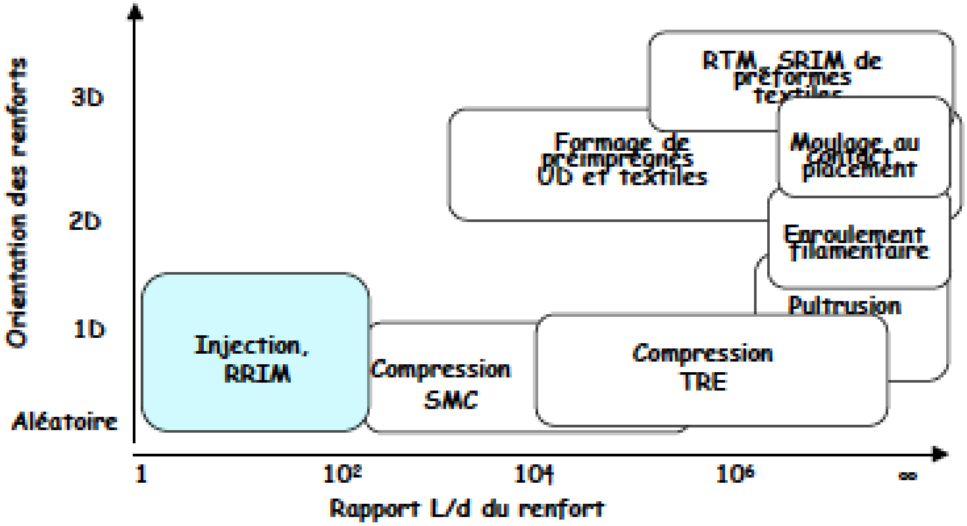
L/d < 100 (et nanorenforts de large L/d)

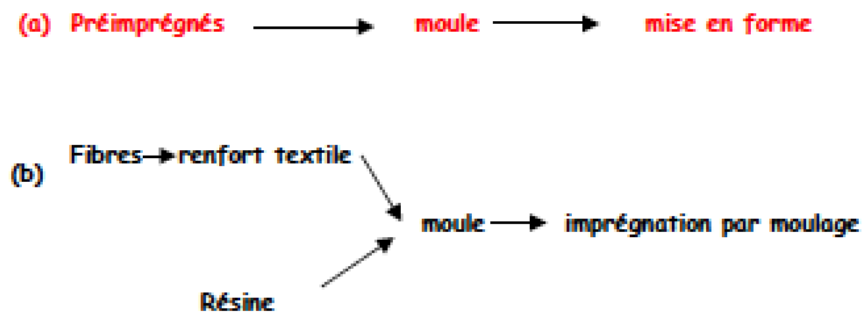
Methods inherited from plastics processing, polymer plus charges

Short fibers /thermoplastic resin

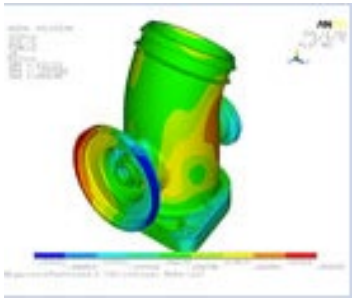








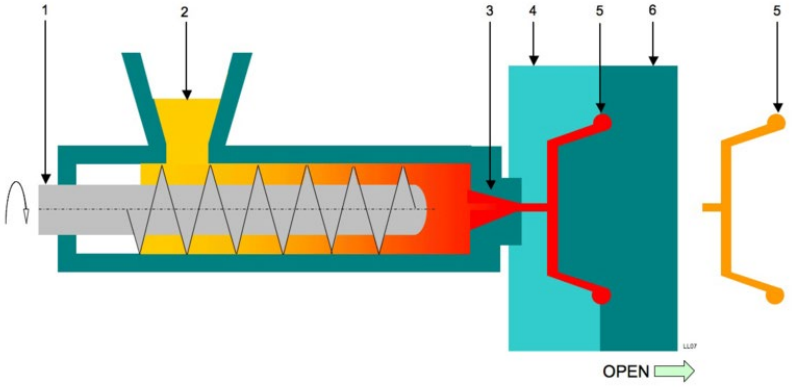
Injection Moulding



http://www.sino-mould.com.cn/auto-mould.html

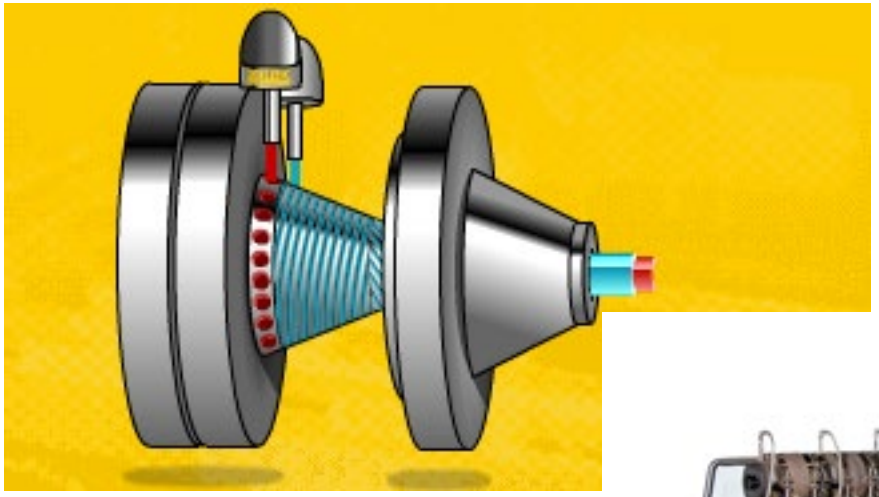
Thermoplastics
Short Fibers

Complex parts



Advantages :	**Drawbacks**
Complex parts High part quality Fast production speed	Tool cost Limited to short fibers Fiber orientation difficult to control Limited to small parts

Extrusion moulding



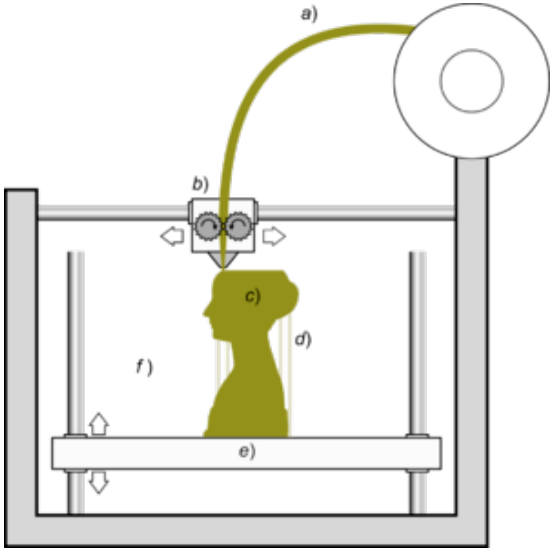
Thermoplastics
Short fibers

Profiles, several layers possible

Twin screw extruder

Advantages :	**Drawbacks**
Cost Part quality High production speed	Tool cost Limited to short fibers Fiber orientation difficult to control Restricted to profiles

3D printing: Fused Deposition Modelling



Wikipedia

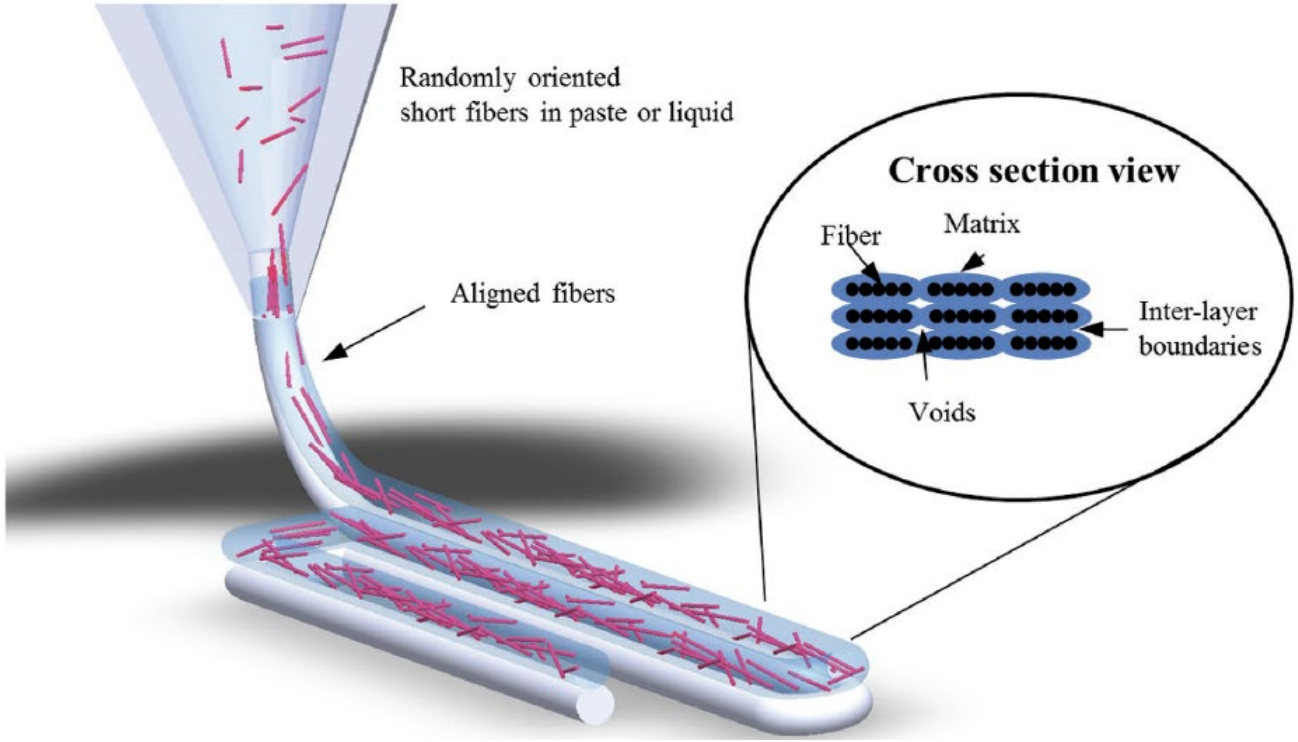
Mark Forged

Thermoplastic matrices
Short fibers
Complex shapes

Arevo labs

Avantages :	**Drawbacks :**
Low cost equipment easy to manufacture prototypes or tailored parts	Limited to short fibers, some attempts with long fibers ongoing. Quality, transverse mechanical properties still limited.

Additive manufacturing: Liquid deposition modeling



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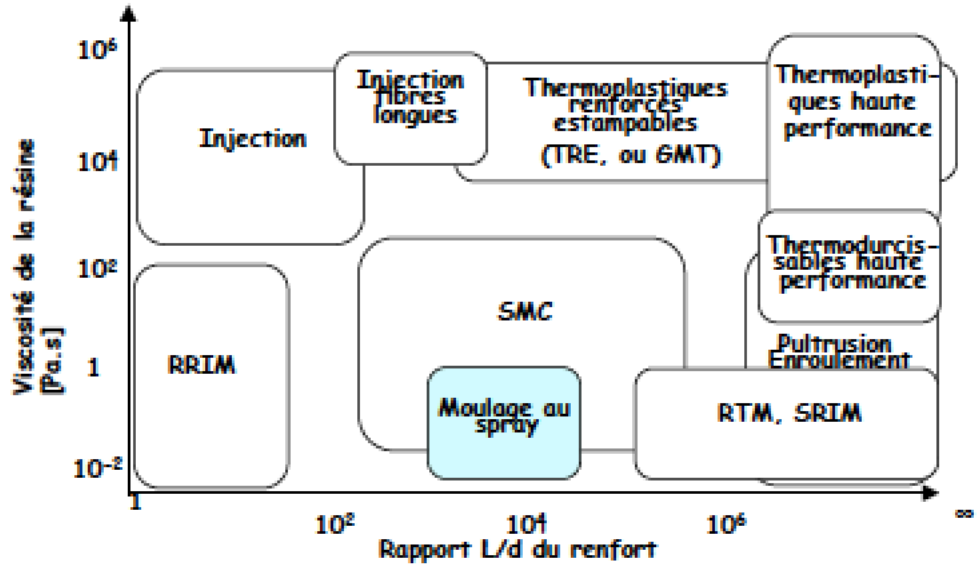
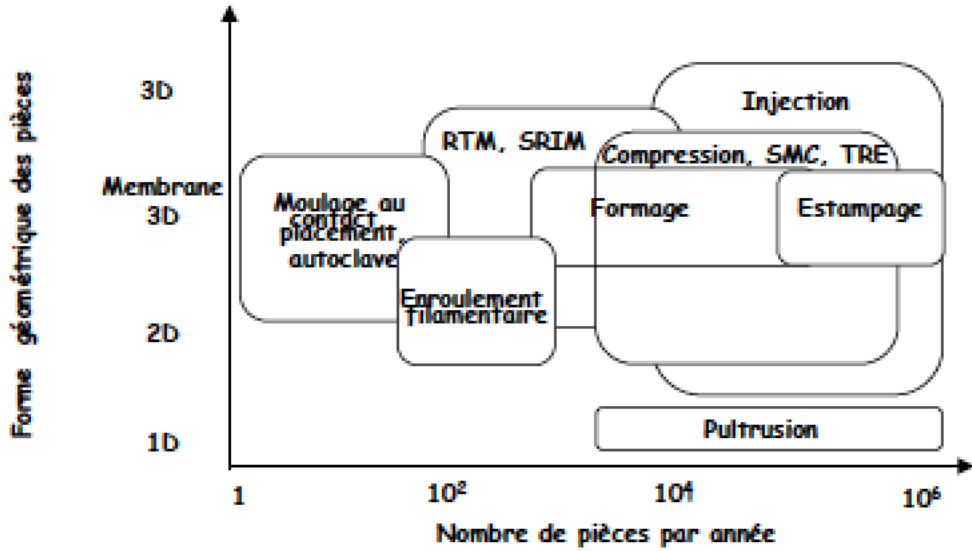
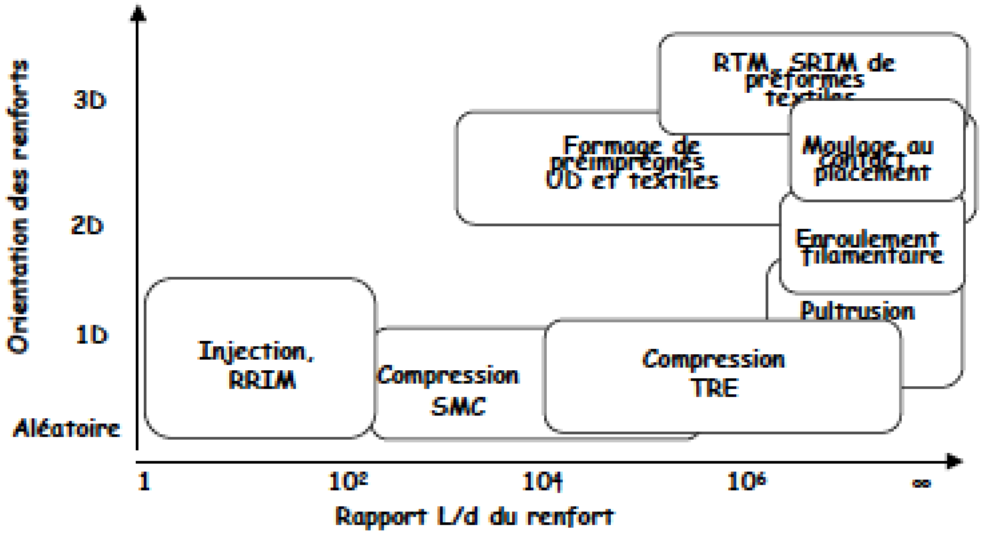
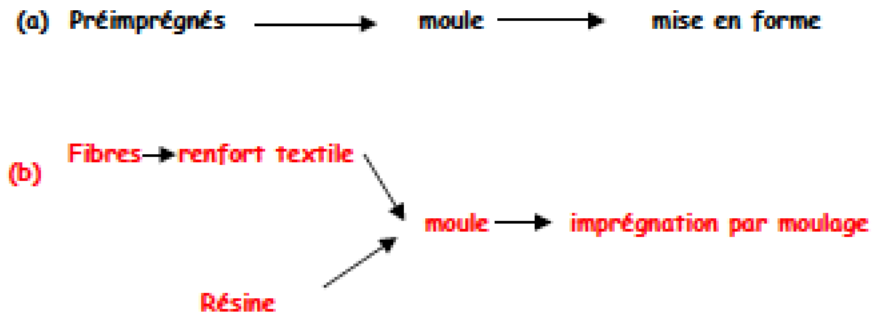
Also possible with thermoset resin, flow-induced orientation of fibers.

A bit less short fibers



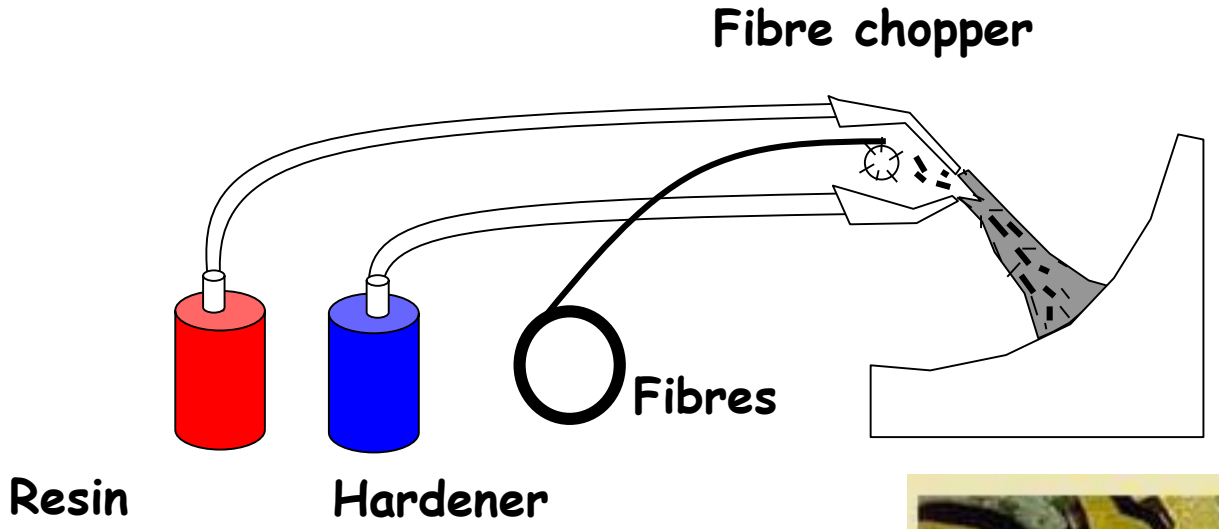




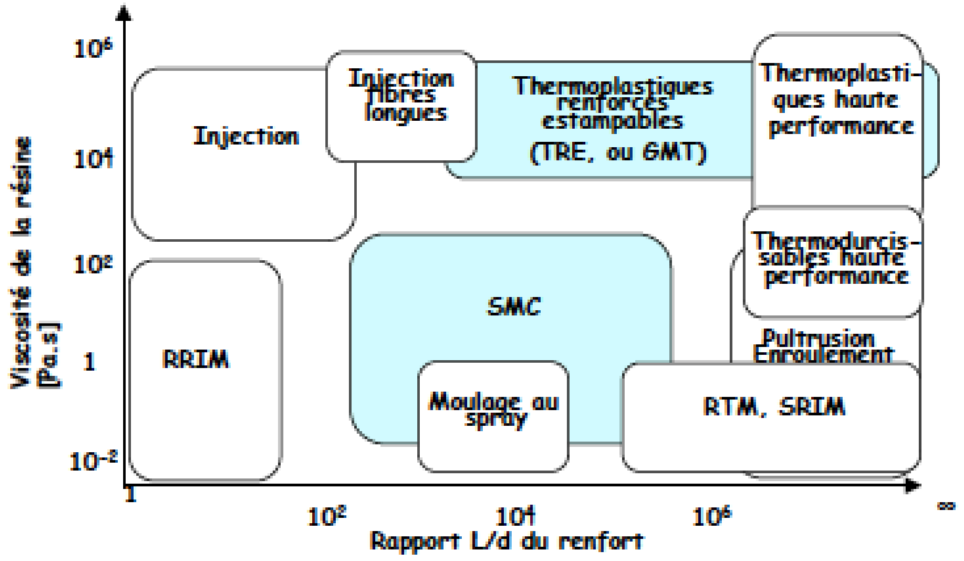


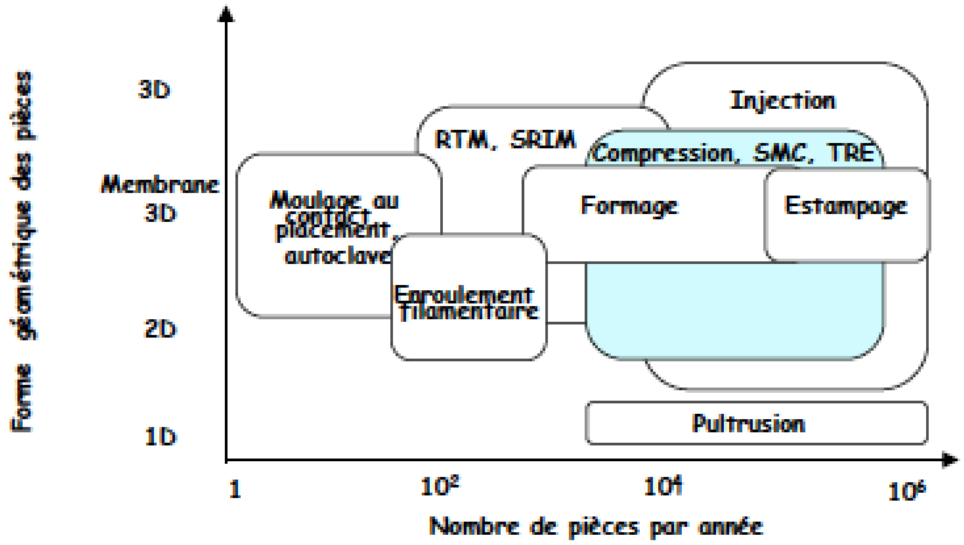
Spray moulding

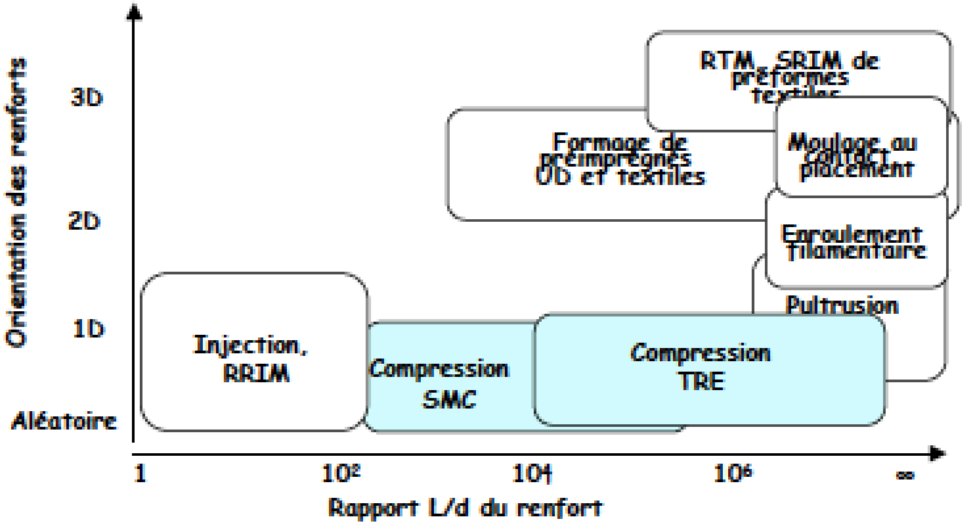
Advantages :	Drawbacks :
Faster rate than wet lay-up No limit in size Light equipment	Numerous and qualified manpower Thcikness control Low stiffness

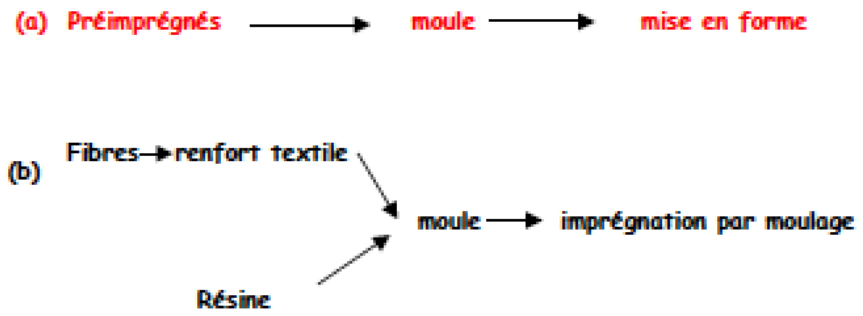


Less short fibers, stamping

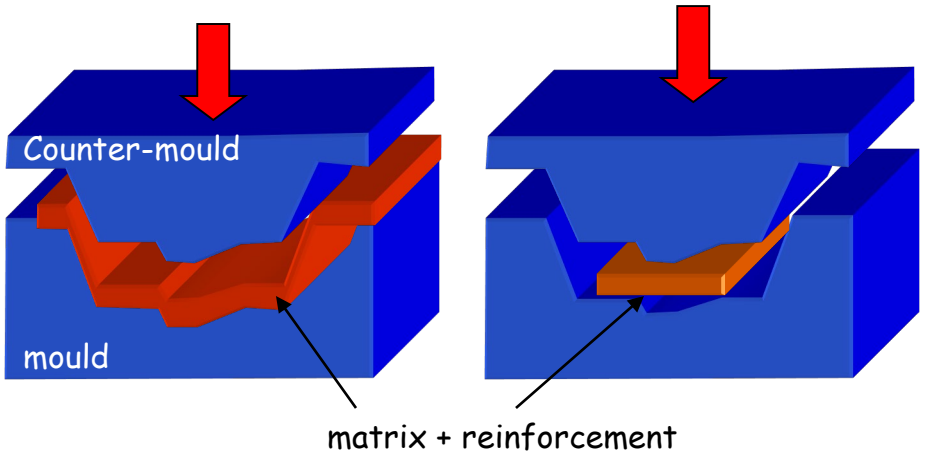








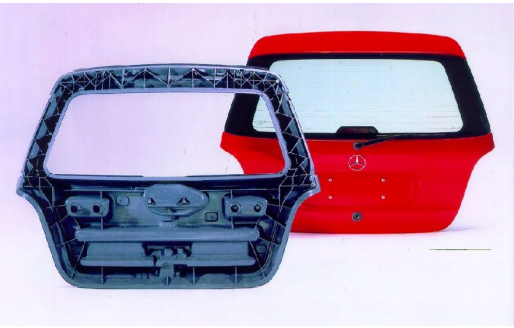
Compression moulding



Without flow **With flow**

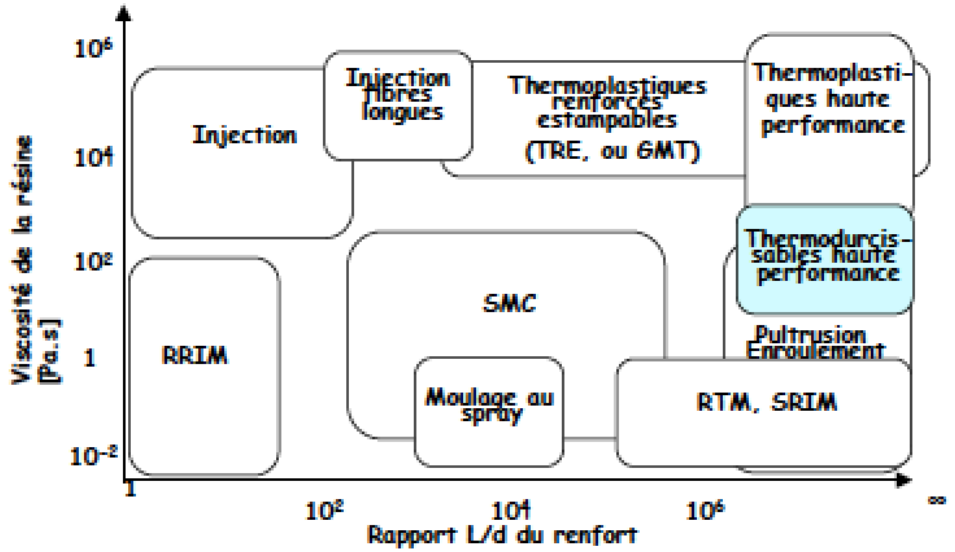
Semi-products processing :
SMC: sheet moulding compound, glass+ polyester
GMT, TRE: glass mat thermoplastics, glass + PP

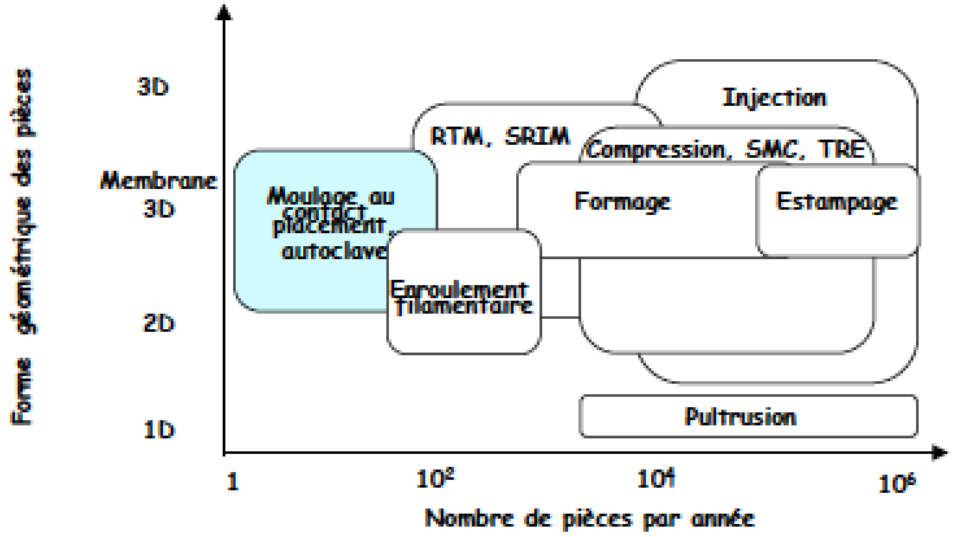
Hoods, car body panels, ….

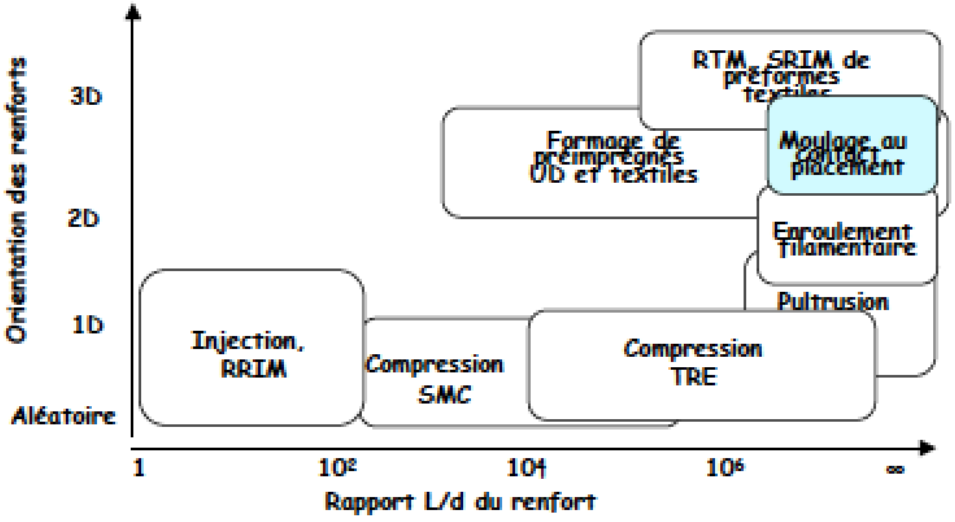


Advantages :	**Drawbacks :**
Large parts moulding Good quality High production rate	Tools cost Trimming necessary Dosing needed for each mould type, potential segregation, fiber orientation

Long fibers


Viscosité de la résine [Pa.s]
10⁶
10⁴
10²
1
10⁻²
Injection
Injection fibres longues
Thermoplastiques renforcés estampables (TRE, ou GMT)
Thermoplastiques haute performance
Thermodurcissables haute performance
SMC
RRIM
Moulage au spray
Pultrusion Enroulement
RTM, SRIM
1
10²
10⁴
10⁶
∞
Rapport L/d du renfort


Forme géométrique des pièces
3D
Membrane 3D
2D
1D
Injection
RTM, SRIM
Compression, SMC, TRE
Moulage au contact placement autoclave
Formage
Estampage
Enroulement filamentaire
Pultrusion
1
10²
10⁴
10⁶
Nombre de pièces par année


Orientation des renforts
3D
2D
1D
Aléatoire
RTM, SRIM de préformes textiles
Formage de préimprégnés UD et textiles
Moulage au contact placement
Enroulement filamentaire
Pultrusion
Injection, RRIM
Compression SMC
Compression TRE
1
10²
10⁴
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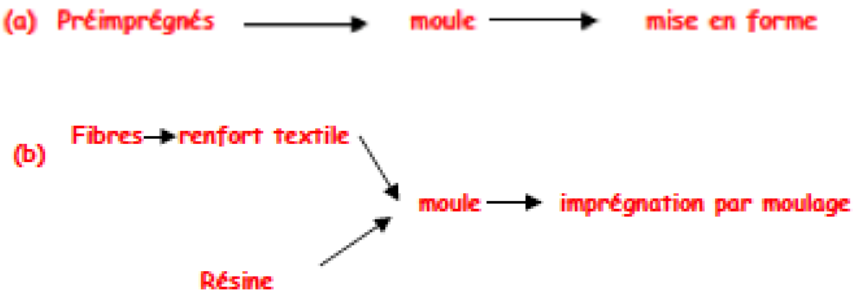
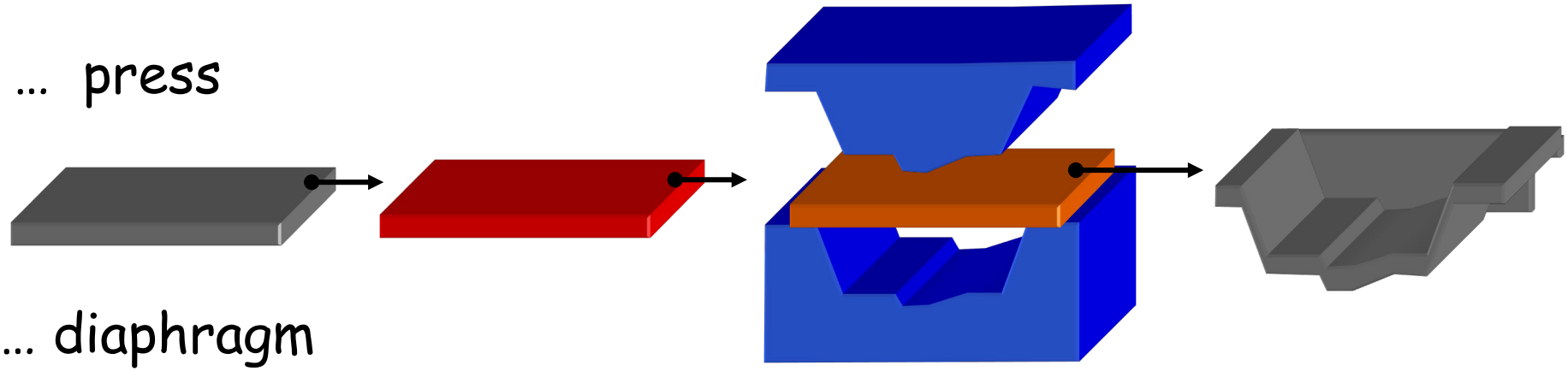
Rapport L/d du renfort

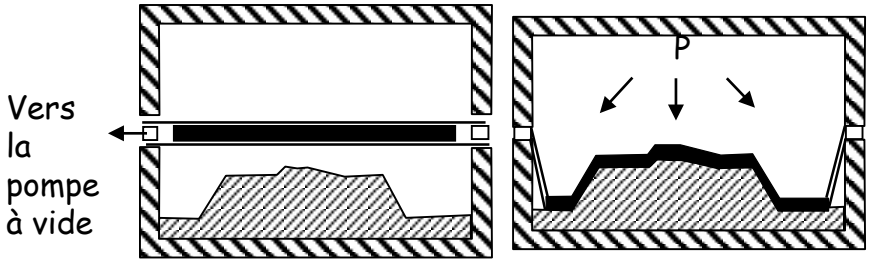

(a) Préimprégnés
moule
mise en forme
(b)
Fibres
renfort textile
moule
imprégnation par moulage
Résine

Thermoforming

… press

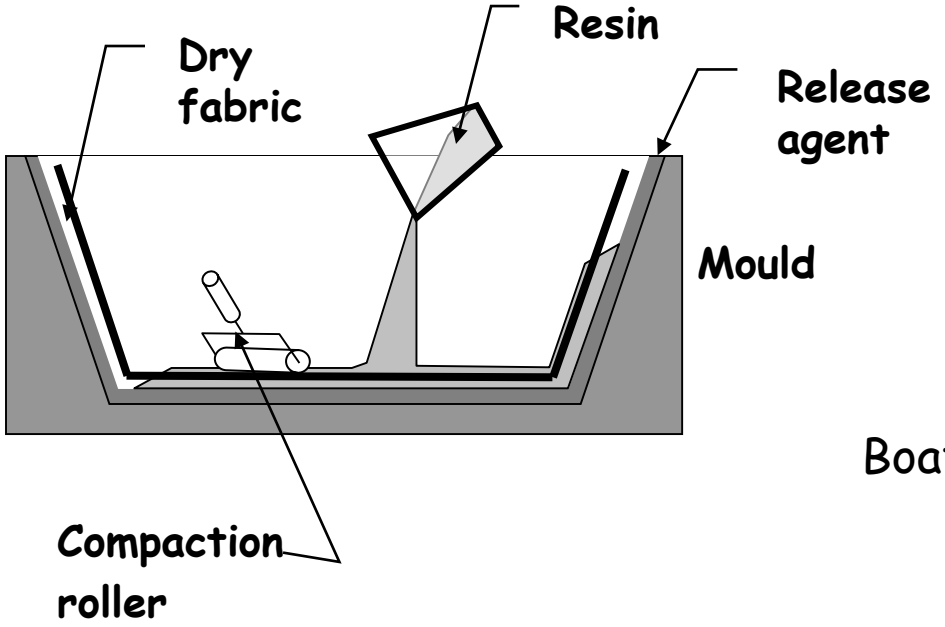


… diaphragm



Advantages :	Drawbacks :
Complex shapes High production rate Good quality	High investments Heat transfer control

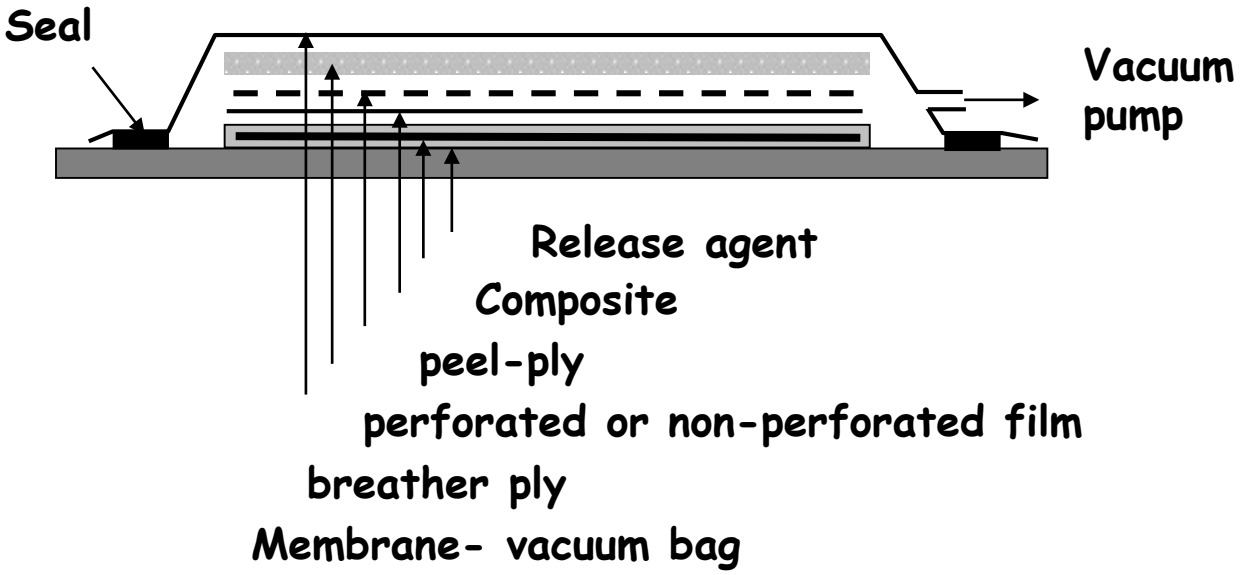
Wet lay-up



Boats, civil engineering

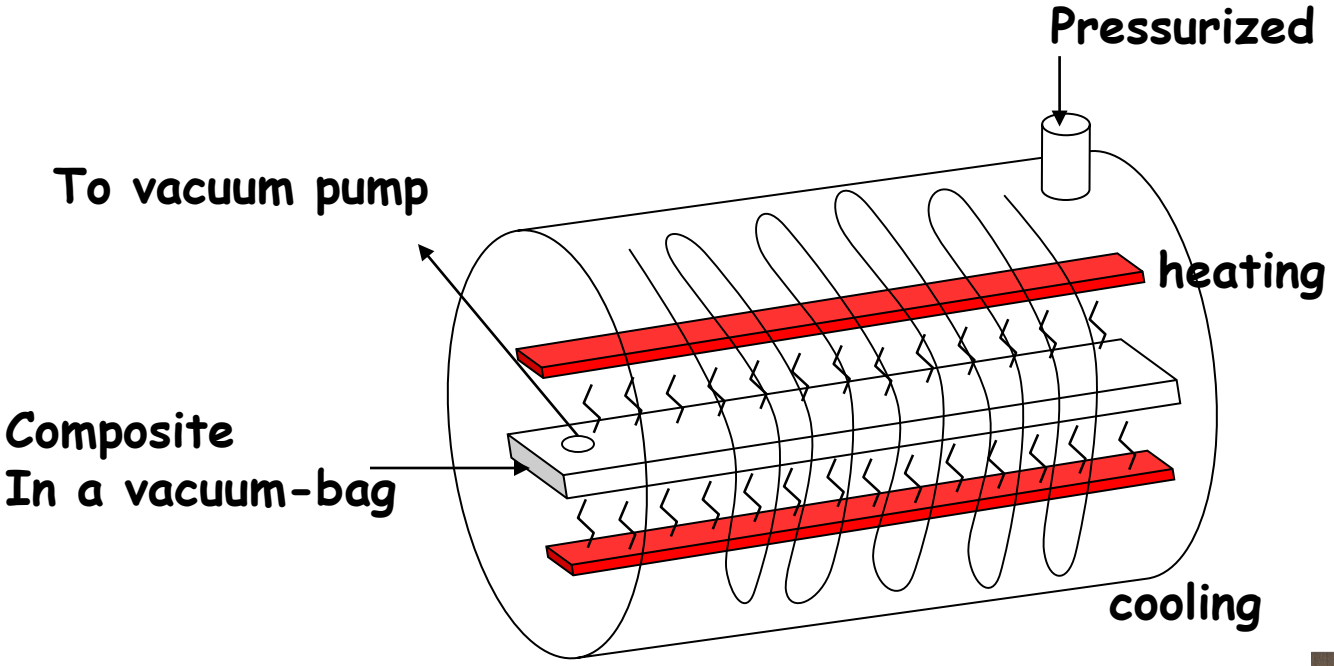
Advantages :	Drawbacks :
Ease of processing Low investments No limitation of size Unqualified manpower	Low production rate Large manpower Thickness control One rough side High void content

Vacuum moulding



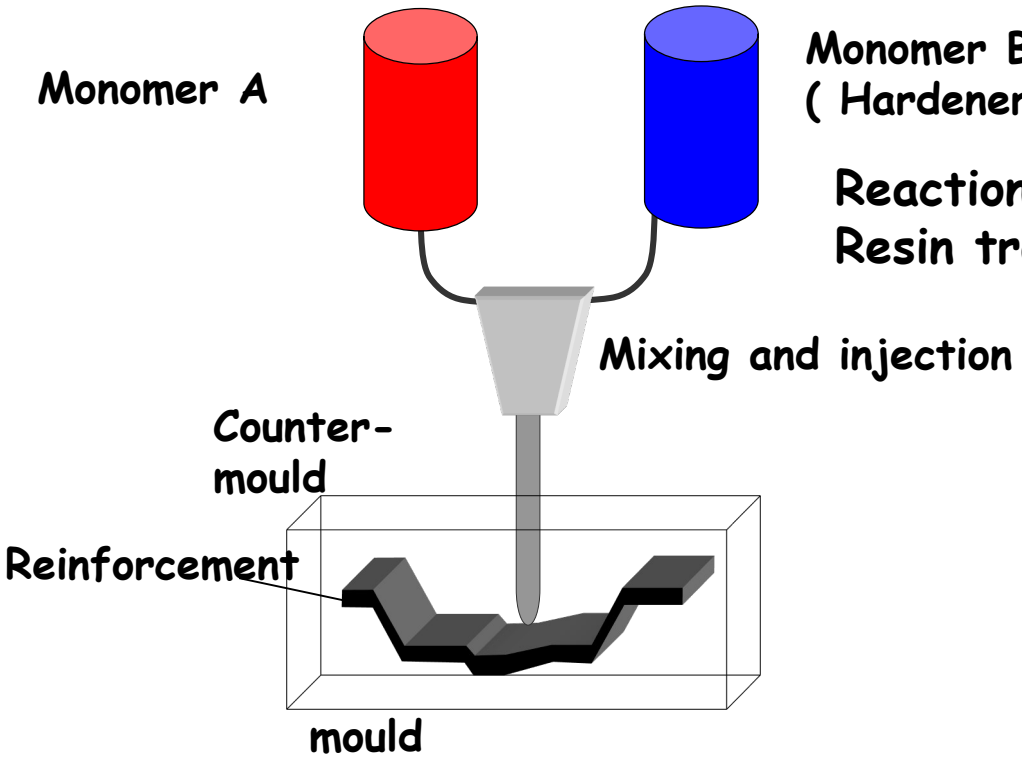
Advantages :	Drawbacks :
Ease of processing Low investments	Low production rate High manpower

Autoclave moulding



Advantages :	**Drawbacks :**
Good parameter control High quality composites	High investments Low production rate

Resin infusion, Liquid composite molding



Reaction injection moulding (RIM, RRIM ou SRIM)
Resin transfer moulding (RTM)

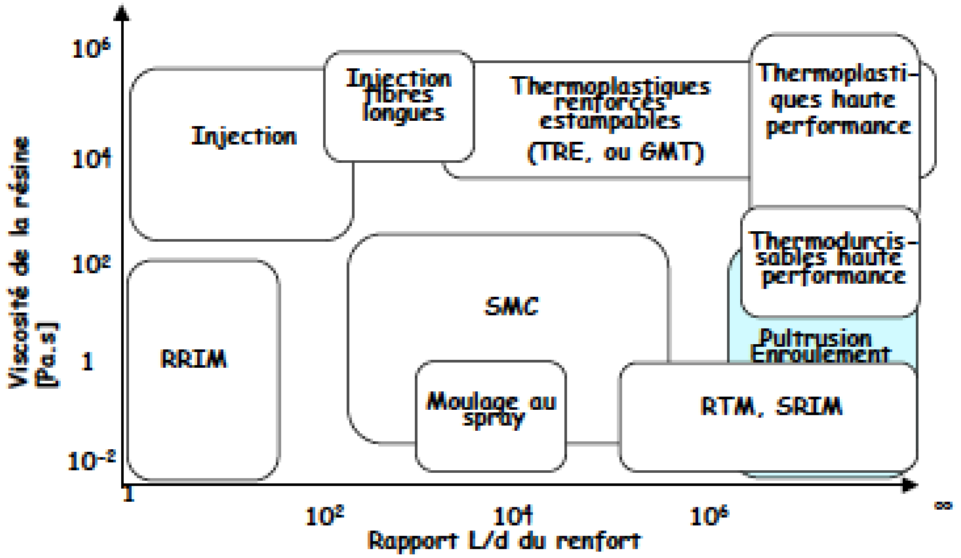
TS and TP (Polyurethane, PA) RTM
Reactive pre-polymers
Short fibres RRIM
or long fibres in the mould SRIM
Vacuum assisted

Advantages :	**Drawbacks :**
Low moulding pressure, low energy large complex parts possible Short cycle time Automatization	Need preforming step for complex parts Risk of dry spots, race tracking... Process variability

Vacuum infusion

Exemple:
Carène de EPFLoop
(2018)

Selection


Viscosité de la résine [Pa.s]
10⁶
10⁴
10²
1
10⁻²
Injection
Injection fibres longues
Thermoplastiques renforcés estampables (TRE, ou GMT)
Thermoplastiques haute performance
Thermodurcissables haute performance
SMC
RRIM
Moulage au spray
Pulrusion Enroulement
RTM, SRIM
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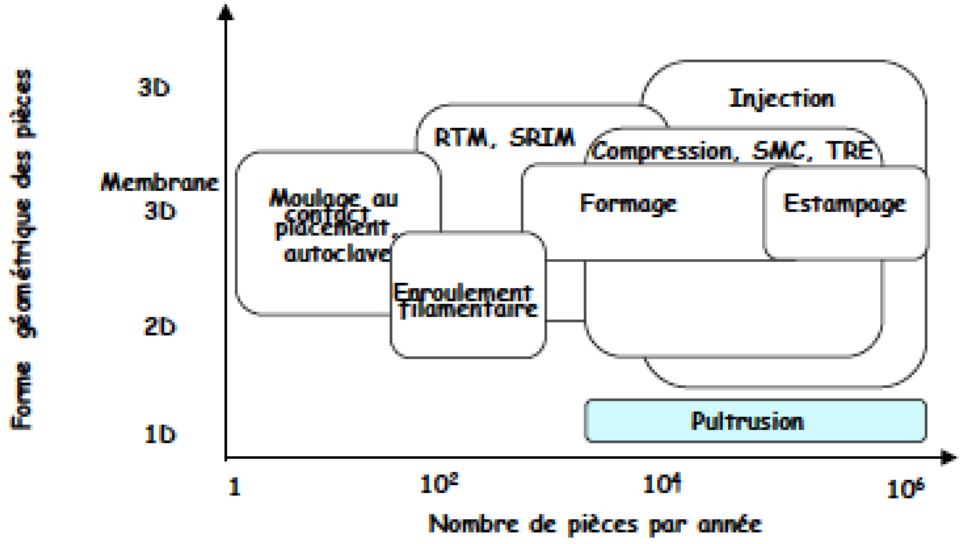
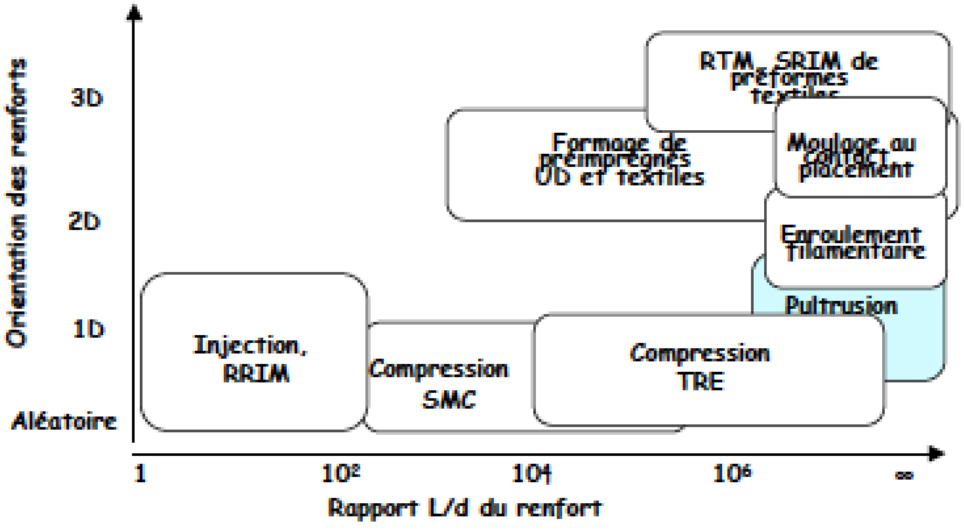
Rapport L/d du renfort


Forme géométrique des pièces
3D
Membrane 3D
2D
1D
Injection
RTM, SRIM
Compression, SMC, TRE
Moulage au contact, placement, autoclave
Formage
Estampage
Enroulement filamentaire
Pultrusion
1
10²
10⁴
10⁶
Nombre de pièces par année


Orientation des renforts
3D
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Aléatoire
RTM, SRIM de préformes textiles
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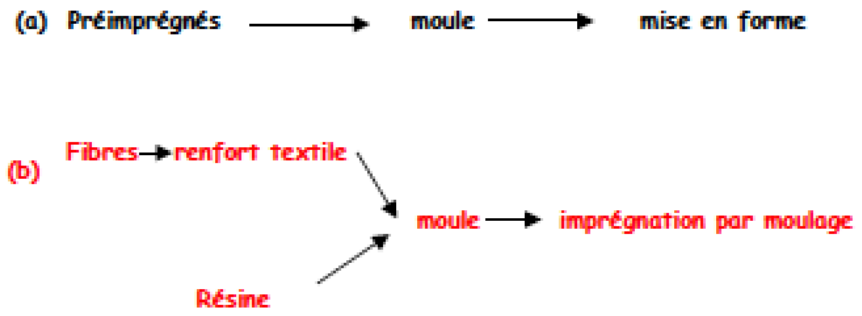
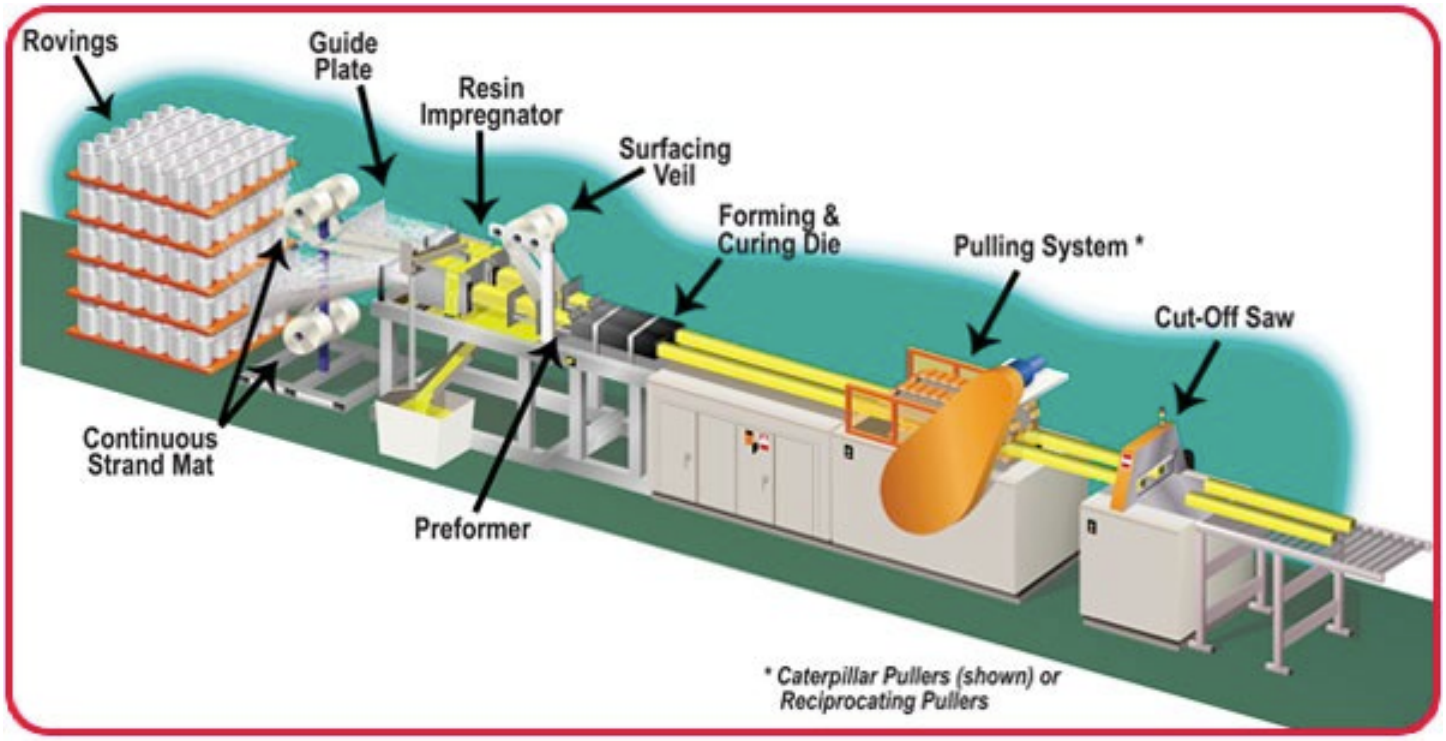
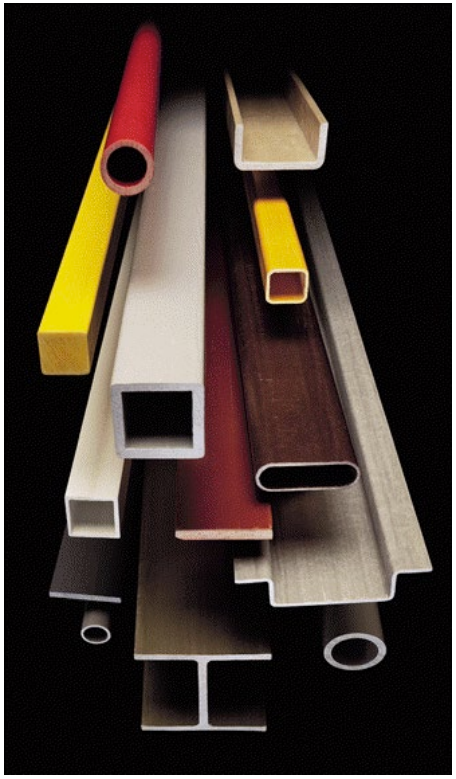

(a) Préimprégnés → moule → mise en forme
(b) Fibres → renfort textile
moule → imprégnation par moulage
Résine

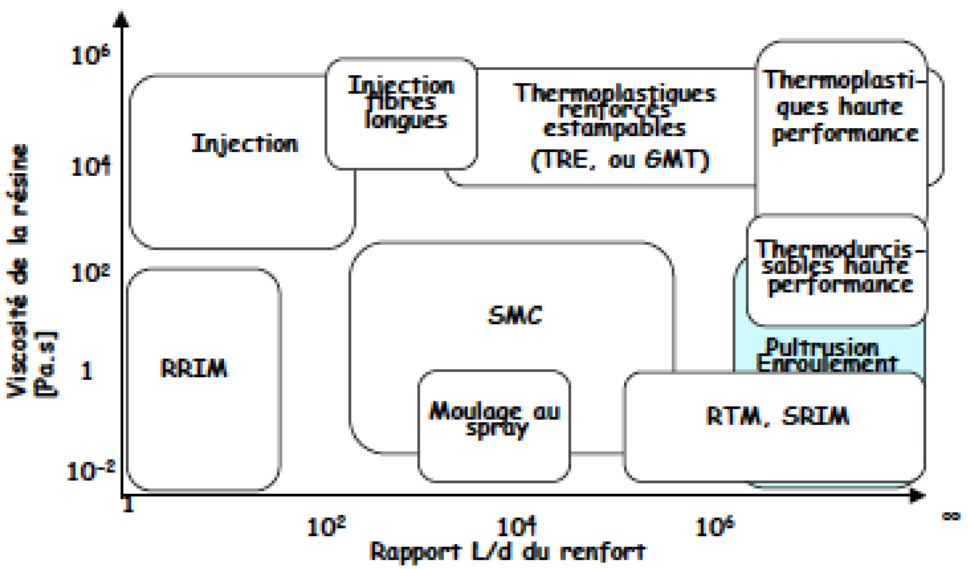
Pultrusion





Advantages :	**Drawbacks :**
Continuous production method Control of the reinforcement volume fraction Automatization High production rate Profiles	High investments Limitations in thickness variation.

Selection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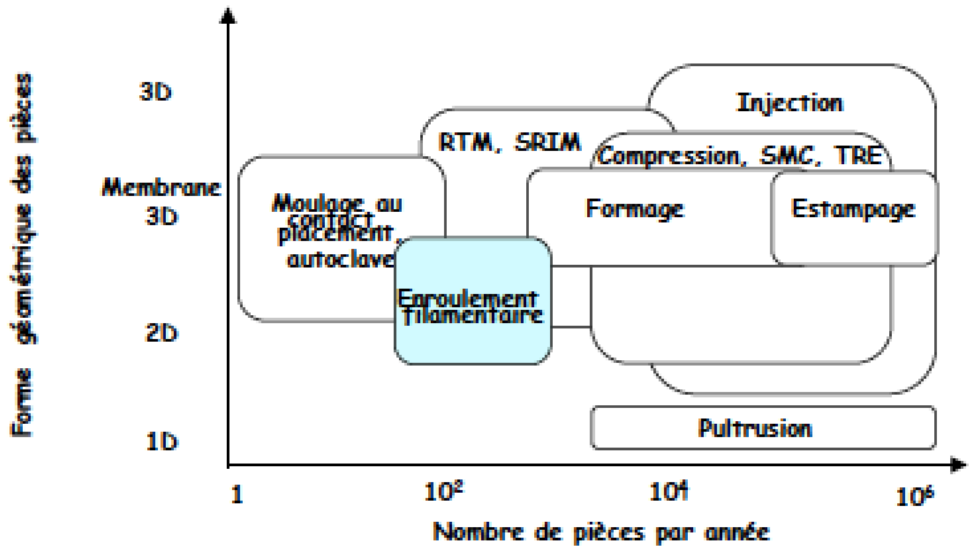
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3D
Membrane 3D
2D
1D
Injection
RTM, SRIM
Compression, SMC, TRE
Moulage au contact placement autoclave
Formage
Estampage
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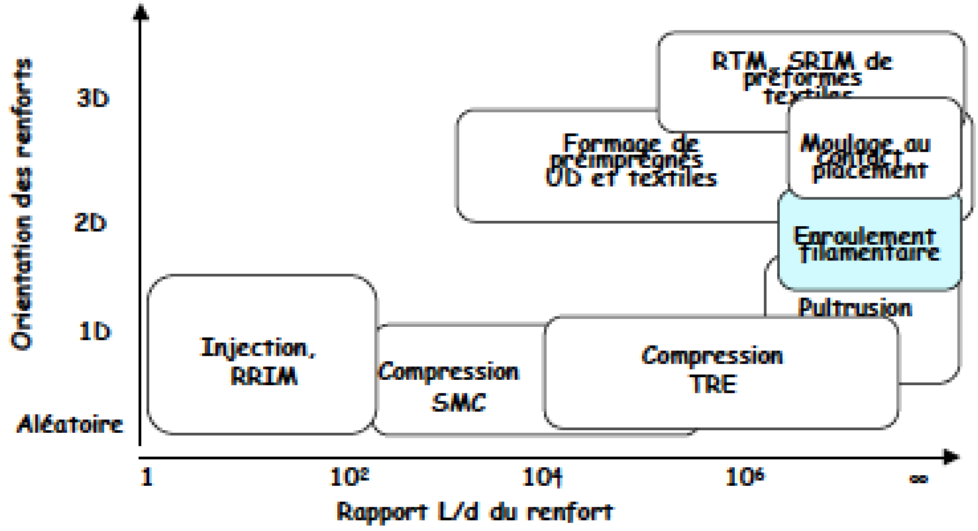
Nombre de pièces par année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RTM, SRIM de préformes textiles
Formage de préimprégnés UD et textiles
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Enroulement filamentaire
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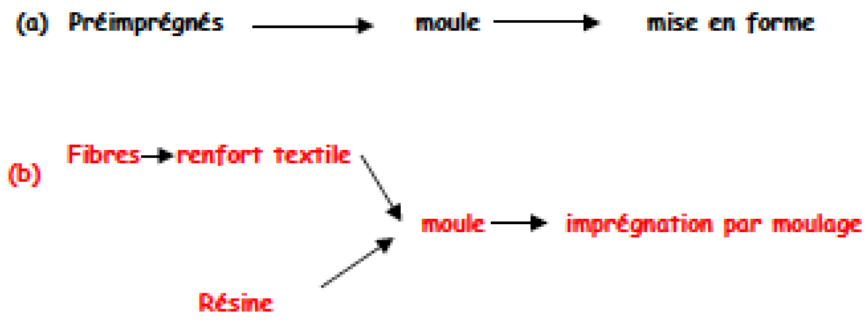
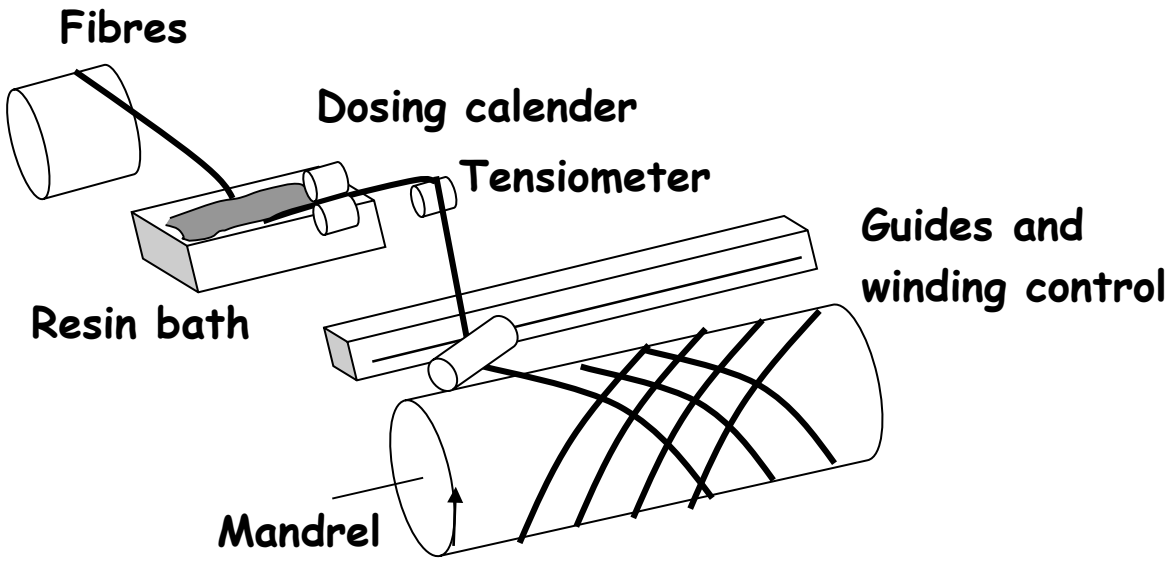

(a) Préimprégnés
moule
mise en forme
(b)
Fibres
renfort textile
moule
imprégnation par moulage
Résine

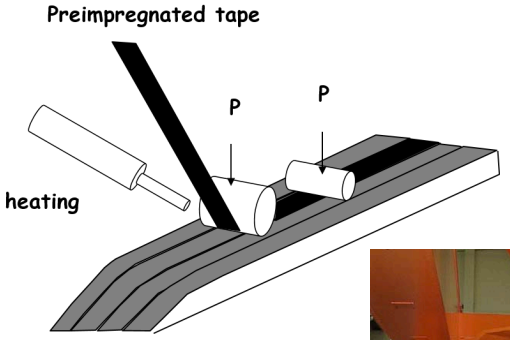
Filament winding

Pressure vessels, tubes….

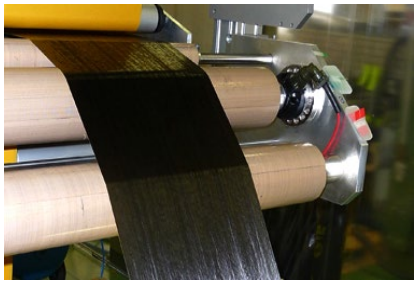


Advantages :	Drawbacks :
Cylindrical parts Internal face smooth, liner Fiber volume up to 80% Preferential fiber orientation	High investments Low production rate External face rough

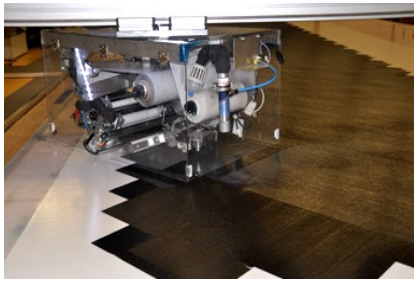
Tape/ tow /fibre placement



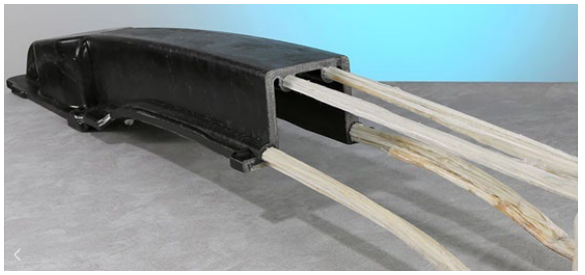
www.thinplytechnology.com



Spread Tow



Tape placement

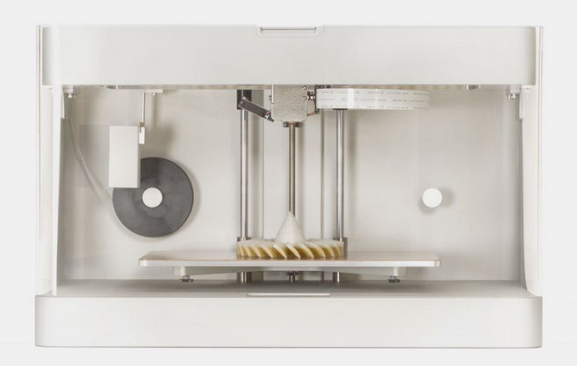


www.eelcee.com

www.inxide.se

Advantages :	**Drawbacks :**
Automatisation Preferential tow or tape placement Convex or concave parts	High investment Bonding control between tapes

markforged.com

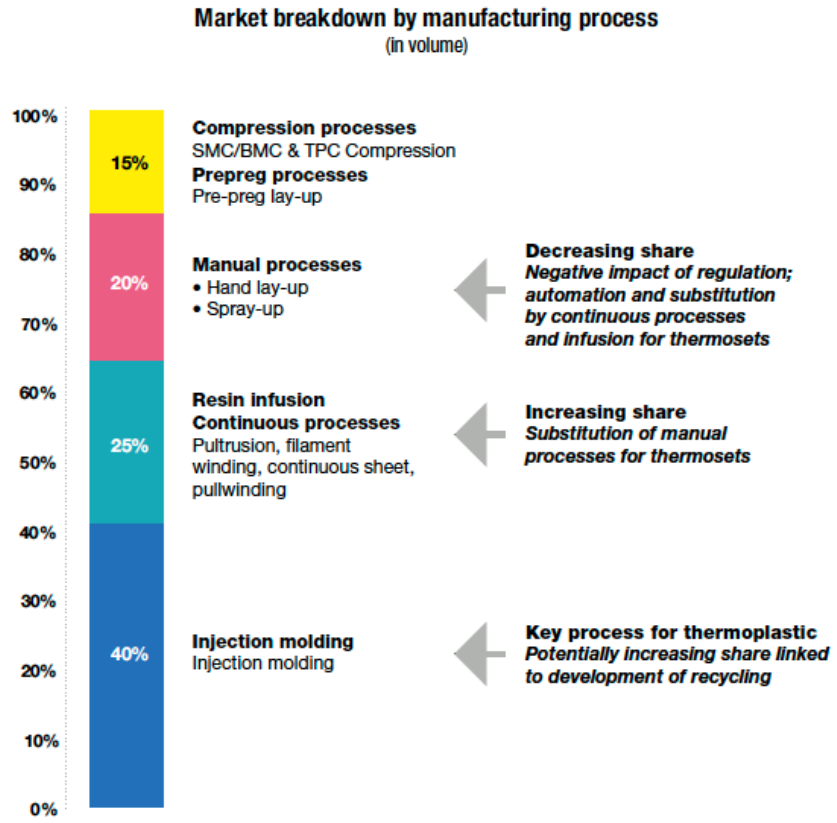


Conclusions

- Many processes exit for making composite materials, depending on the application, volume of production, required mechanical and other properties, etc.

Main processes for composites and key trends

By manufacturing process - 2023 - In volume - (Estimates)



Note: Simplified; others (including TFP, blow molding, bladder molding, diaphragm forming,...) not represented
Sources: Lucintel, interviews, Estin & Co analyses and estimates.