Unit 5 Technical and functional textiles
Lecture 5.2 Advances in composite textile materials

D 2.1 Training toolkit and e-book

Month Year – Savin Dorin Ionesi (TUIASI)

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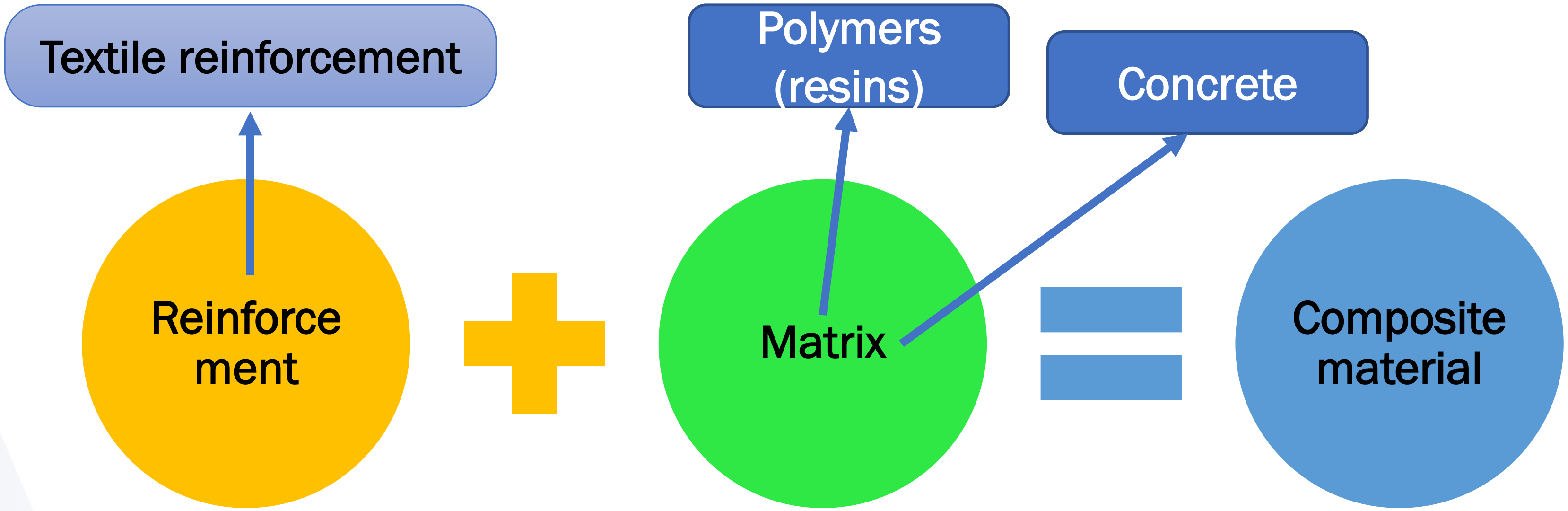
1. General aspects of textile reinforced composites

A **composite material** is a combination of two or more structurally and chemically different materials, with an interface between them.



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Advantages of the textile reinforced composites (TRCs)

- ✓ controlled anisotropy, as the textile structure can be designed so that the fibres are placed along preferential directions to resist maximum strain during use
- ✓ textile reinforcements allow better weigh/strength ratio compared to classic materials, such as steel
- ✓ composites maintain their integrity and behaviour under extreme conditions
- ✓ TRCs present an improved fatigue during their life

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AXIS / Dimension		Non-axial	Mono-axial	Biaxial	Triaxial	Multi-axial
1D			Roving yarn			
2D		Chopped	Pre-impregnation sheet	Plane weave	Triaxial weave	Multi-axial
3D	Linear element	Strandmat	3D braid	Multi-ply WEAVE	Triaxial 3D weave	Multi-axial 3D weave
	Plane element		Laminate type	H or I beam	Honeycomb type	

Classification of textile reinforcements for composites (Fukuta et al.)

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Raw materials for textile reinforcement – High performance fibres (HPFs)

	Carbon fibres	Glass fibres (E)	Aramid fibres
Tensile strength (GPa)	2.0-6.0	1.9-3.0	3.5-4.1
Young's modulus (GPa)	125-400	4.127	70-130
Tensile elongation (%)	<3.5	3-4.5	2.5-4.5
Density (g/cm^3)	1.58	2.66	1.44
Thermal Conductivity at 20 °C ($Wm^{-1}K^{-1}$)	0.04	0.8	0.4
	Used mostly as rovings for applications where low/ medium/high/ultra-high modulus or strength is required	**Cheapest HPF, used for applications where lower mechanical strength is required. Mostly used is glass fibres type E.**	**Higher strength and are lighter than glass fibres, are more ductile than carbon fibres and present high thermal and chemical resistance**

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Matrix	Resin type	Applications
1. Thermoset resins	Epoxy	Aerospace industry, aviation, sport equipment, automotive
	Polyester and vinyl ester	Automotive, shipbuilding, chemical industry, electrical installations, consumer goods
	Polyurethane and polyurea	Automotive (car components)
	Phenols	Aerospace industry and automotive
2. Thermoplast resins	Bismaleimide, polyimide, etc.	Aerospace industry, for applications characterised by very high temperatures
	Nylon 6, nylon 6,6, thermoplastic polyesters (PET and PBT), etc.	Composites with short fibres reinforcement obtained using injection moulding
	Polyetherketone (PEEK), polyphenylene sulphide, polyamide imide, polyether imide, etc.	Composites with short fibres/filament reinforcement, for applications at relatively high temperatures

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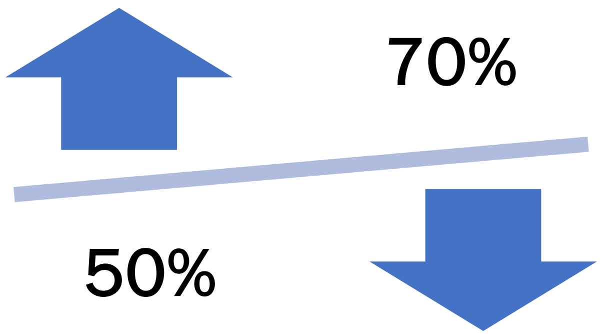
Fibre volume fraction (FVF) represents the percentage of fibre volume in the entire volume of a fibre-reinforced composite material. It is a powerful indicator of the performance of composite materials, showing the direct influence of the reinforcement.

$$FVF = \frac{W_f/\rho_f}{W_f/\rho_f + (1 - W_f)/\rho_a}$$

W_f = mass of fibres in composite (g); ρ_f = fibre density (g/cm^3); ρ_a = resin density (g/cm^3)

the matrix cannot penetrate completely the textile reinforcement



affect mechanical behaviour

Structure of the reinforcement has the most important influence on FVF through the specific fibre/yarn geometry and material density/porosity.

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2. 3D textile reinforcements

Three-dimensional (3D) textile materials are materials with fully integrated continuous fibre assemblies, having multi-axial in-plane and out-of-plane fibre orientation.

Comparison of 3D reinforcement possibilities

Material	Solid	Hollow	Shell	Nodal
Woven	Multilayer Interlock ortho Interlock angle	Multilayer	Single layer Multilayer	Multilayer Interlock ortho Interlock angle
Braided	3D rotary (solid, hexagonal) Cartesian (2/4/6-step)	Tubular/triaxial 2D braiding Multilayer 2D circular braiding	Overbraiding	3D rotary
Knitted	Multiaxial	Spacers (weft/warp knitting)	3D shaped weft knit	Weft knitting Warp knitting
Nonwoven	Multilayer (needle punch)		Cylindrical/conical fibre deposition; Fibre deposition on a mould (meltblown / fibre spray / air laying); Thermobonding	

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Advantages:

- increased complexity of the shapes that can be obtained without any assembly, thus eliminating cutting and assembly operations and resulting waste.
- strict control of the material behaviour along all 3 axes through fabric architecture and yarn characteristics. This means the material strength is controlled along all directions from the beginning, its design stage.
- in the case of composites, there is no risks of delamination (when layers of 2D materials are used in composite reinforcement, delamination is a significant problem).
- the possibility of developing hybrid structures that combine textile fibres with other materials with specific properties (like plastics, ceramics, etc.) that can play the role of matrix.

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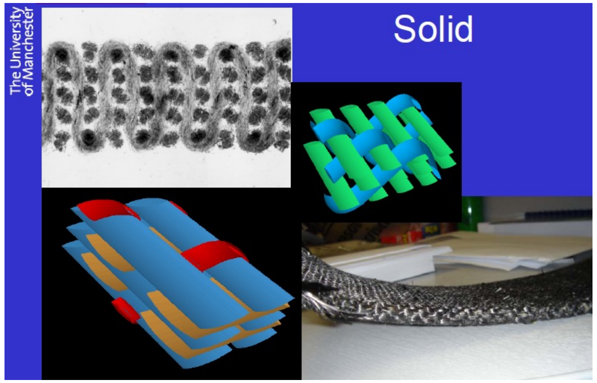
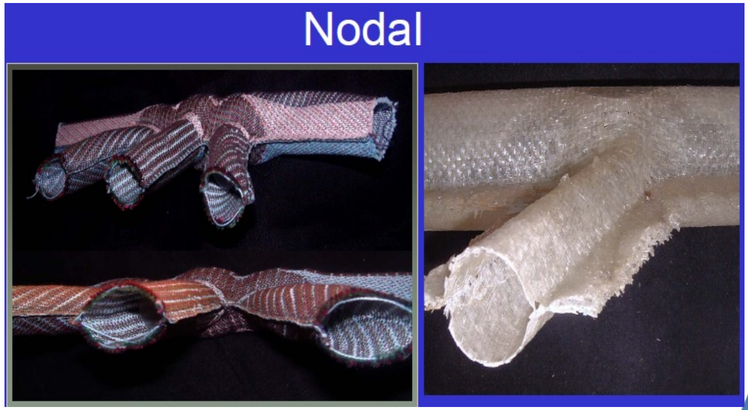
3D woven shapes





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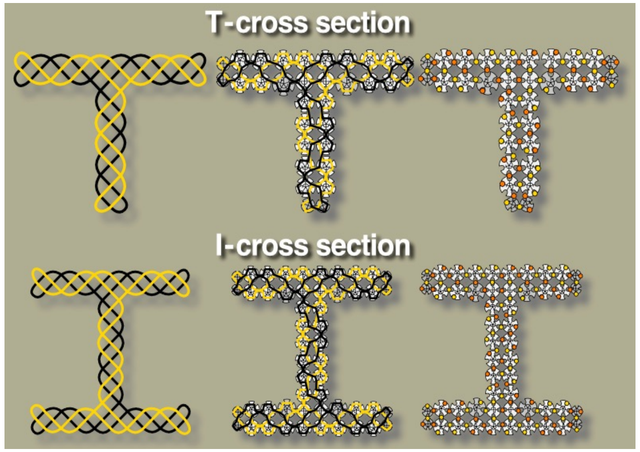
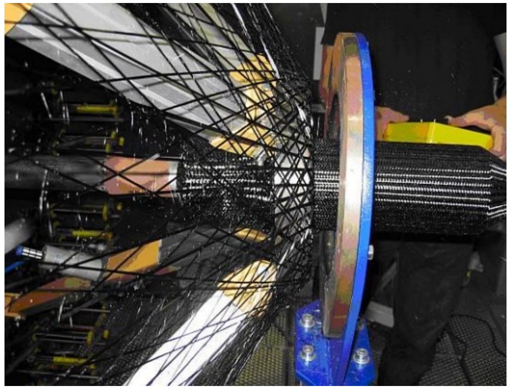
3D braided shapes

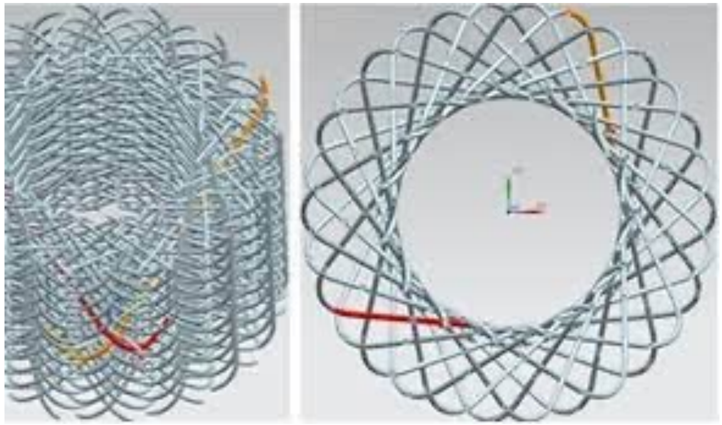
Solid



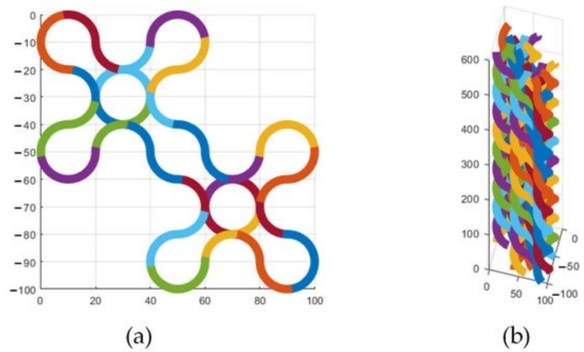
Shell



Hollow



Nodal



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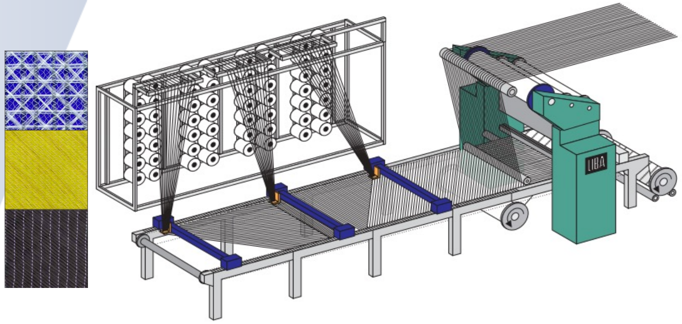
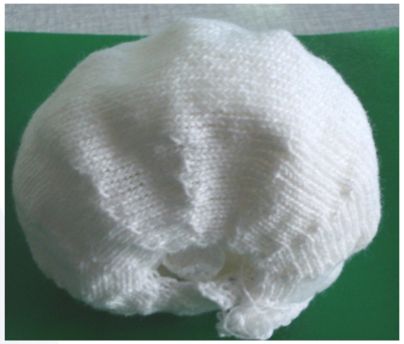
3D knitted shapes



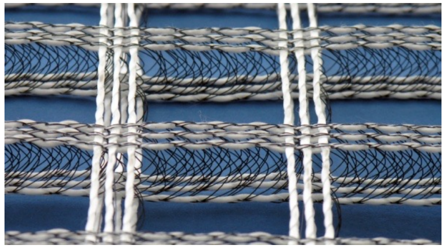
Mutiaxial warp knit (solid)

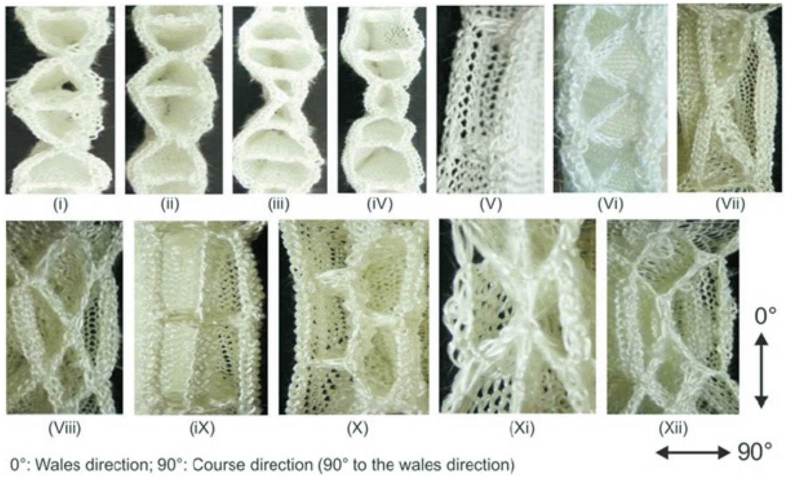
Tubular - nodal

Spacers - hollow



3D shaped (shell)





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3. Advanced manufacturing processes

- how the reinforcement and matrix come into contact - direct processes (the reinforcement and the matrix come into direct contact only during composite manufacturing) or indirect processes (the matrix is included in the reinforcement – hybrid materials)
- type of reinforcement – short fibres or continuous fibres (filaments)
- type of resin – thermoset or thermoplastic
- type of mould – open (single mould) or closed moulding

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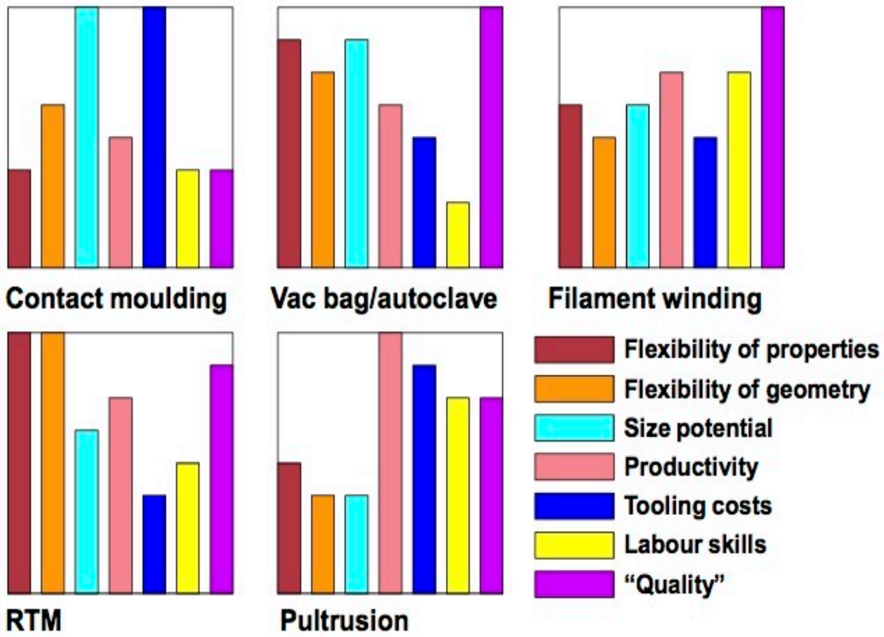
Most common manufacturing processes are

- compression moulding (thermoforming),
- resin transfer moulding (RTM),
- pultrusion,
- filament winding,
- vacuum bag/autoclave,
- contact moulding.



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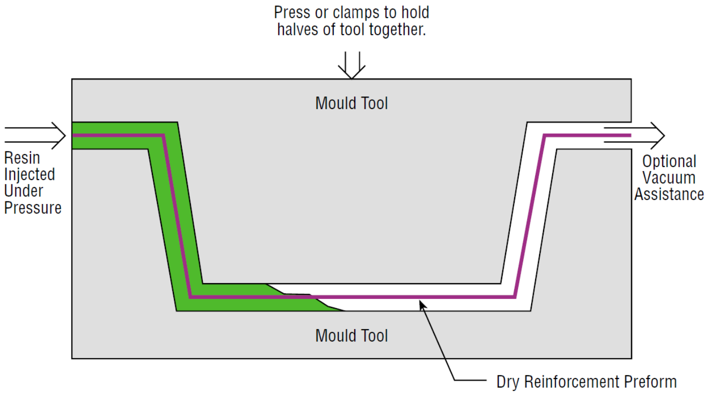
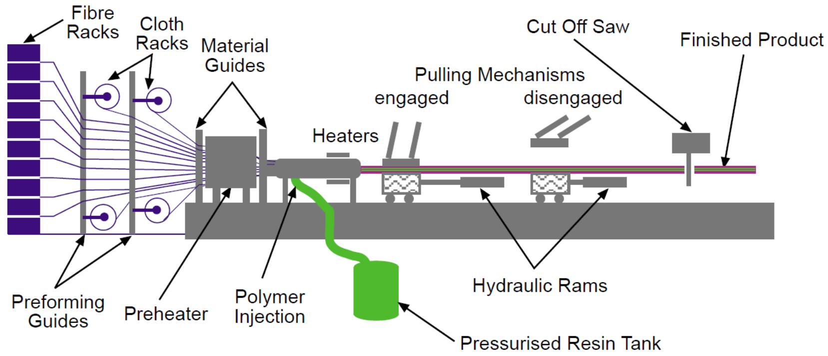
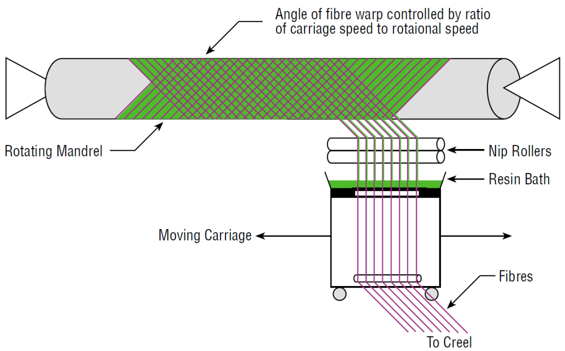


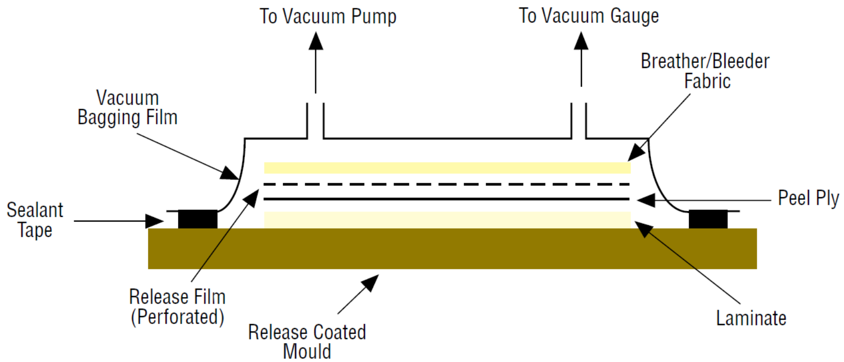
Resin Transfer Moulding



Pultrusion



Filament winding



Vacuum bag/autoclave

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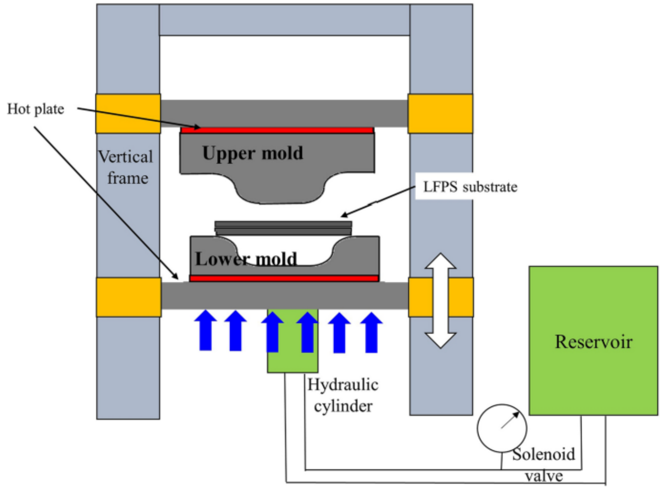
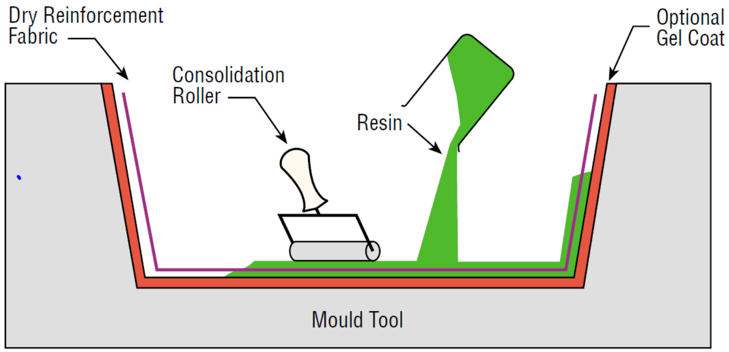
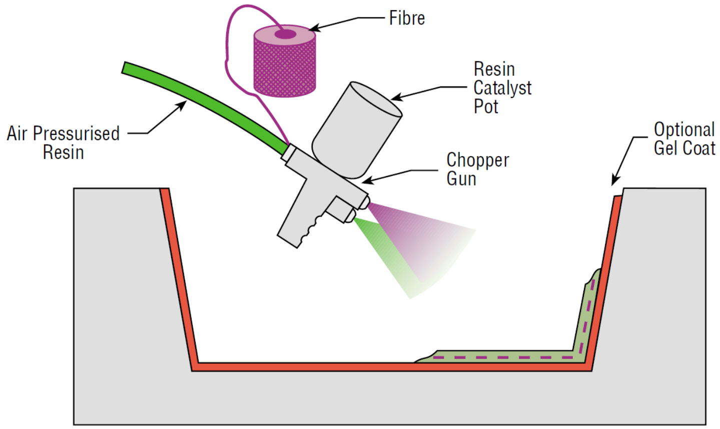


Compression moulding (thermoforming)





Direct manual processes

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Hybrid reinforcements are characterized by the presence of the high-performance reinforcement fibres (glass, carbon, aramid) and other type of fibres that act as matrix when the composite is manufactured.

Hybrid reinforcements (prepregs) are used:

- to reduce the consumption of HPF by using natural fibres like linen, while maintaining the required level of performance (to be discussed in 5.2.5)
- to eliminate the introduction of matrix into the textile reinforcement during composite manufacturing stage, cutting production costs and time. This is done by introducing in the reinforcement material fibres that later under temperature become the matrix (thermoplastic polymers like polypropylene or PEEK).

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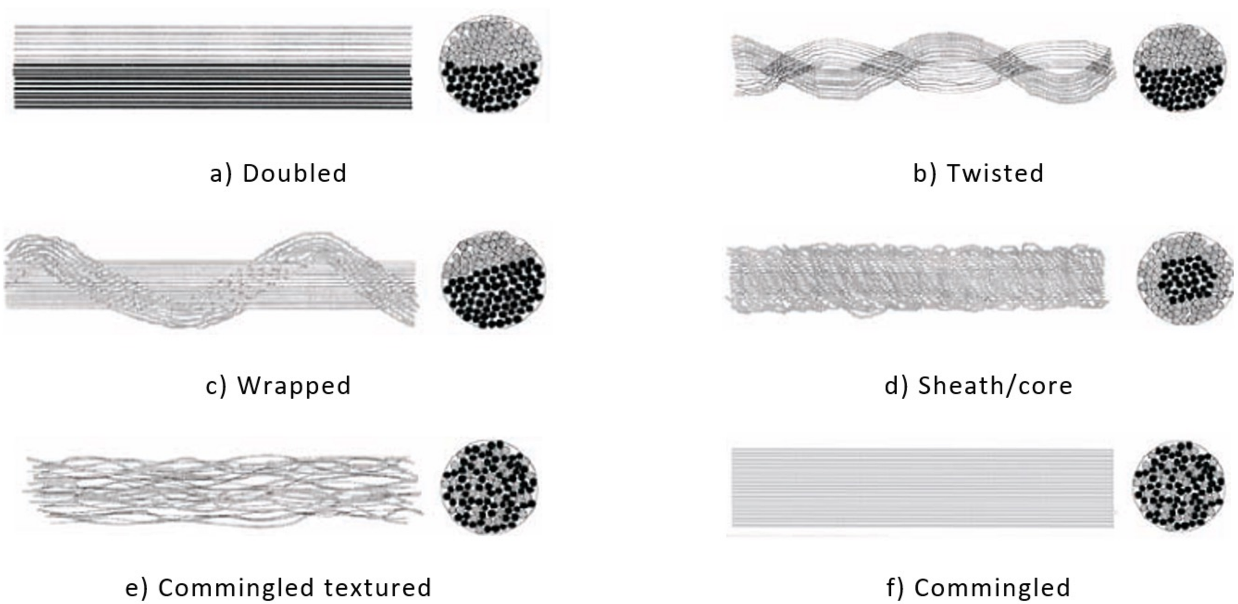
Hybrid yarns used for composite prepregs
(black represents matrix filaments)



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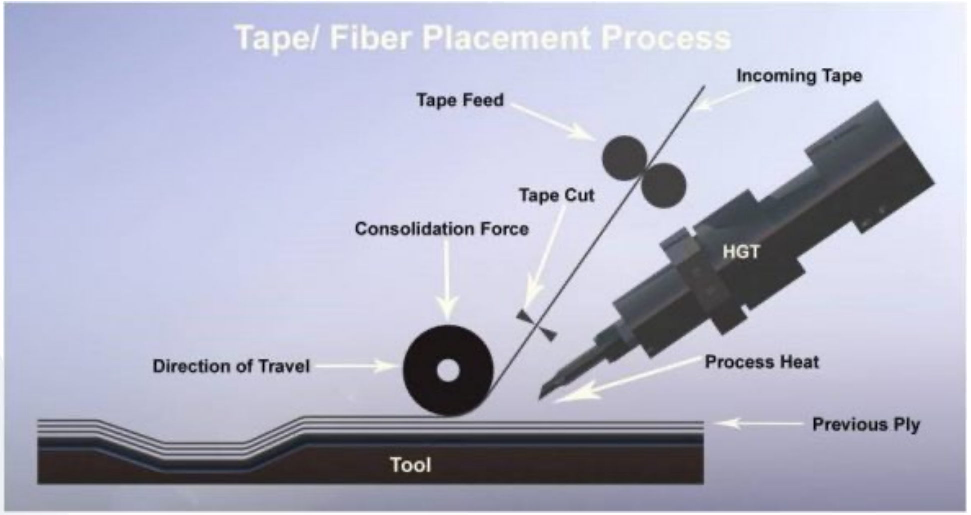
3.2. Automated Fibre/Tape Placement



Tape/fibre feeding takes place in the following conditions:

- Pre-heating (gas, laser, etc) in order to melt the thermoplastic resin or to facilitate the adhesion between layers if a thermoset tape is used
- Under pressure, a roller being placed on the layers to consolidate the ensemble.

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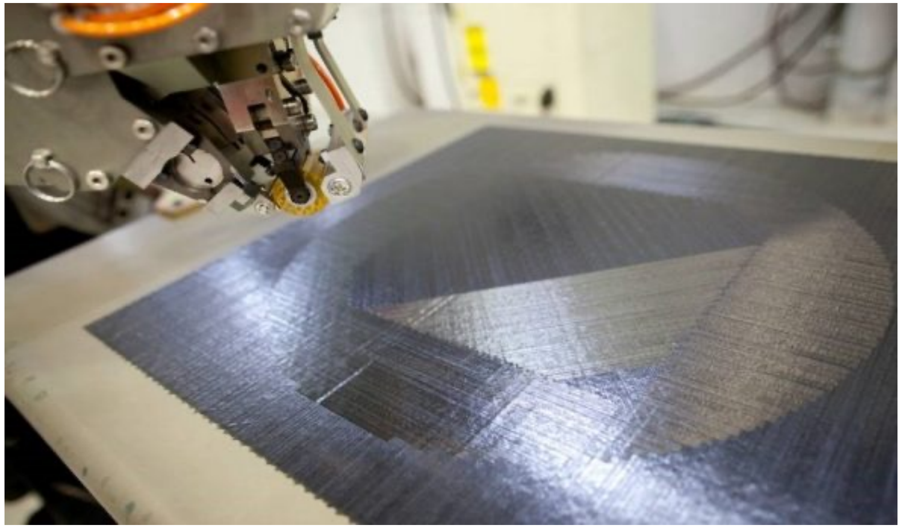
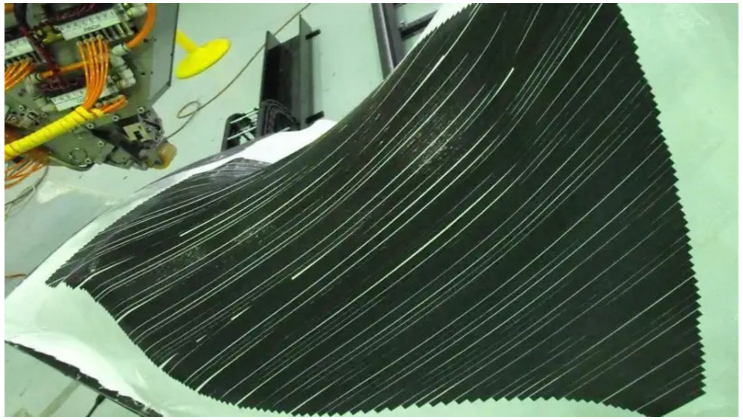


Multiple layers with predefined angles (thermoset AFP)

Trelleborg Sealing Solutions



AFP on surfaces with complex geometries

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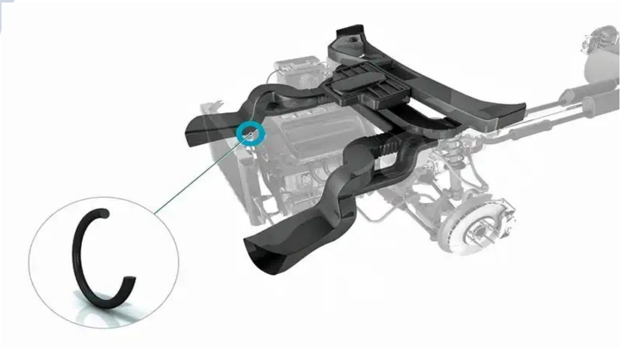
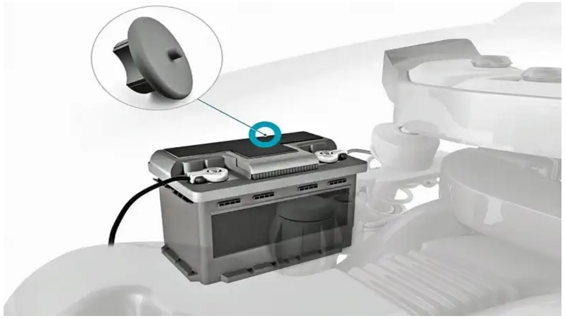
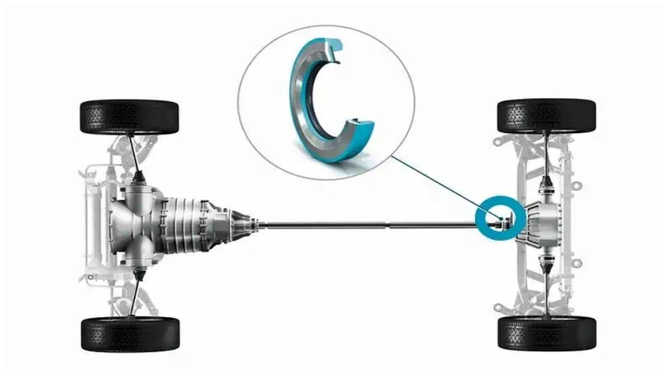


Air Conditioning



Car battery

Car brakes



Drive & transmission

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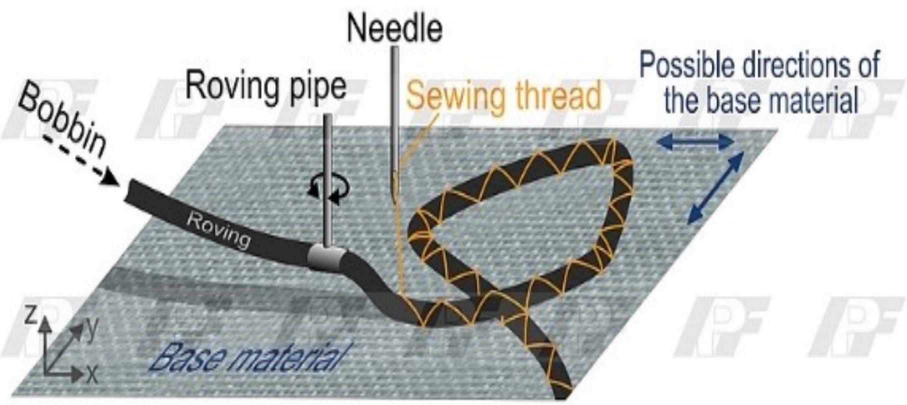
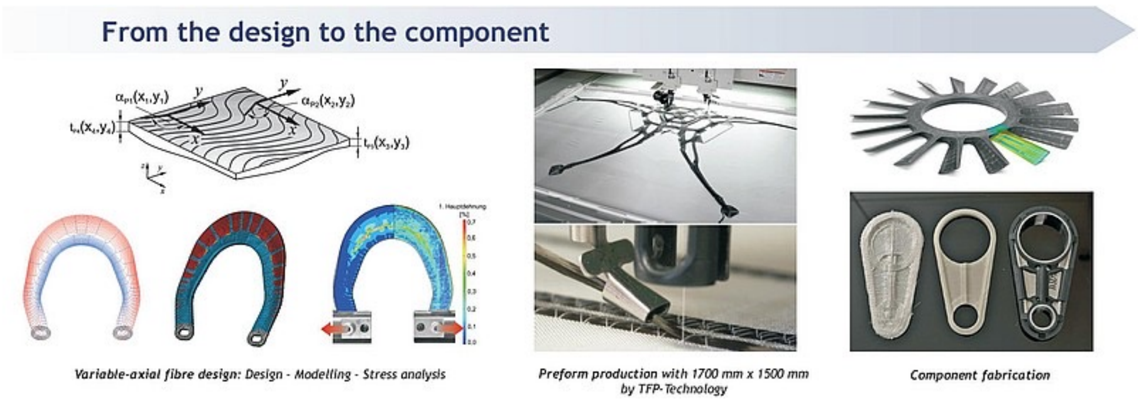


Tailored Fibre Placement

Leibniz-Institut fur Polymerforschung Dresden



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3.3. Additive technologies

Thermoplastic materials (ABS or nylon) are deposed in layer-by-layer technique to create a geometry defined in the design stage.

- Additive manufacturing technologies
  - Fused deposition modelling (FDM)
  - Direct ink writing (DIW)
  - Directed energy-based deposition
  - Binder jetting process
  - Vat photo polymerization
  - Powder bed fusion with a laser sintering process

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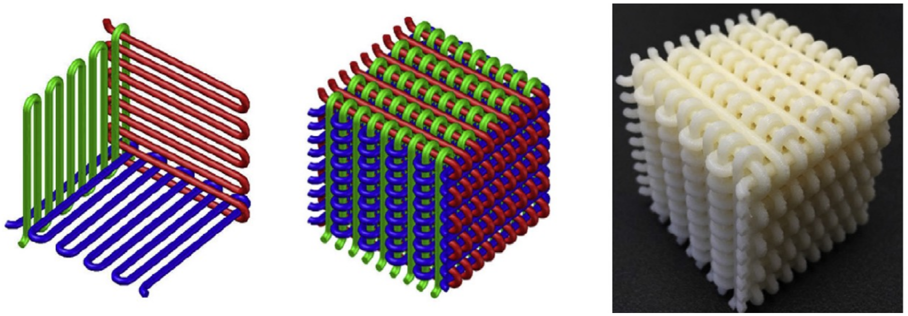
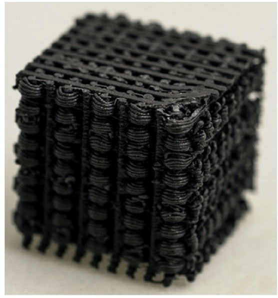
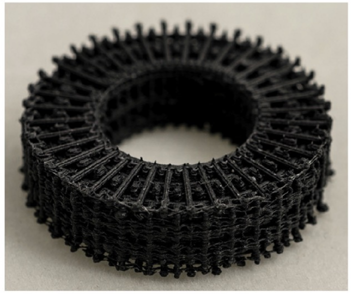


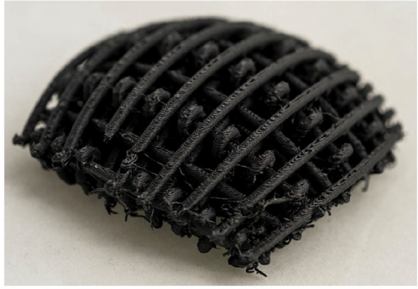


2 cm * 2 cm * 2 cm



(3.5 cm - 1.5 cm) * 1 cm

The process involves the design and 3D printing of the 3D orthogonal preforms using short fibre carbon / thermoplastic ABS wires, followed by the introduction of a silicone elastomeric matrix. The layer-by-layer nature of additive manufacturing enables the fabrication of 3D orthogonal preforms with certain topologies which are not achievable by conventional preforming techniques.



6 cm * 6 cm * 2 cm

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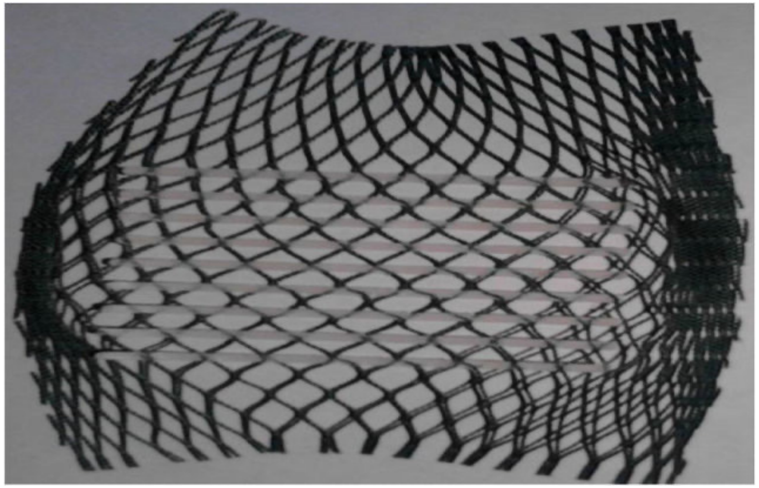
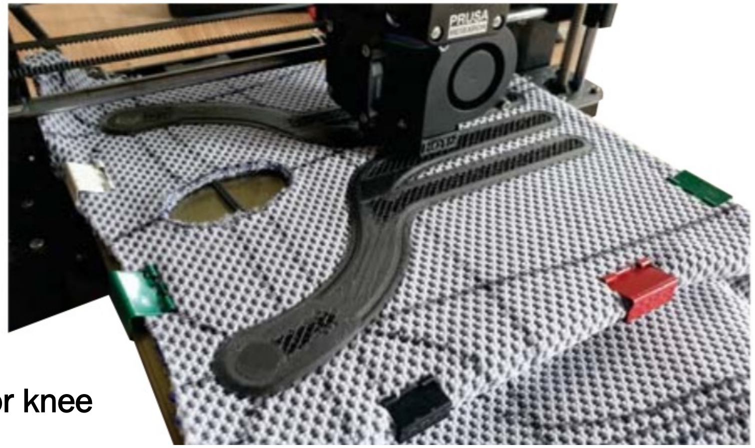


Polylactic acid (PLA) strips with different warp knitted mesh structures as inlays: fishing net produced from 100% polyamide 6



Direct 3D printing of rigid functional elements onto a knitted fabric for knee support
(D. Ahrendt et al., CAE-SUPPORTED PROCESS FOR ADDITIVE MANUFACTURING OF ORTHOPAEDIC DEVICES, International Textile Conference, Dresden , 2019

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4. Smart composites

Smart textiles = textiles capable of sensing different stimuli and have a dynamic response to their action

1. Phase Change Materials
2. Shape memory materials
3. **Conductive materials, electronic textiles**
4. Chromatic materials

monitoring the health of composite materials, improved functionality, sensor/actuator functions and assessment of their life-cycle

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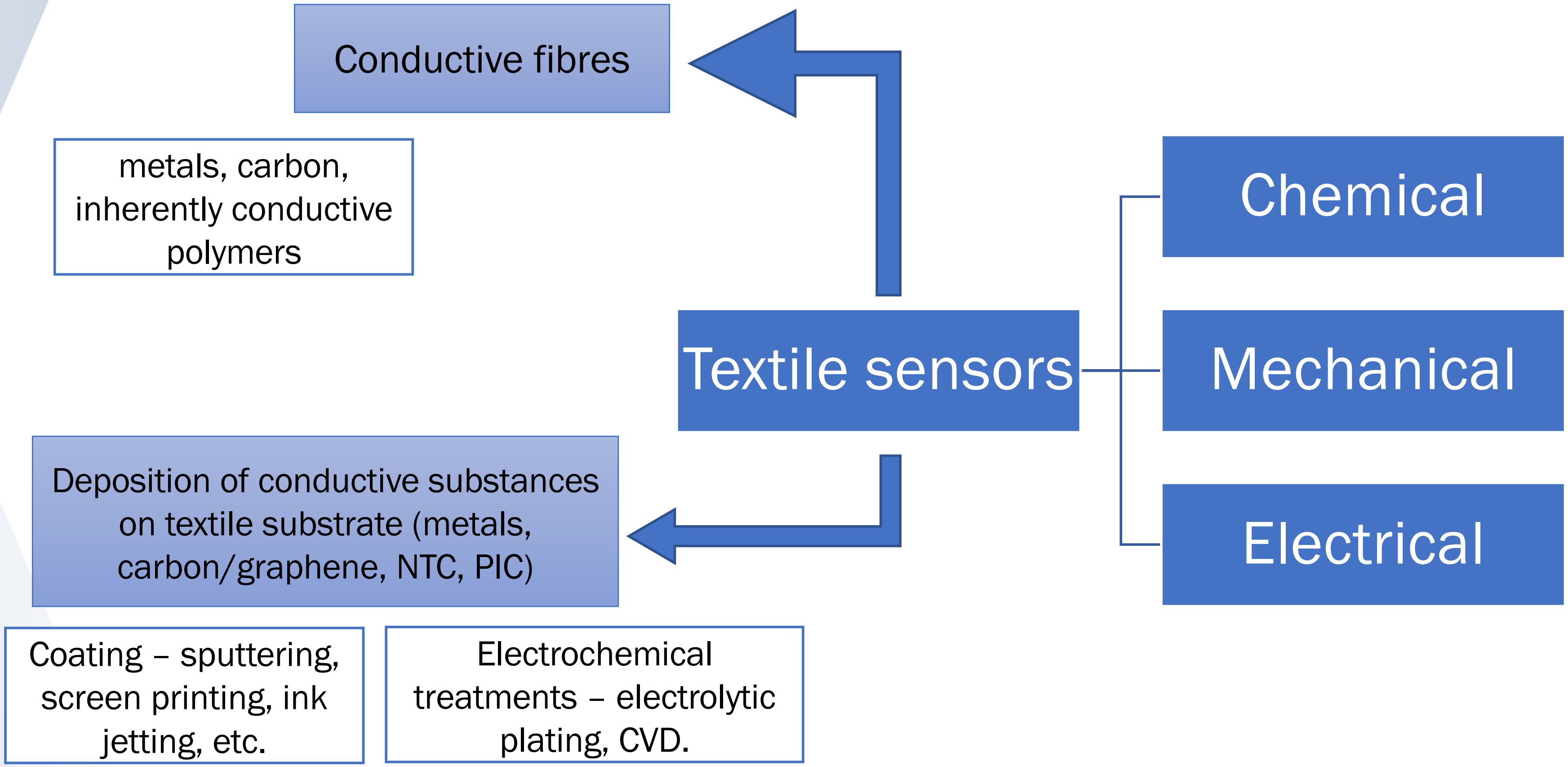
Lecture 5.2 Advances in composite textile materials



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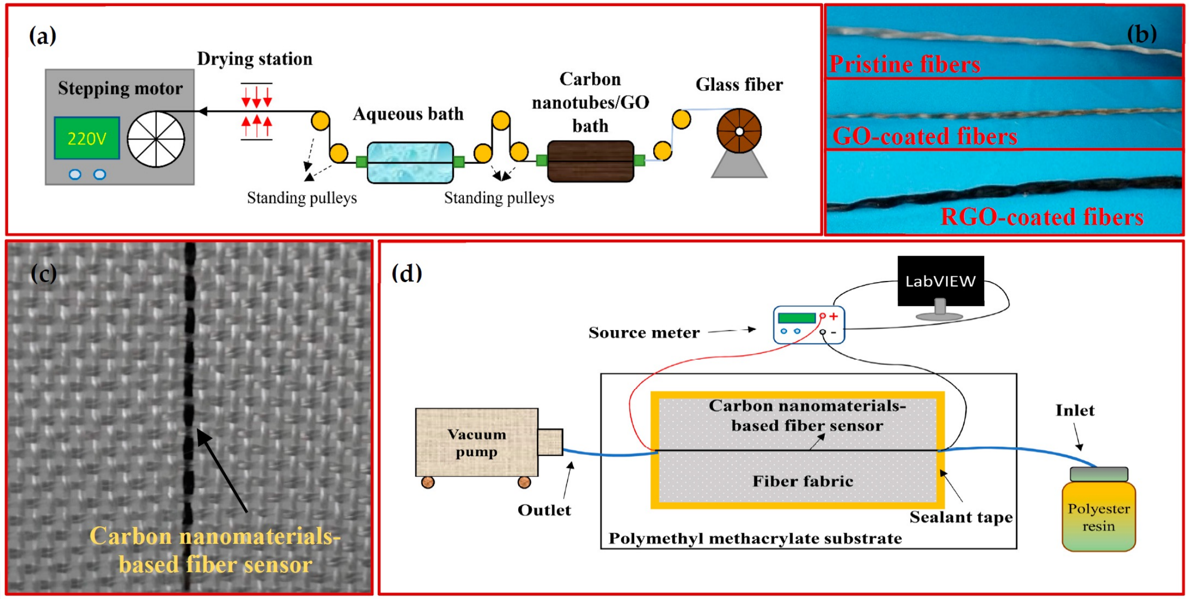
G. Wang et al., **Carbon Nanomaterials Based Smart Fabrics with Selectable Characteristics for In-Line Monitoring of High-Performance Composites,** https://www.mdpi.com/1996-1944/11/9/1677/htm



(a) Schematic diagram of the fibre winding and coating system. (b) Photographs of the pristine, graphene oxide (GO) and reduced graphene oxide (RGO)-coated fibres. (c) A representative smart fabric with an embedded carbon nanomaterials-based fiber sensor. (d) The schematic diagram of the setup for the monitoring of the vacuum-assisted resin transfer molding (VARTM) process.

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Lecture 5.2 Advances in composite textile materials

SMARTCOMP (AYTEX and IVACE, Spain) https://www.aitex.es/wp-content/uploads/2019/01/Informe-final_IVACE-FEDER-SMARTCOMP.pdf

Smart Composites Based on the Implementation of Textronic Elements and Functional Materials for use in the manufacture of composites for decoration, interior design, habitats and the creative industries in general.

Textile embroidered circuit technology
Digital printing for flexible circuits
Continuous laminating technology

– Composites for electromagnetic shielding
– Composites that can be heated
– Piezoelectric composites
– Luminescent composites (LEDs, OLEDs, electroluminescent devices)

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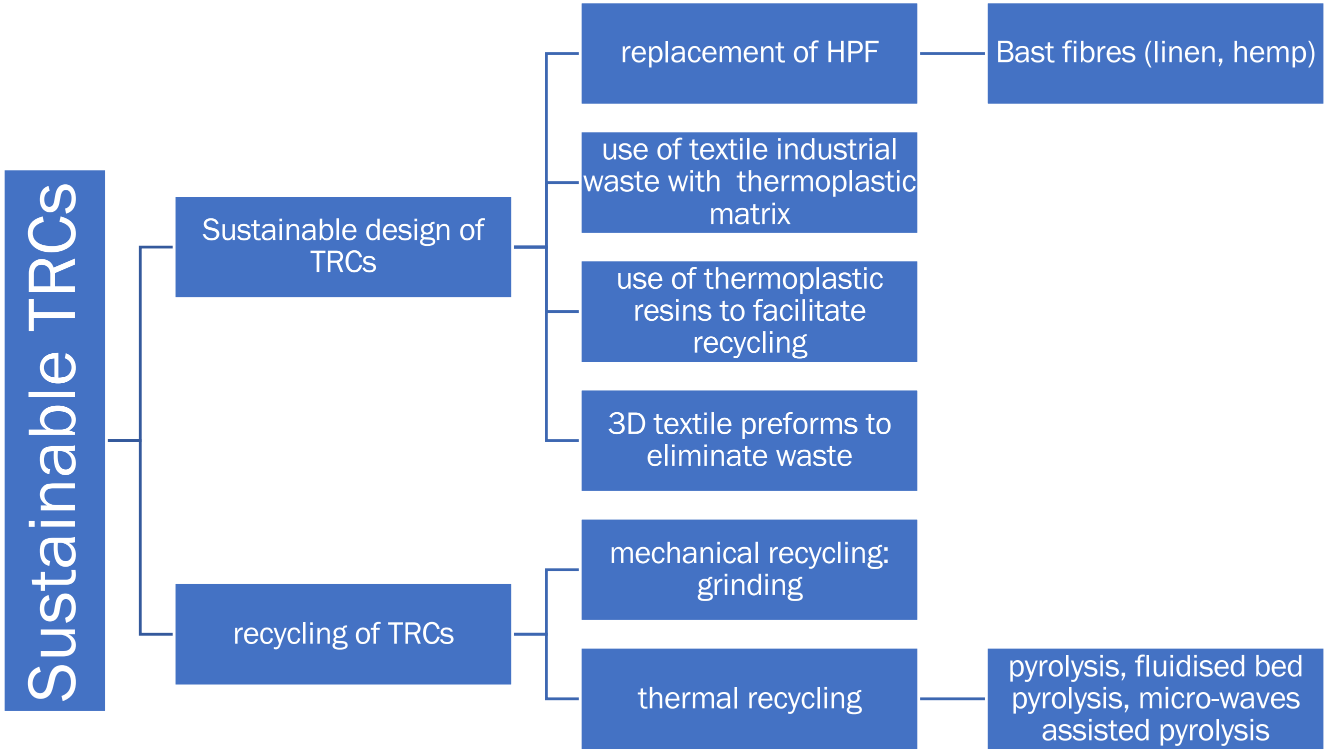
5. Sustainable textile reinforced composites



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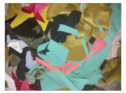
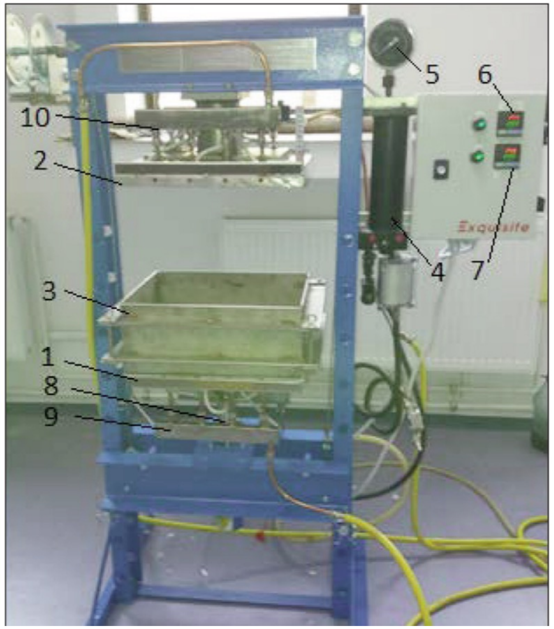
RAW MATERIALS USED TO OBTAIN COMPOSITE MATERIALS			
Raw material		Description	Function
	Polyester (PES) woven fabric scraps	Clippings generated in garment manufacturing	Reinforcement
	BOPP bag waste	Nonconformities of BOPP bags used in food packaging	Matrix
	Polypropylene nonwoven waste (TNT)	Clippings generated in upholstery industry	Matrix
	Virgin polypropylene fibres	Linear density 6.69 dtex, fibre length 76 mm, tenacity 3.33 cN/dtex, elongation at break 222.62%, melting point 165ºC	Matrix



New composite materials using polyester woven fabric scraps as reinforcement and thermoplastic matrix (TUIASI)

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The partners

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UPC - Universitat Politècnica de Catalunya
Spain

CEDECS – TCBL – Consultancy for European Development of Ecological and Social entrepreneurship – Textile and Clothing Business Labs
France

CRNS - Centre de Recherche en Numérique de Sfax
Tunisia

ATCTex - Tunisian Association for Textile Researchers
Tunisia

ISMMM - Higher Institute of Fashion of Monastir
Tunisia

ISET - Higher Institute of Technological Studies of Ksar Hellal
Tunisia

MFCPole - The Pôle de Compétitivité Monastir-El Fejja
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