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Application of Materials

Composite materials KYF0190

Prof. Renno Veinthal
Tel: 6203351, e-post: renno.veinthal@ttu.ee

Literature

1. Mallick, P. K. Fiber-reinforced composites : materials, manufacturing, and design. New York [etc.] : Dekker, 1993. 566 p
2. Campbell, Flake C. Manufacturing processes for advanced composites. Oxford [etc.] : Elsevier Advanced Technology, c2004. 517 lk.
3. Chawla, Nikhilesh. Metal matrix composites. New York : Springer, c2006. 401 p.
4. A practical guide to composites. Bolton : Multi-Sport Composites, 1995. 140 p
5. Metal matrix composites : custom-made materials for automotive and aerospace engineering. Weinheim : Wiley-VCH, c2006. 314 p.
6. Bunsell, A. R. Fundamentals of fibre reinforced composite materials.Bristol ; Philadelphia (Pa.) : Institute of Physics Publishing, c2005. 398 p

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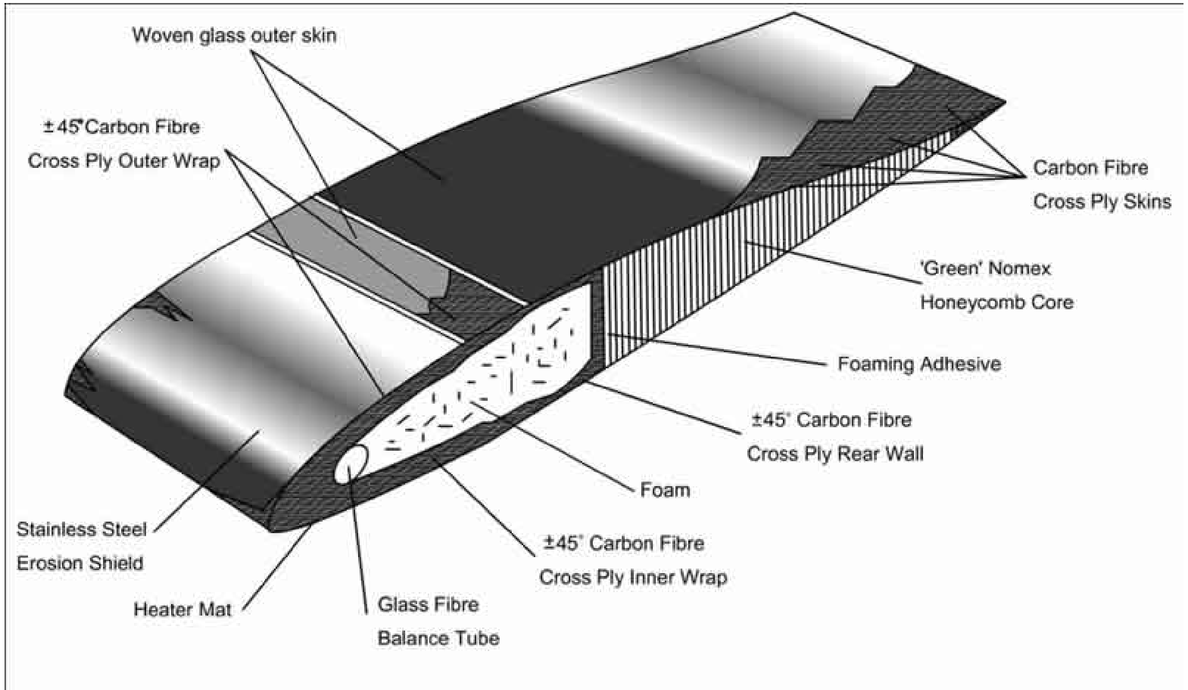
Definitions



Cross-Sectional View of a Composite Blade

- **Composite materials**, often shortened to **composites**, are engineered or naturally occurring materials made from **two or more constituent** materials with significantly different physical or chemical properties which remain separate and distinct at the macroscopic or microscopic scale within the finished structure.

Main properties

- Main advantages of polymer matrix composites (PMC-s)
  - High specific strength and specific stiffness
  - Tailored (strength properties)
  - Relatively big freedom in differents sheapes
  - Large products can be manufactured as one
  - High resistance to chemical attack
- Disadvantages:
  - Relatively low strength in shear and compression
  - Low heat and radiation resistance
  - Hygrtoscopic
  - Chemical and pysical properties change in time and are affected by environment

Facts and figures

- *Total annual turnover in 2010 was 9.3 bil EUR*
- *Current trend: decrease of raw product prices*
- *Annual growth of the sector ca 2.5%*
- *Annual production of PMCs in 2003 was 5 mil ton. In the same period approx 100 mil ton of plastics was consumed*

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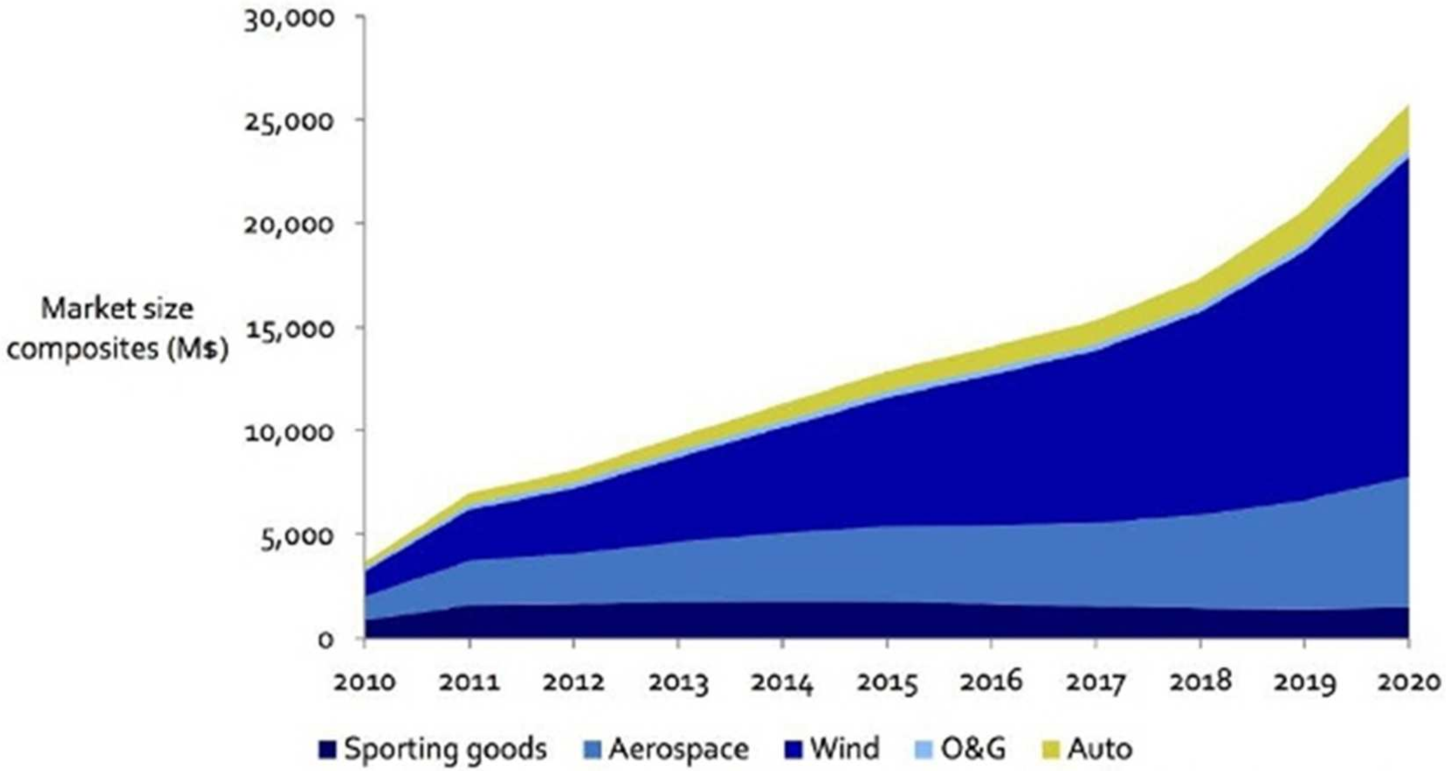
Composite market dynamics



Source: Lux Research, Inc.
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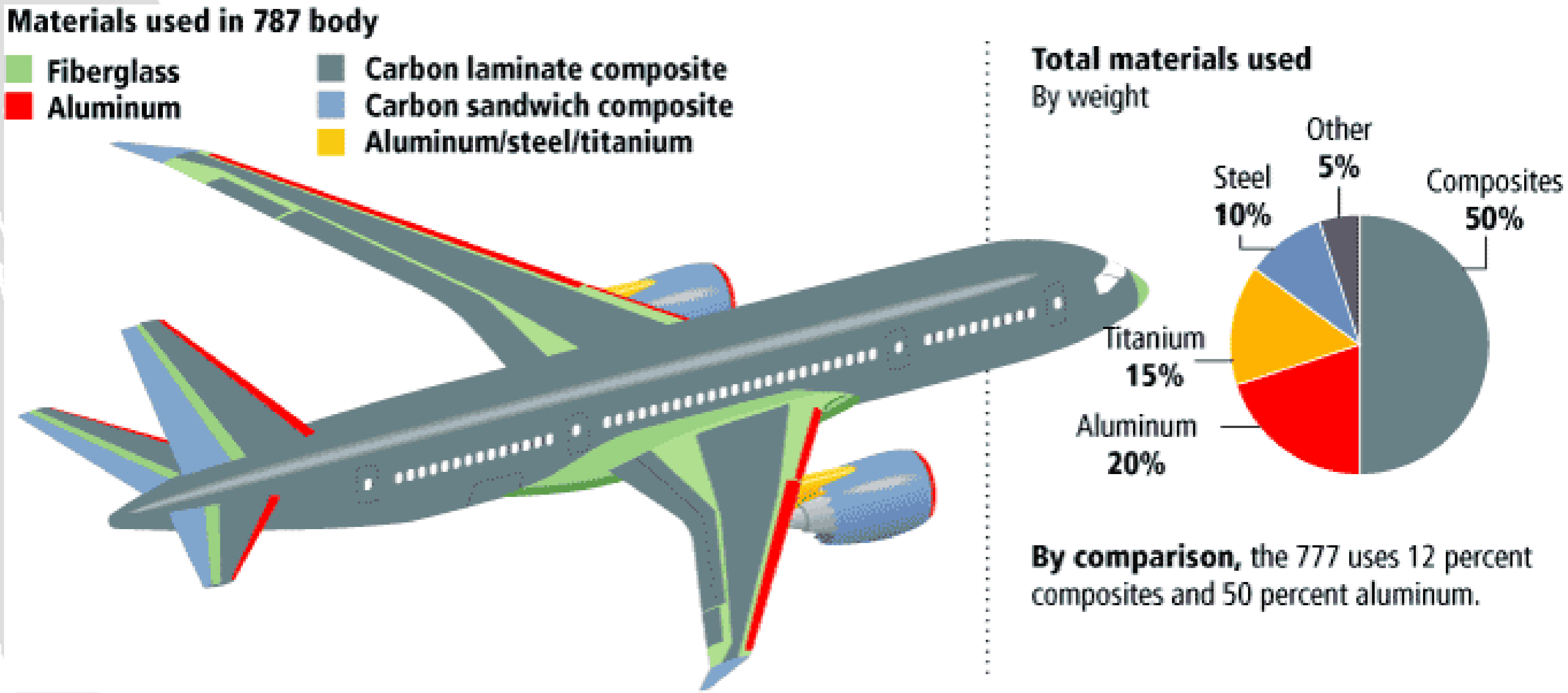
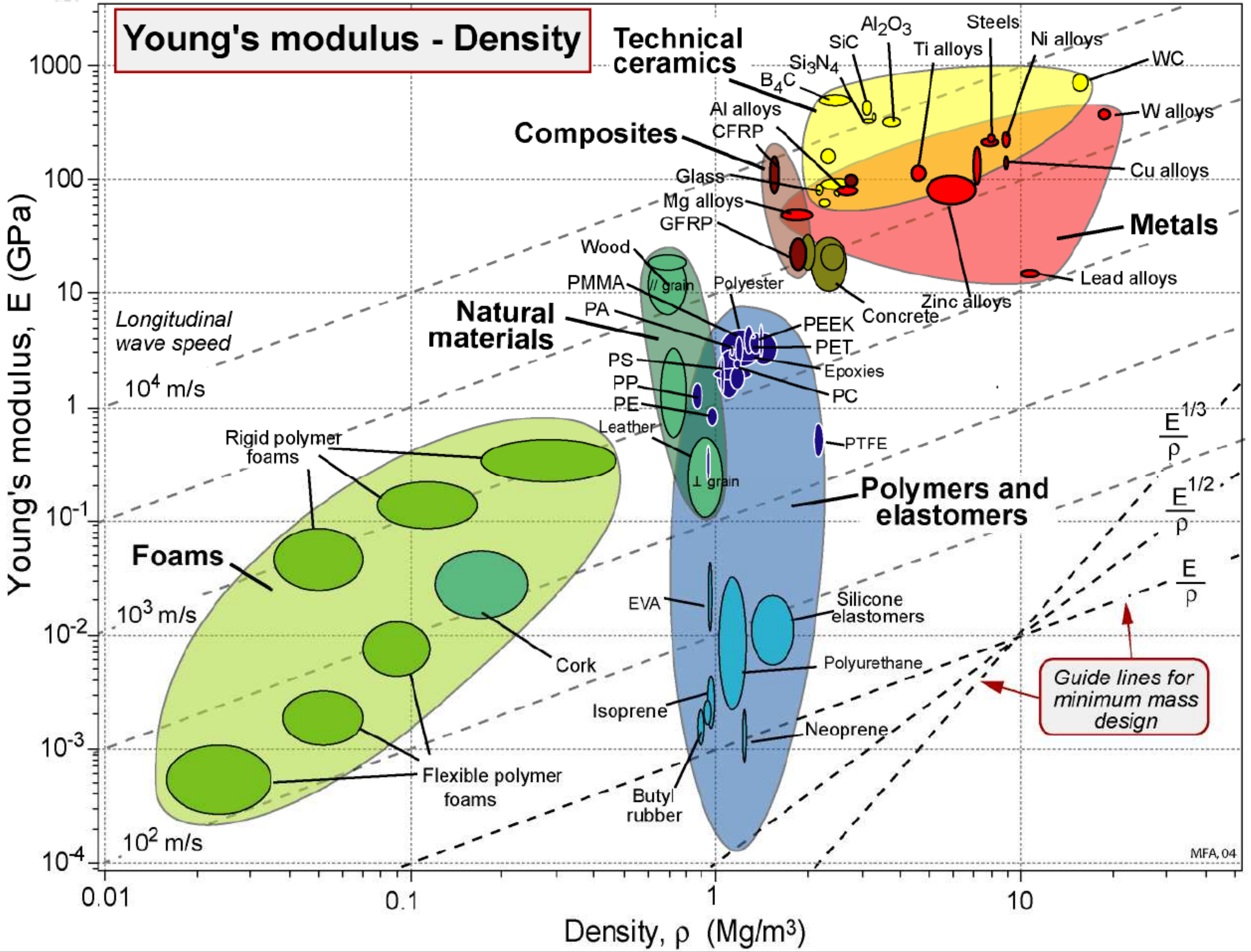
Polymer composites in aviation



Comparision of composites (Property diagram by *CES)*



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Composite classification

By production method

- Lamination methods
- Compression/compaction
- Injection
- Extrusion
- Pultrusion

Application area:

- General/structural CM
- Heat resistant CM
- (Anti)Friction materials
- Impact resistant CM
- Specific thermal properties CM

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Composite classification

By matrix material

- Metal matrix composites (MMC)
- Polymer matrix composites (PMC)
  - thermoplastic
  - thermosets
- Ceramic matrix composites (CMC)
- Carbon (graphite) matrix composites

By the shape of reinforcing phase

- powder reinforcement
- continious or discontinous reinforcement
- laminate composite
- honeycombs

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Types of Composites

Matrix phase/ Reinforcement Phase	Metal	Ceramic	Polymer
Metal	Powder metallurgy parts – combining immiscible metals	Cermets (ceramic-metal composite)	Brake pads
Ceramic	Cermets, TiC, TiCN Cemented carbides – used in tools Fiber-reinforced metals	SiC reinforced Al2O3 Tool materials	Fiberglass
Polymer			Kevlar fibers in an epoxy matrix
Elemental (Carbon, Boron, etc.)	Fiber reinforced metals Auto parts aerospace		Rubber with carbon (tires) Boron, Carbon reinforced plastics

MMC's
Metal Matrix Composites

CMC's
Ceramic Matrix Comp's.

PMC's
Polymer Matrix Comp's

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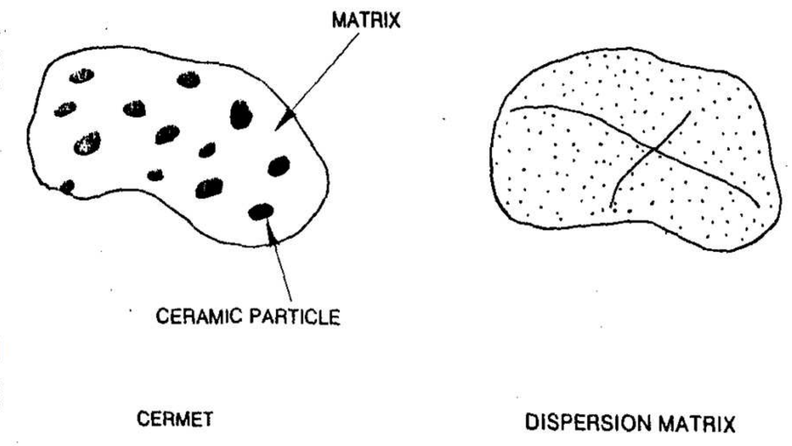
Particle Composites

- Particles usually reinforce a composite equally in all directions (called *isotropic*). *Plastics*, *cermets* and *metals* are examples of particles.
- Particles used to strengthen a matrix do not do so in the same way as fibers. For one thing, particles are not directional like fibers. Spread at random through out a matrix, particles tend to reinforce in all directions equally.

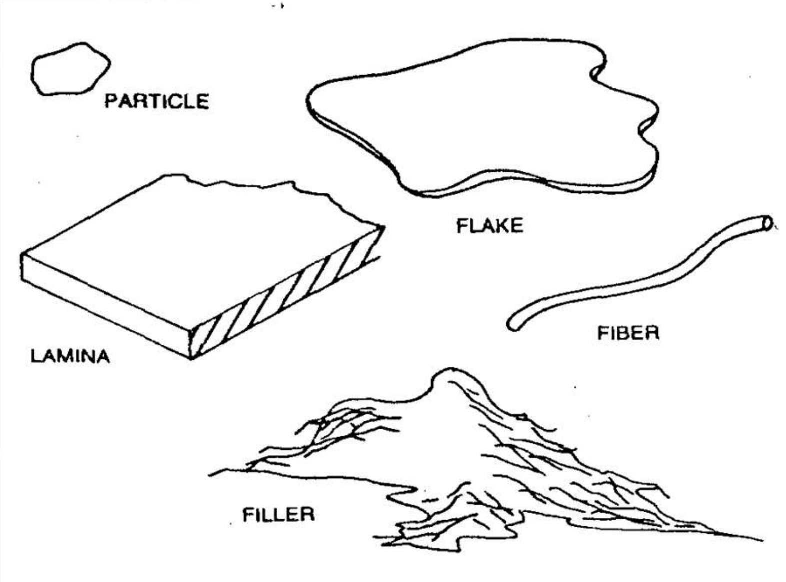
Cermets

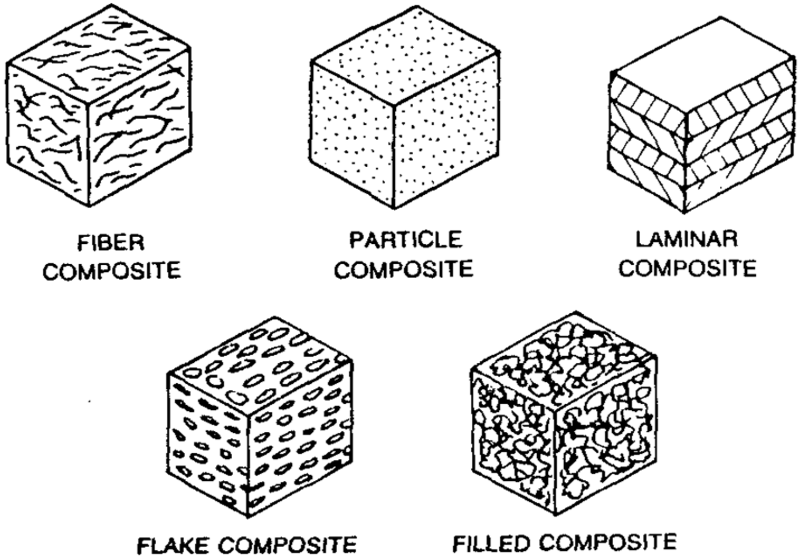
- (1) Oxide–Based cermets (e.g. Combinati Al2O3 with Cr)
- (2) Carbide–Based Cermets (e.g. Tungste carbide, titanium–carbide)
- Metal–plastic particle composites (e.g. Alumin & steel, copper particles)
- Metal–in–metal Particle Composites and Disp Hardened Alloys (e.g. Ceramic–oxide particles



Types of Composite Materials

There are five basic types of composite materials: Fiber, particle, flake, laminar or layered and filled composites.





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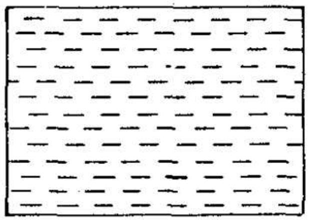
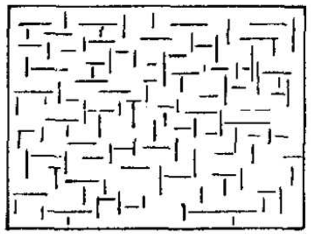
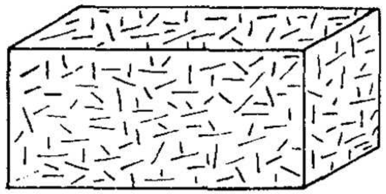
Fiber Composites

In fiber composites, the fibers reinforce along the line of their length. Reinforcement may be mainly 1-D, 2-D or 3-D. Figure shows the three basic types of fiber orientation.

- 1-D gives maximum strength in one direction.
- 2-D gives strength in two directions.
- Isotropic gives strength equally in all directions.

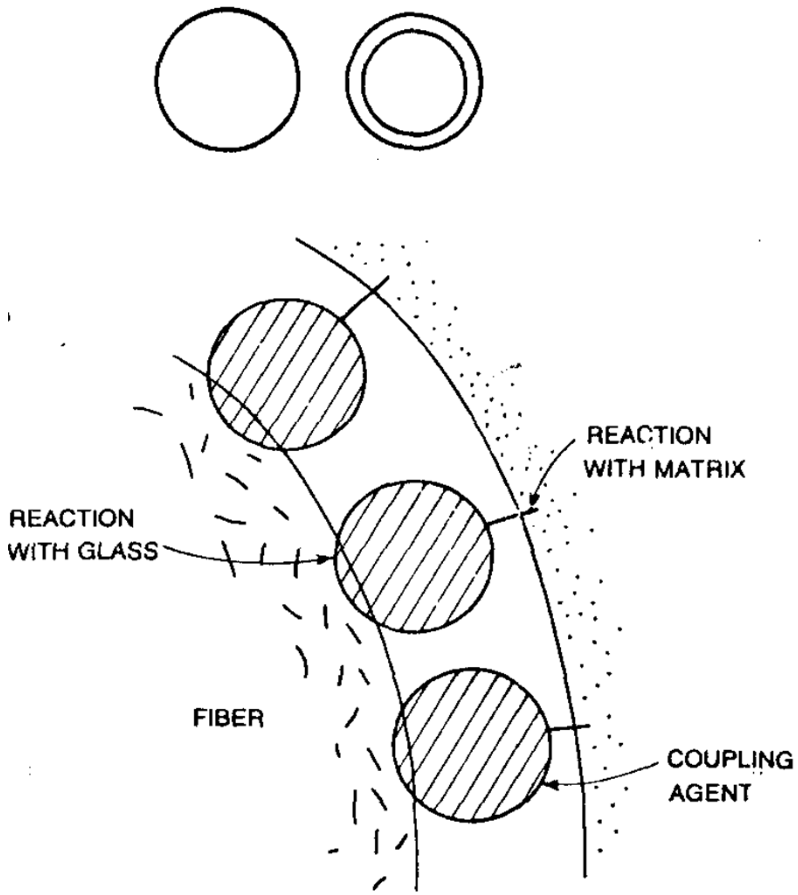

ONE–DIMENSIONAL REINFORCEMENT


TWO–DIMENSIONAL REINFORCEMENT


ISOTROPIC REINFORCEMENT

Composite strength depends on following factors:

- Inherent fiber strength, Fiber length, Number of flaws
- Fiber shape
- The bonding of the fiber (equally stress distribution)
- Voids
- Moisture (coupling agents)



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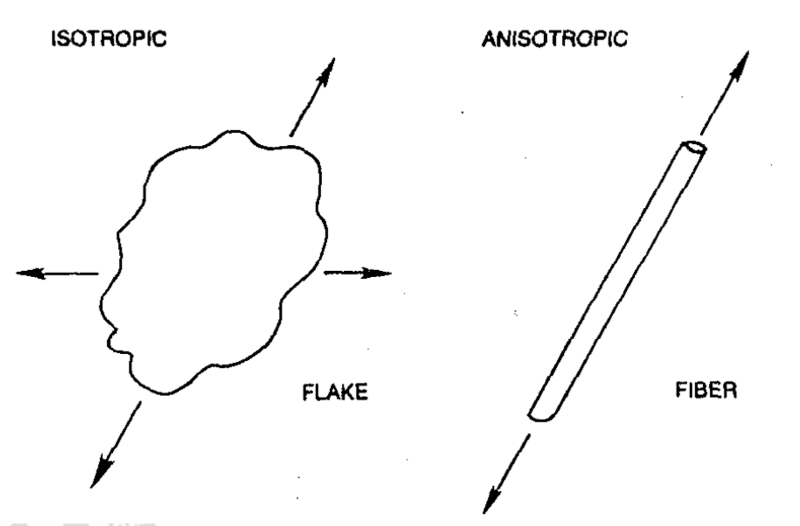
Flake Composites

Flakes, because of their shape, usually reinforce in 2-D. A flake composite consists of thin, flat flakes held together by a *binder* or placed in a *matrix*. Two common flake materials are *glass* and *mica*. (Also *aluminum* is used as metal flakes)



Chemically, micas can be given the general formula

$X_2Y_{4-6}Z_8O_{20}(OH,F)_4$

in which *X is* K, Na, or Ca or less commonly Ba, Rb, or Cs;

Y is Al, Mg, or Fe or less commonly Mn, Cr, Ti, Li, etc.;

Z is chiefly Si or Al, but also may include Fe^{3+} or Ti.

Structurally, micas can be classed as dioctahedral (*Y = 4) and trioctahedral (Y = 6). If the X ion is K or Na, the mica is a "common" mica, whereas if the X ion is Ca, the mica is classed as a "brittle" mica.*

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Flake Composites

Basically, *flakes* will provide:

- Uniform mechanical properties in the plane of the flakes
- Higher strength
- Higher flexural modulus
- Higher dielectric strength and heat resistance
- Better resistance to penetration by liquids and vapor
- Lower cost

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Laminar Composites

- Like all composites laminar composites aim at combining constituents to produce properties that neither constituent alone would have.

- In laminar composites outer metal is not called a matrix but a *face*. The inner metal, even if stronger, is not called a reinforcement. It is called a *base*.

Laminar Composite

We can divide *laminar composites* into three basic types:

- Unreinforced–layer composites

  (1) All–Metal

  (a) Plated and coated metals (electrogalvanized steel – steel plated with zinc)

  (b) Clad metals (aluminum–clad, copper–clad)

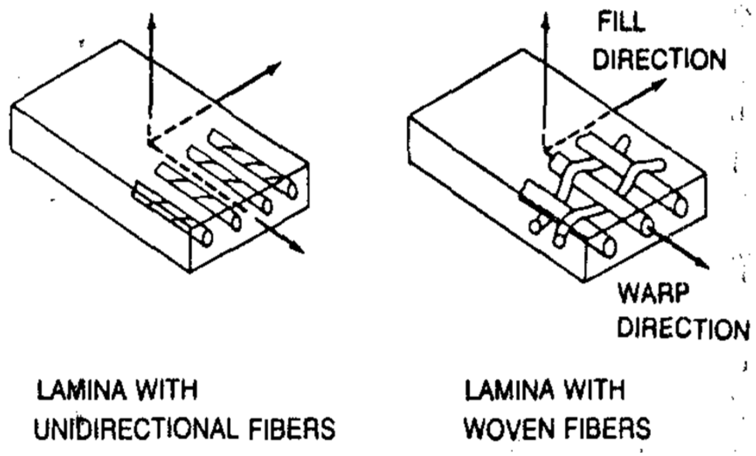
  (c) Multilayer metal laminates (tungsten, beryllium)

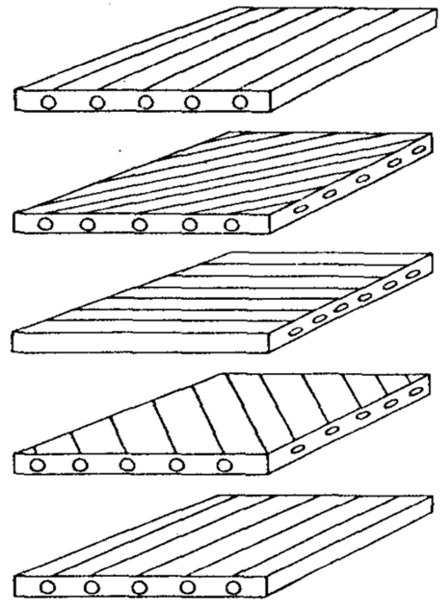
  (2) Metal–Nonmetal (metal with plastic, rubber, etc.)

  (3) Nonmetal (glass–plastic laminates, etc.)
- Reinforced–layer composites (laminate and laminates)
- Combined composites (reinforced–plastic laminates well bonded with steel, aluminum, copper, rubber, gold, etc.)

Laminar Composite

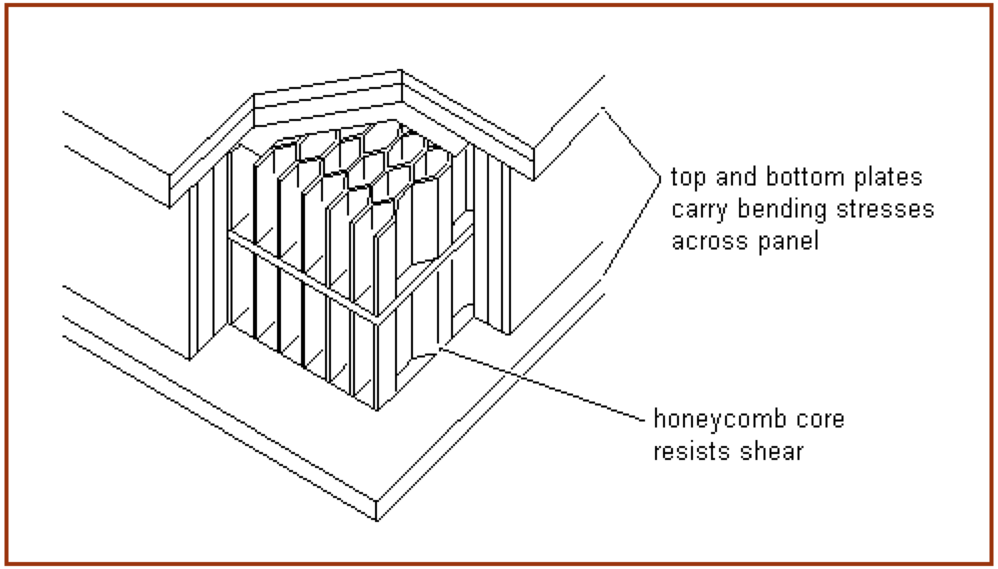
- A lamina (laminae) is any arrangement of *unidirectional* or *woven* fibers in a matrix. Usually this arrangement is flat, although it may be curved, as in a shell.
- A laminate is a stack of lamina arranged with their main reinforcement in at least two different directions.





Filled Composites

- There are two types of filled composites. In *one*, filler materials are added to a normal composite result in strengthening the composite and reducing weight. The *second* type of filled composite consists of a skeletal 3-D matrix holding a second material. The most widely used composites of this kind are *sandwich structures* and *honeycombs.*



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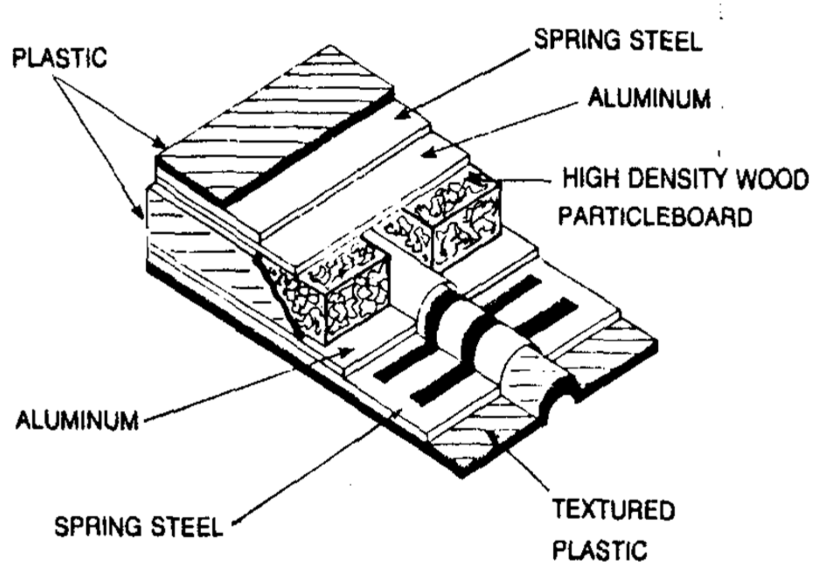
Combined Composites

- It is possible to combine several different materials into a single composite. It is also possible to combine several different composites into a single product. A good example is a modern ski. (combination of wood as natural fiber, and layers as laminar composites)



SKI COMPOSITE

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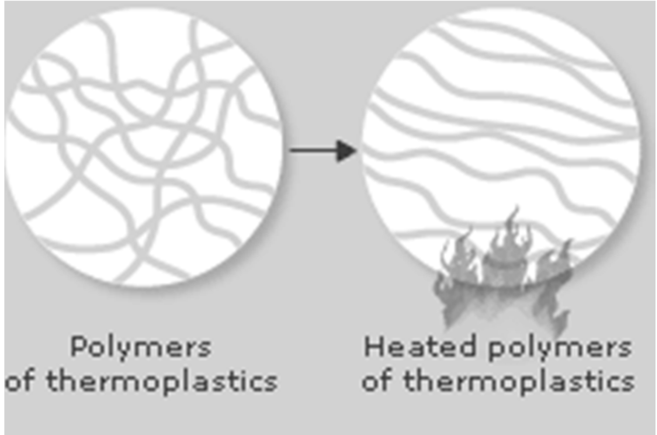
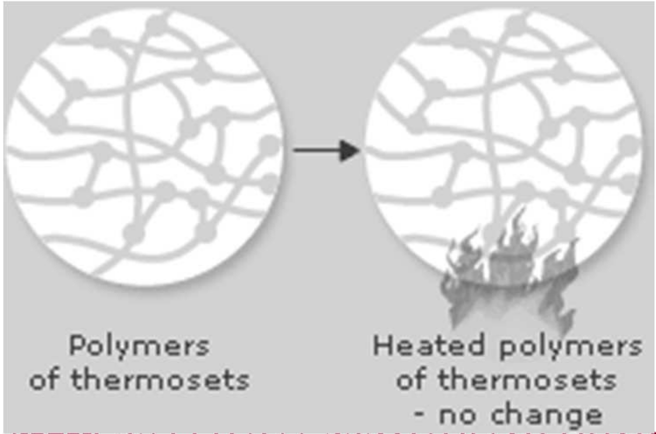
Matrix systems in PMC-s

- **In PMC-s mainly termosets are used**
  - **epoxy,**
  - **vinylester**
  - **polyester**
- At less extent also thermoplastics:
  - **TPU, PE, PVC, PS**





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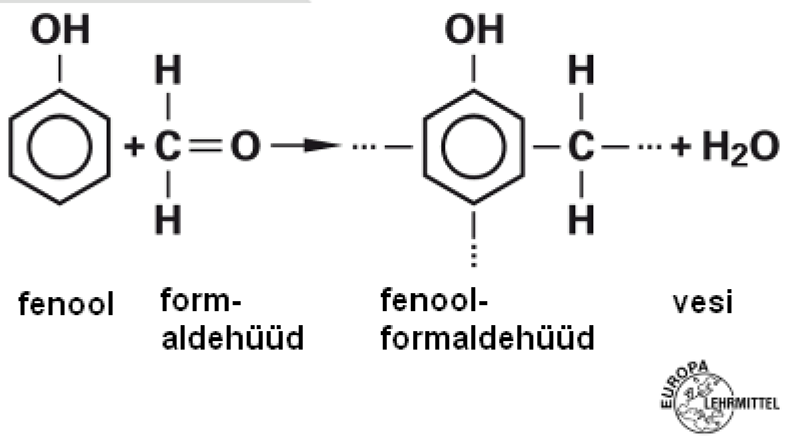
Resins used as matrix systems

- (PF) include synthetic thermosetting resins such as obtained by the reaction of phenols with formaldehyde.
- Sometimes the precursors include other aldehydes or other phenol.



- Novolacs are phenol-formaldehyde resins made where the molar ratio of formaldehyde to phenol of less than one. The polymerization is brought to completion using acid-catalysis. The phenol units are mainly linked by methylene groups. The molecular weights are in the low thousands, meaning that about 10-20 phenol units
- Base-catalysed phenol-formaldehyde resins are made with a formaldehyde to phenol ratio of greater than one (usually around 1.5). These resins are called resols. Phenol, formaldehyde, water and catalyst are mixed in the desired amount, depending on the resin to be formed, and are then heated.

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Phenol formaldehyde resins (PF)

- Phenolic laminates are made by impregnating one or more layers of a base material such as paper, fiberglass or cotton with phenolic resin and laminating the resin-saturated base material under heat and pressure.
- The resin fully polymerizes (cures) during this process. The base material choice depends on the intended application of the finished product.
- Paper phenolics are used in manufacturing electrical components such as punch-through boards and household laminates.
- Glass phenolics are particularly well suited for use in the high speed bearing market.
- Typical price 3-6 EUR/kg

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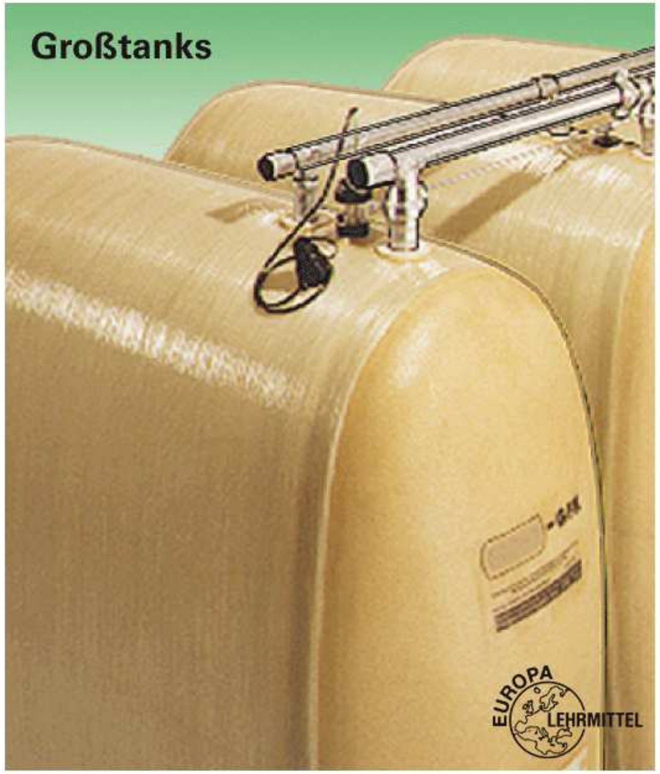
Unsaturated polyester resins UP

- Unsaturated polyesters are condensation polymers formed by the reaction of polyols (also known as polyhydric alcohols), organic compounds with multiple alcohol or hydroxy functional groups, with saturated or unsaturated dibasic acids.
- Typical polyols used are glycols such as ethylene glycol; acids used are phthalic acid and maleic acid.
- Water, a by-product of esterification reactions, is continuously removed, driving the reaction to completion.
- The use of unsaturated polyesters and additives such as styrene lowers the viscosity of the resin.
- The initially liquid resin is converted to a solid by cross-linking chains



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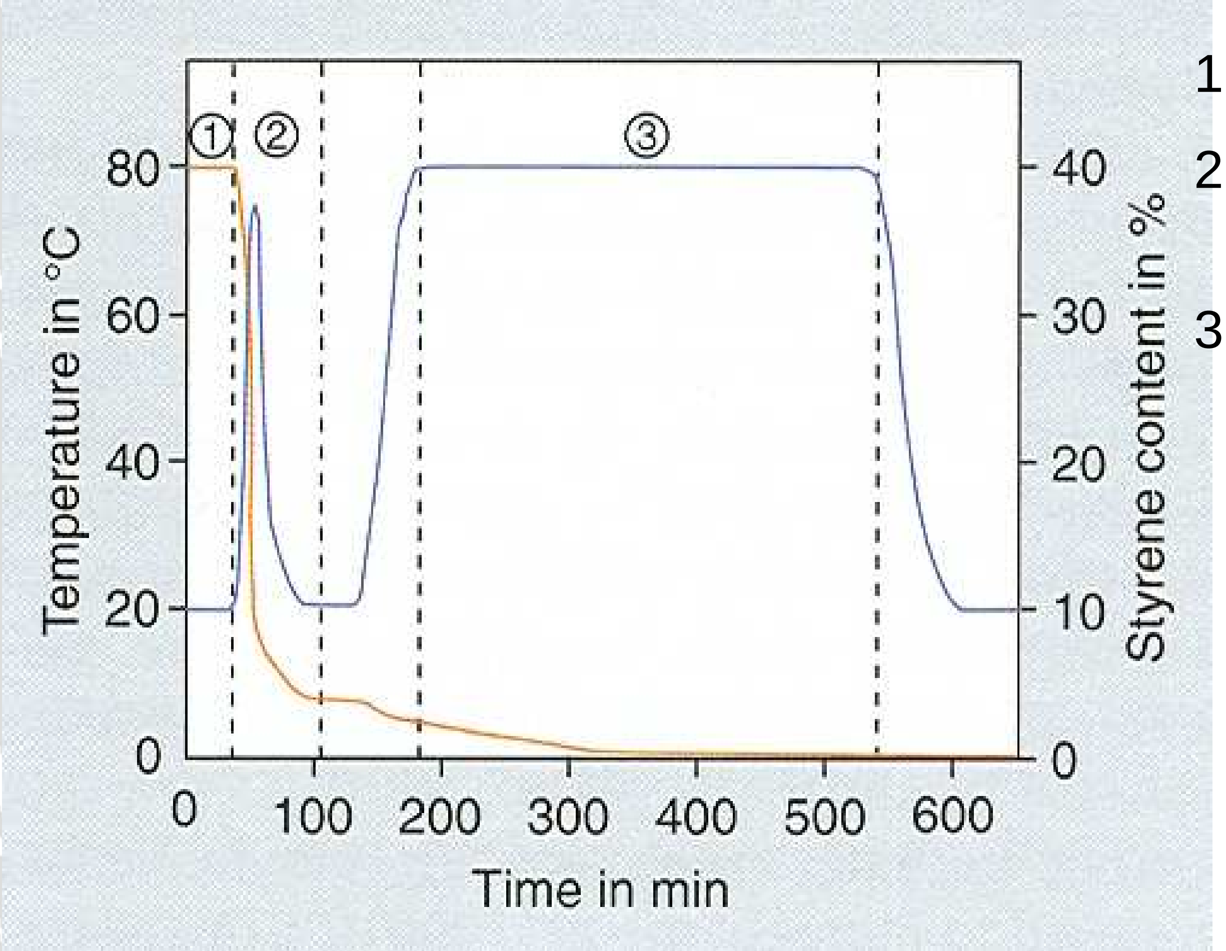
Polyester resins

- Polyester resins are thermosetting and, as with other resins, cure exothermically. The use of excessive catalyst can, therefore, cause charring or even ignition during the curing process. Excessive catalyst may also cause the product to fracture or form a rubbery material.
- The UTS of glass-fiber reinforced polyester resin is 120 - 350 MPa while without reinforement max 75 MPa
- The disadvantage of polyester resin is relatively large shrinkage during curing process, limited adhesion with reinforcement, relative brittelness and short pot-life.
- Typical price 1,5-3 EUR/kg

Curing of polyester resin



1. Gel-time
2. Curing at ambient temperature
3. Post-curing in autoclave or furnace

Epoxy resisns

- poxy is a copolymer; that is, it is formed from two different chemicals. These are referred to as the "resin" and the "hardener".
- The resin consists of monomers or short chain polymers with an epoxide group at either end.
- Most common epoxy resins are produced from a reaction between epichlorohydrin and bisphenol-A, though the latter may be replaced by similar chemicals.
- The hardener consists of polyamine monomers, for example Triethylenetetramine (TETA).
- When these compounds are mixed together, the amine groups react with the epoxide groups to form a covalent bond.
- Each NH group can react with an epoxide group, so that the resulting polymer is heavily crosslinked, and is thus rigid and strong

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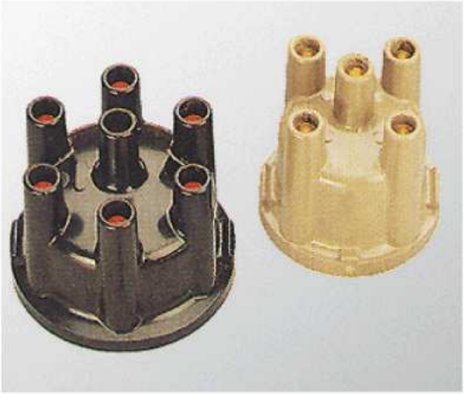
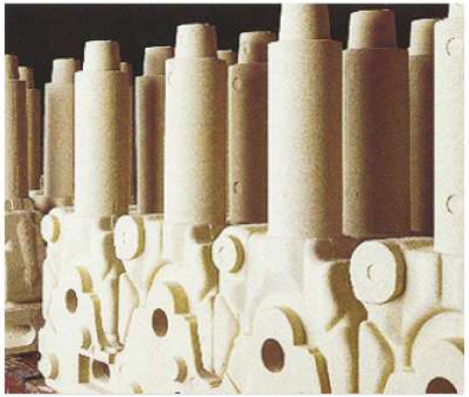
Epoxy resins (EP)



Sõiduauto
jagaja korpuse kaan EP-vaigust



EP-vaiksideainega
valuvormid

EUROPA LEHRMITTEL

- The applications for epoxy-based materials are extensive and include coatings, adhesives and composite materials such as those using carbon fiber and fiberglass reinforcements.
- The chemistry of epoxies and the range of commercially available variations allows cure polymers to be produced with a very broad range of properties.
- In general, epoxies are known for their excellent adhesion, chemical and heat resistance, good-to-excellent mechanical properties and very good electrical insulating properties.
- Many properties of epoxies can be modified (for example silver-filled epoxies with good electrical conductivity are available, although epoxies are typically electrically insulating).
- Variations offering high thermal insulation, or thermal conductivity combined with high electrical resistance for electronics applications, are available
- Typical price 2-20 EUR/kg

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Types of Fibers

The fibers are divided into two main groups:

- Glass fibers: There are many different kinds of glass, ranging from ordinary bottle glass to high purity quartz glass. All of these glasses can be made into fibers. Each offers its own set of properties.
- Advanced fibers: These materials offer high strength and high stiffness at low weight. Boron, silicon, carbide and graphite fibers are in this category. So are the *aramids*, a group of plastic fibers of the polyamide (nylon) family.

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Fibers - Glass

- Tensile strength is highly dependent on surface defects. The shorter the sample, the higher the value.
- Moisture has a detrimental effect on strengths
- Temperature has profound impact on strength and modulus. The higher the temperature, the lower the strength (E-glass will be lower than S-glass). The higher the temperature, the higher the tensile modulus (E and S are about the same)

- Glass is an amorphous material that consists of a silica (SiO_2) backbone with various oxide components to give specific compositions and properties.
- Types: E-glass, S-glass, C-glass, quartz
- E-glass: calcium aluminoborosilicate with 2% alkali; good strength and electrical resistivity; the least expensive one
- S-glass: 40% higher than E-glass; high temp application
- C-glass: soda limeborosilicate; use in corrosive environments
- Quartz: low dielectric; use for protecting antennas and radomes

Fibers - Glass

- Most widely used fiber
- Uses: piping, tanks, boats, sporting goods
- Advantages
  - Low cost
  - Corrosion resistance
  - Low cost relative to other composites:
- Disadvantages
  - Relatively low strength
  - High elongation
  - Moderate strength and weight
- Types:
  - E-Glass - electrical, cheaper
  - S-Glass - high strength

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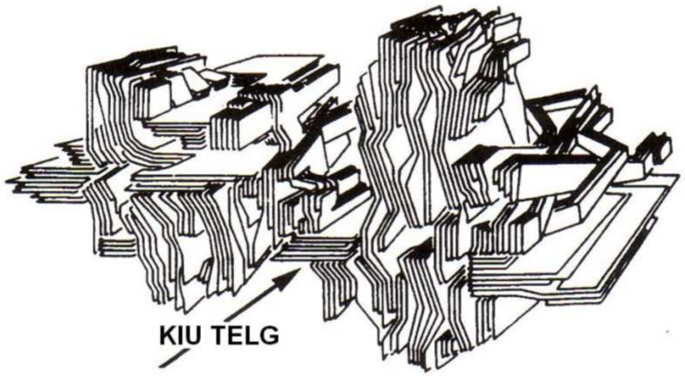
Fibers - Carbon

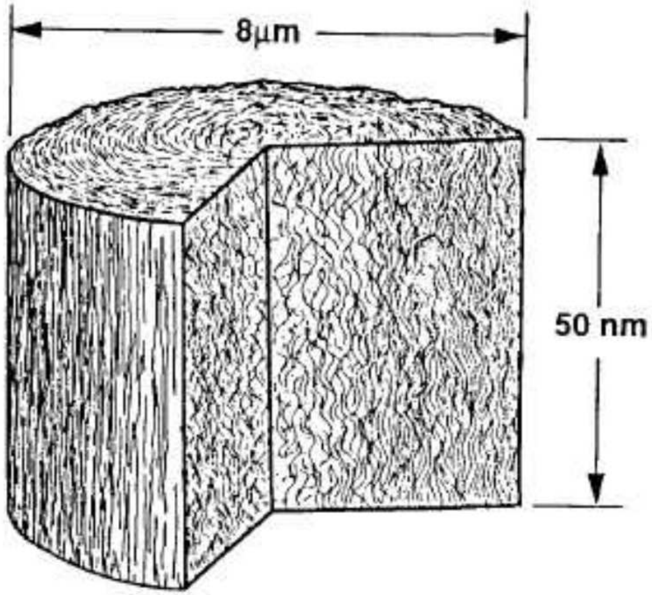
- 2nd most widely used fiber
- Examples
  - aerospace, sporting goods
- Advantages
  - high stiffness and strength
  - Low density
  - Intermediate cost
  - Properties:
    - Standard modulus: 207-240 GPa
    - Intermediate modulus: 240-340 GPa
    - High modulus: 340-960 GPa
    - Diameter: 5-8 microns, smaller than human hair
      - Fibers grouped into tows or yarns of 2-12k fibers



Fibers - Carbon

- Types of carbon fiber
  - vary in strength with processing
  - Trade-off between strength and modulus
- Intermediate modulus
  - PAN (Polyacrylonitrile)
    - fiber precursor heated and stretched to align structure and remove non-carbon material
- High modulus
  - made from petroleum pitch precursor at lower cost
  - much lower strength

Carbon fiber (PAN precursosr)



	Standard Modulus	(Type II) Intermediate Modulus	(Type I) High Modulus
Modulus, GPA	205 - 235	275 - 310	345 - 550
Msi	30 - 34	40 - 45	50 - 80
Tensile strength, MPa	3450 - 4650	4350 - 6900	1860 - 4140
ksi	500 - 675	630 - 1000	270 - 600
Tensile strain, %	1.4 - 1.6	1.6 - 2.2	0.81 - 0.9
Density, g/cm^3	1.76 - 1.79	1.76 - 1.79	1.87

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Organic fibers

- Para-phenylene diamine and terephthaloyl chloride are mixed in an organic solvent to form poly paraphenyleneterephthalamide.
- Developed from aromatic polyamides, also known as aramid fibers Manufactured by E.I. Du Pont with a trade name – Kevlar
- It is fully aligned and closely packed
- The polymer is washed and then dissolved in sulfuric acid. 20 wt% polymer solution is then passed through an extruder and spinnerettes to develop a high degree of orientation (liquid crystal form; process patented)
- Four types of aramid fibers: Kevlar®, Kevlar 29 (high toughness), kevlar 49 (high modulus) and kevlar 149 (ultra-high modulus)
- Kevlar fibers are less brittle than carbon or glass fibers, however, a combination of good strength, light weight and excellent toughness has led to the unique applications for aramid composites

High performance fibers comparison

Fiber Type	Density	Tensile Strength			Tensile Modulus			Tensile Toughness		
	g/cm^3	g/d	Mpa	ksi	g/d	Gpa	ksi	g/d	Mpa	ksi
Innegra S	0.84	8.5	630	92	190	14	2,100	0.70	52	7.5
Aramid (Kevlar K29)*	1.44	23	2900	430	550	70	10,000	0.30	38	5.5
UHMWPE (Spectra 900)*	0.97	30	2600	370	1400	120	17,000	0.70	60	8.7
Carbon (PAN med modulus)*	1.76	11	1700	250	1940	302	44,000	0.07	11	1.6
E-Glass*	2.55	11	2600	380	320	72	10,000	0.34	78	85
E-Glass**		5.5	1200	180	220	49	7,000	0.14	32	35

Steel: density (Fe) = 7.87 g/cc; TS=0.380 GPa; Modulus=207 GPa

Al: density=2.71 g/cc; TS=0.035 GPa; Modulus=69 GPa

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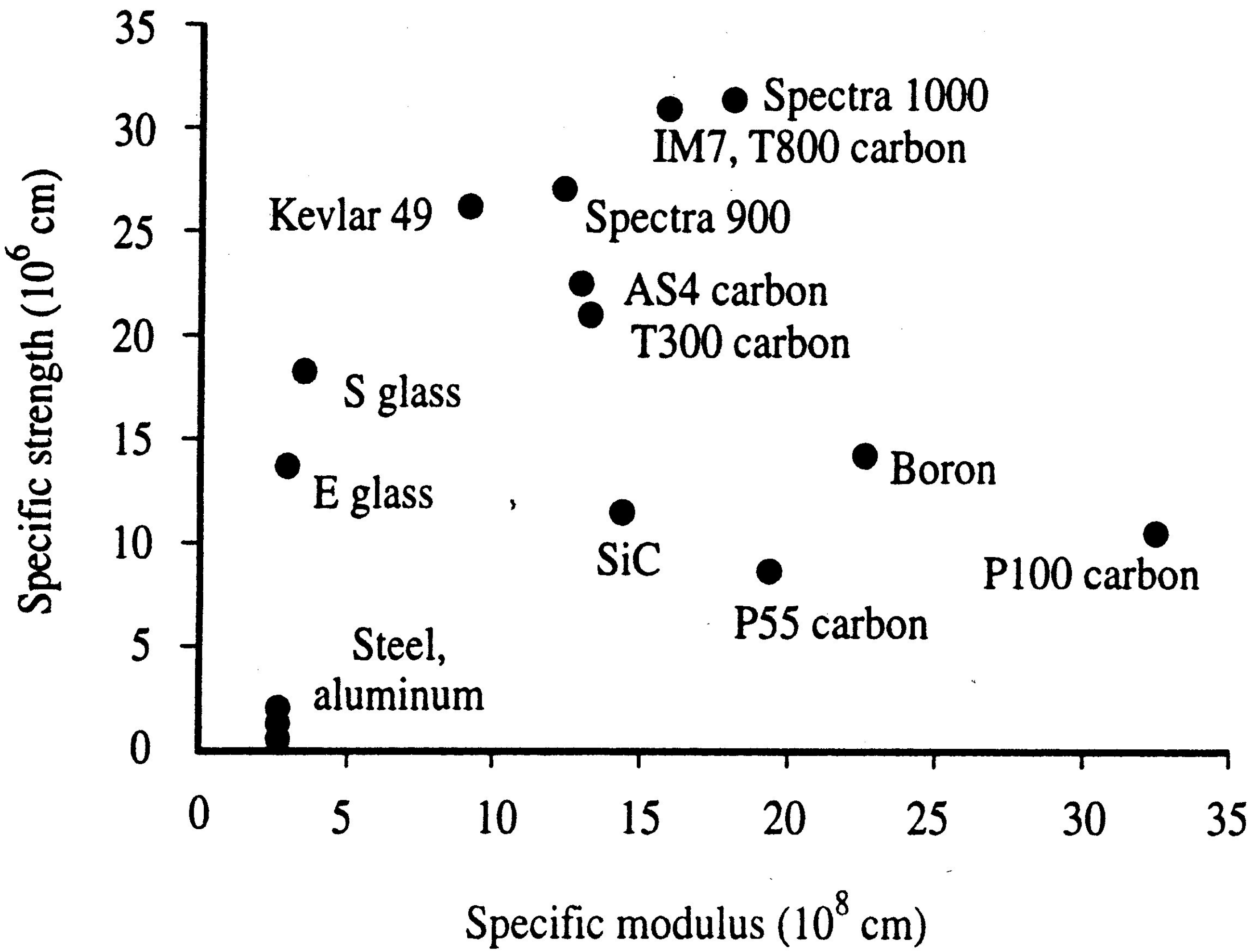
Fiber Strength



Reinforcement

- Reinforcing fibre is manufactured in both two dimensional and three dimensional orientations
- Two Dimensional Fibre Reinforced Polymer are characterized by a laminated structure in which the fibres are only aligned along the plane in x-direction and y-direction of the material.
- Three-dimensional Fibre Reinforced Polymer composites are materials with three dimensional fibre structures that incorporate fibres in the x-direction, y-direction and z-direction.
- Most widely E-glass fibers are used (price 1,5-3 EUR/kg), boron-, silicon-, carbon and graphite fibers are are in used in more demanding applications (price 22-60 EUR/kg).
- Organic fibers: aramid and PE fibers are used (price 22-36 EUR/kg)

Reinforcement

- Fiber preforms are how the fibres are manufactured before being bonded to the matrix.
- Fibre preforms are often manufactured in sheets, continuous mats, or as continuous filaments for spray applications.
- The four major ways to manufacture the fibre preform is though the textile processing techniques of weaving, knitting, braiding and stitching.

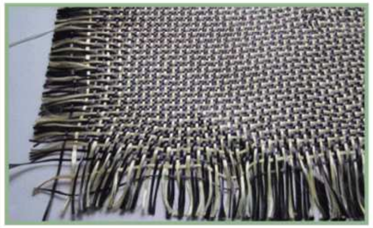
klaaskiudvilt

klaaskiudmatt

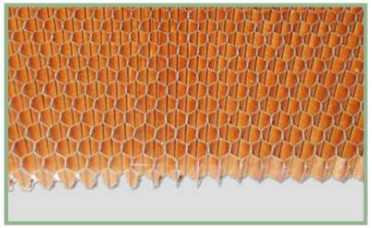
klaaskiudkangas

klaaskiudkangas

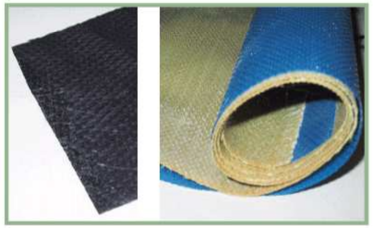
süsinikkiudkangas



süsinik/aramiid hübriidkangas



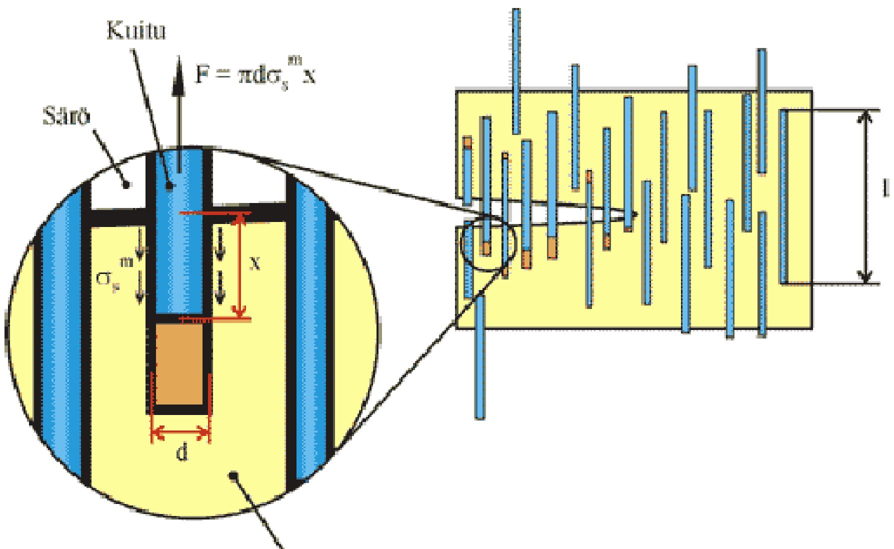
paberkärg



süsinikkiud / aramiidkiud-prepreg

Long fibers versus short fibers

- discontinuous fibers, short fibers are about 60% of all fibers used
- Short fibers are used mostly in BMC-, SMC- ja TMC-compounds and RRIM (r *Reinforced Reaction Injection Moulding*) process



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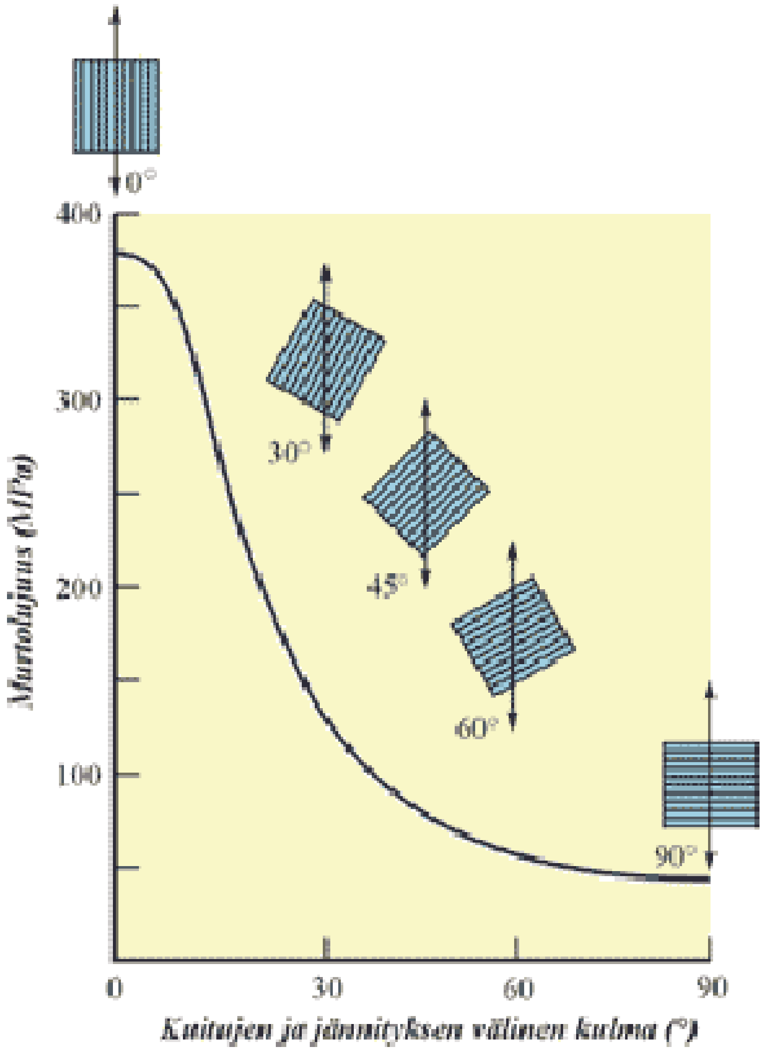
Anisotropical properties of composites



- Glass-fiber reinforced plastics. How are the mechanical proprties dependent on loading direction?
- Y-axes: Tensile strength, (UTS) MPa
- X-axes: angle bitween loading direction and reinforcement direction

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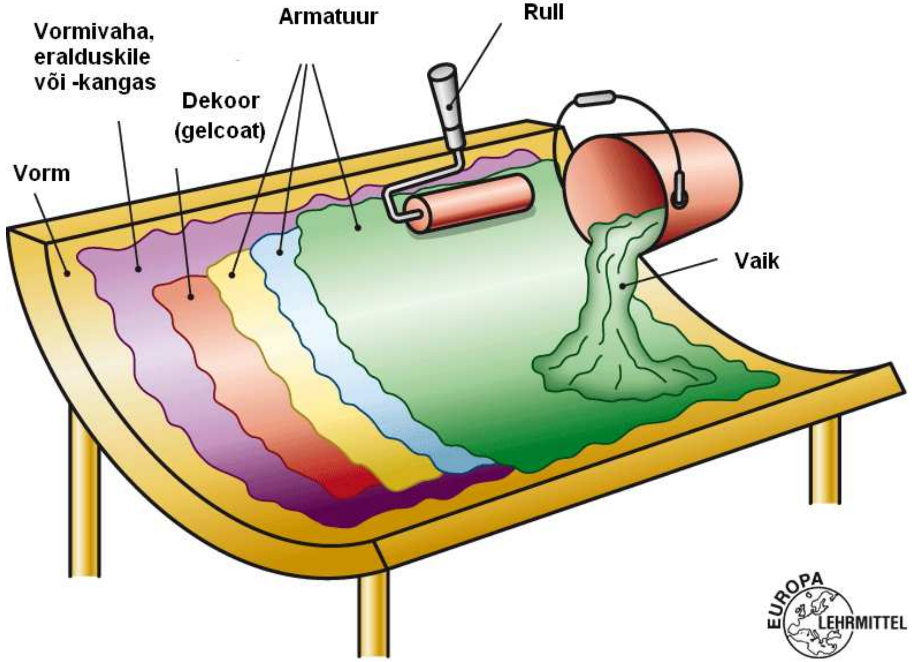
Manufacturing processis of PMC-s

- Moulding processes
  - Wet layup
  - Autoclave / vacuum bag
  - Filament winding
  - Chopper gun etc
- Compression moulding methods
  - Compression moulding
  - Rolling
- Injection methods
  - RTM & VARTM
  - Injection moulding
  - Centrifugal casting
- Extrusion
- Pultrusion

Wet lamination (wet layup process)

- Fibre reinforcing fabric is placed in an open mould and then saturated with a wet [resin] by pouring it over the fabric and working it into the fabric and mould.
- The mould is then left so that the resin will cure, usually at room temperature, though heat is sometimes used to ensure a proper curing process.
- Glass fibres are most commonly used for this process, the results are widely known as fibreglass, and is used to make common products like skis, canoes, kayaks and surf boards



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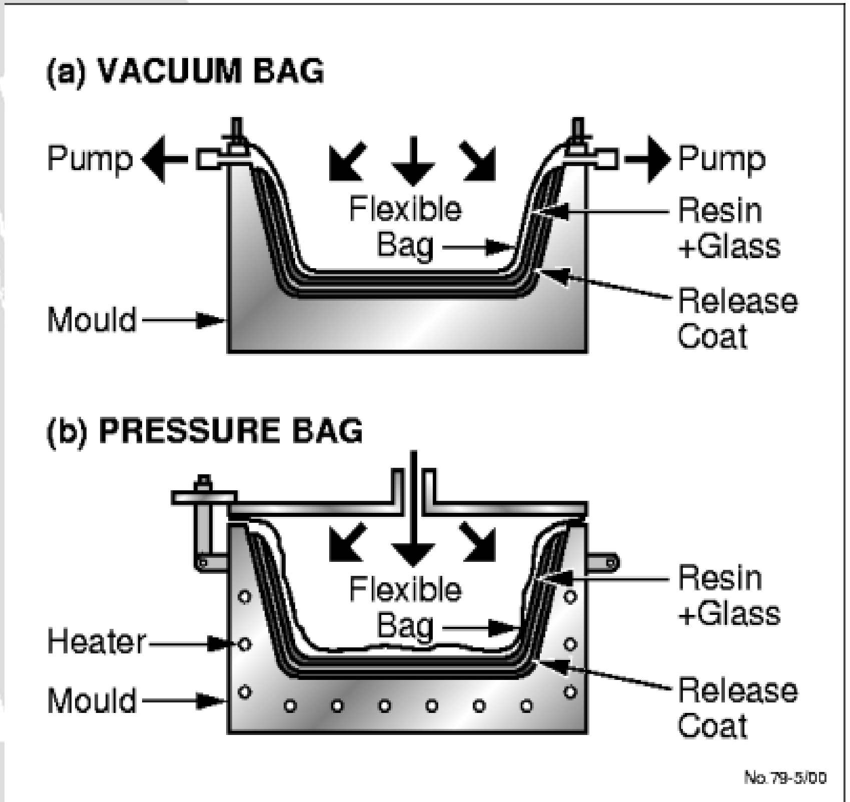
Vacuum or pressure moulding



- Individual sheets of prepreg material are laid-up and placed in an open mold. The material is covered with release film, bleeder/breather material and a vacuum bag.
- A vacuum is pulled on part and the entire mould is placed into an autoclave (heated pressure vessel)-> **see next slide**.
- The part is cured with a continuous vacuum to extract entrapped gasses from laminate.

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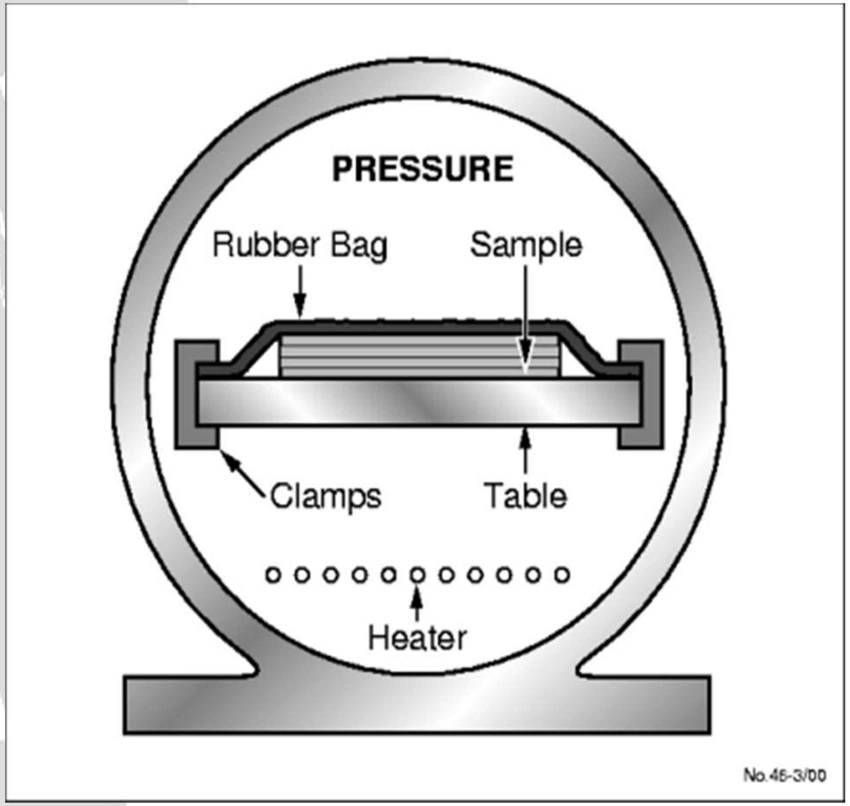
Moulding in autoclave



- This is a very common process in the aerospace industry because it affords precise control over the moulding process due to a long slow cure cycle that is anywhere from one to two hours.
- This precise control creates the exact laminate geometric forms needed to ensure strength and safety in the aerospace industry, but it is also slow and labour intensive, meaning costs often confine it to the aerospace industry.

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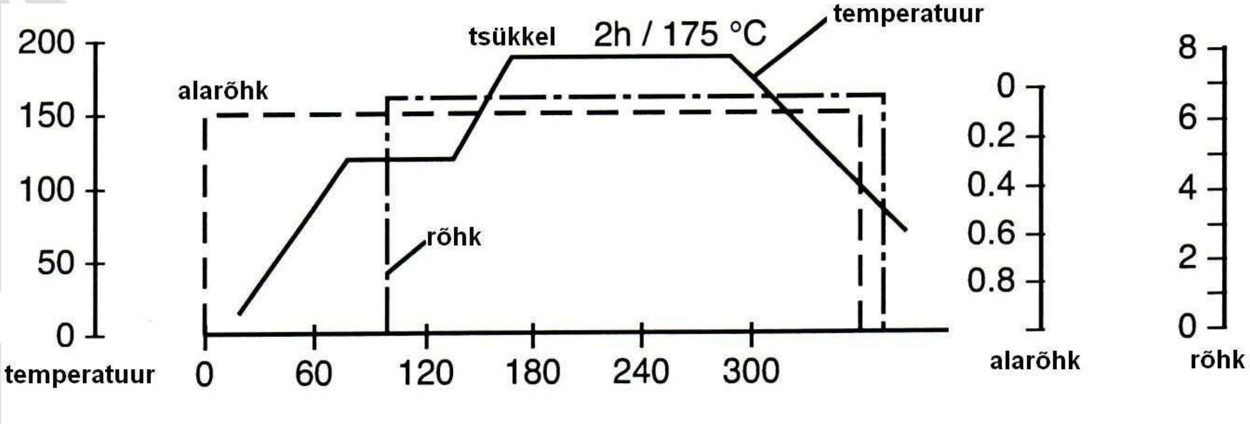
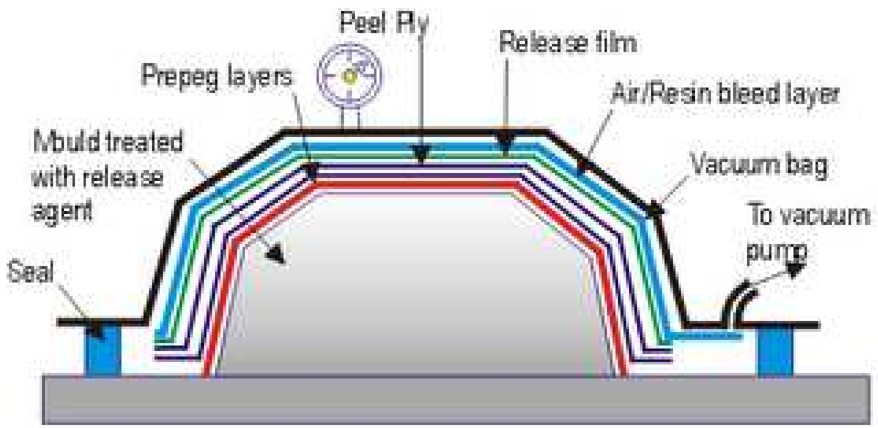
Use of prepregs





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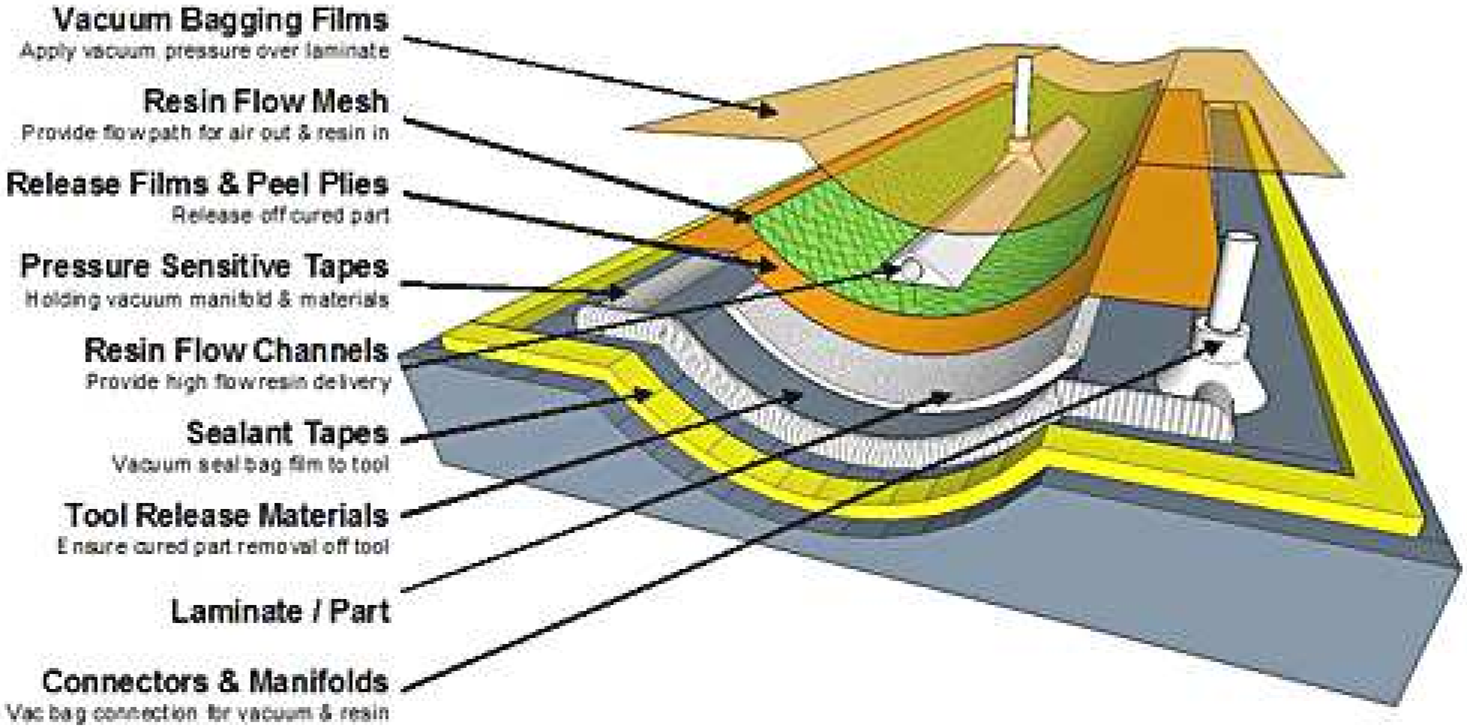
Vacuum bag moulding



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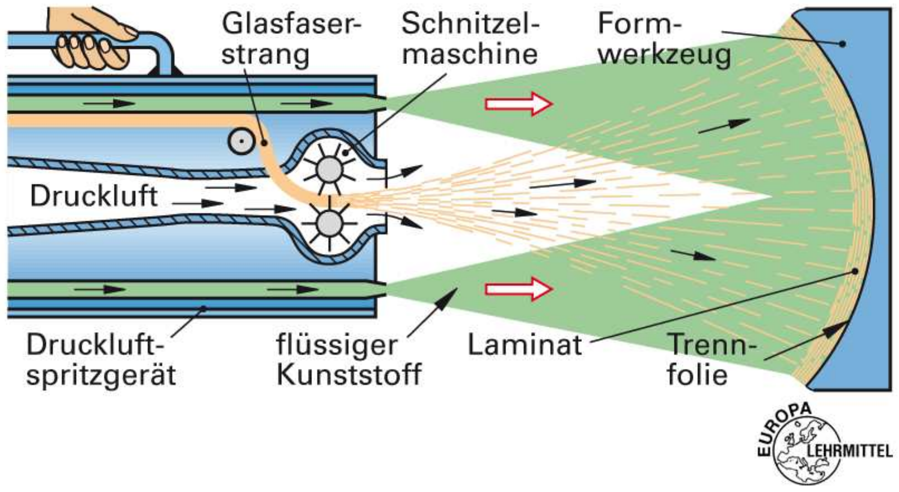
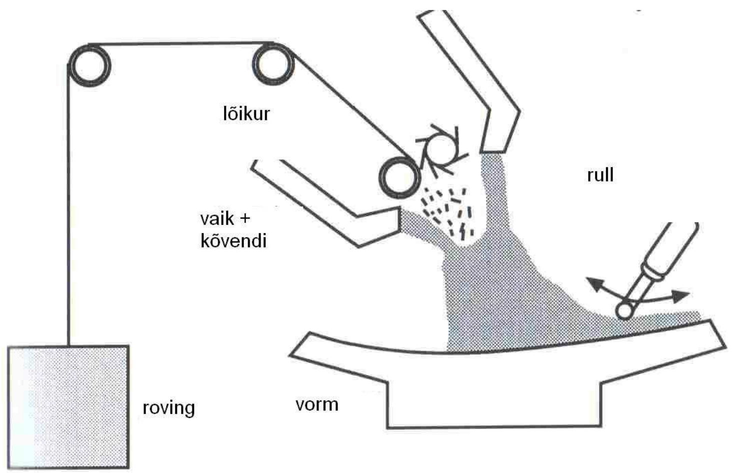
Spray-up lamination





- Continuous strand of fibreglass are pushed through a hand-held gun that both chops the strands and combines them with a catalyzed resin such as polyester.
- The impregnated chopped glass is shot onto the mould surface in whatever thickness the design and human operator think is appropriate.
- This process is good for large production runs at economical cost, but produces geometric shapes with less strength then other moulding processes and has poor dimensional tolerance.

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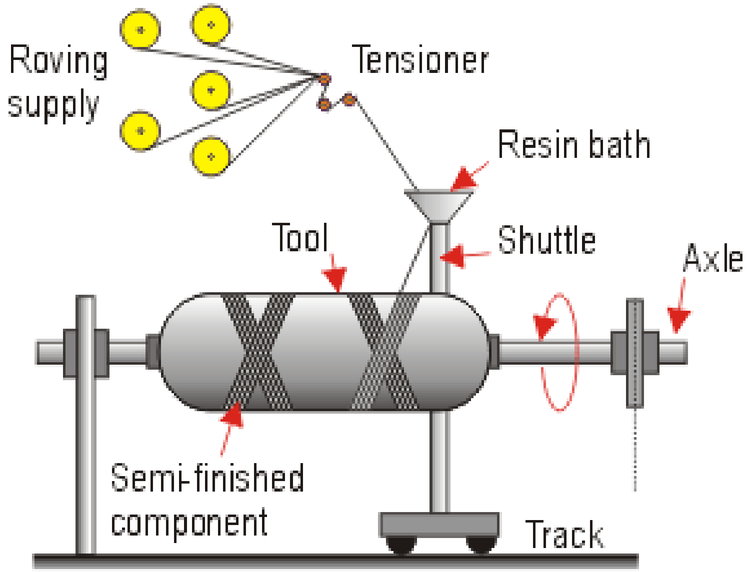
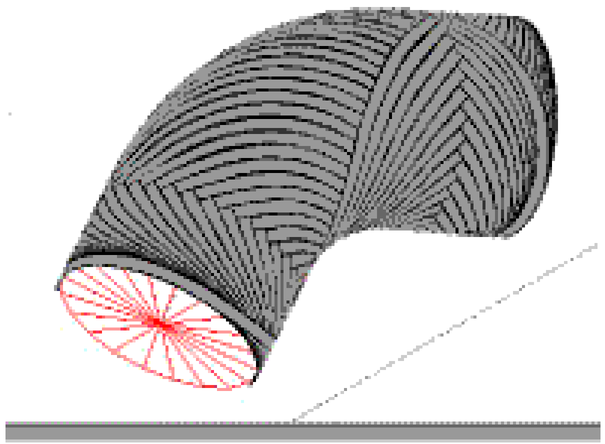
Filament winding

- Machines pull fibre bundles through a wet bath of resin and wound over a rotating steel mandrel in specific orientations
- Parts are cured either room temperature or elevated temperatures.
- Mandrel is extracted, leaving a final geometric shape but can be left in some cases





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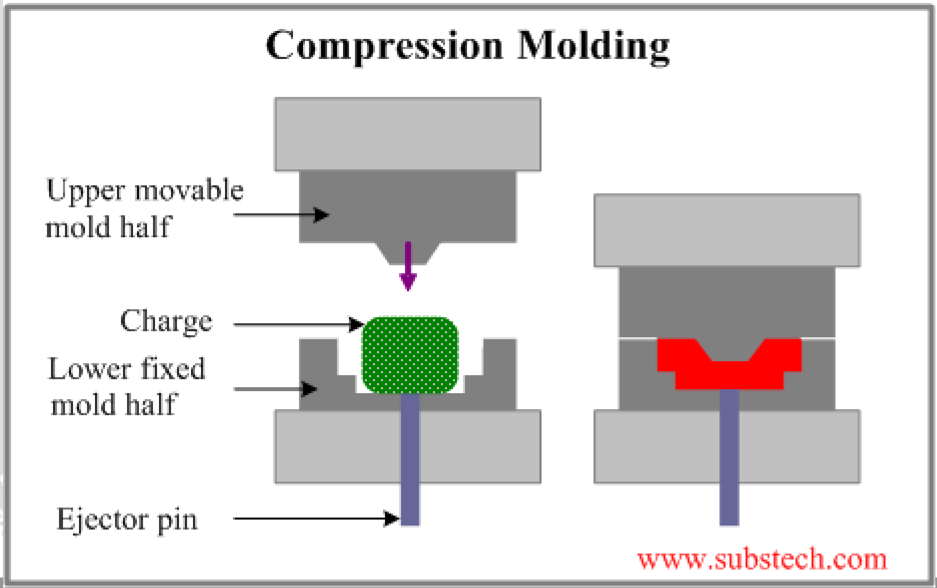
Could compression moulding

- A "preform" or "charge", of SMC, BMC or sometimes prepreg fabric, is placed into mould cavity.
- The mould is closed and the material is compacted & cured inside by pressure and heat.
- Compression moulding offers excellent detailing for geometric shapes ranging from pattern ad relief detailing to complex curves and creative forms, to precision engineering all within a maximum curing time of 20 minutes



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Could compression moulding

- The major advantages of compression molding:
- Very large parts (>80 kg) can be produced with minimal fiberglass degradation, yielding the strongest parts of all molding processes.
- Material can be placed in the cavity to achieve optimum fiber orientation in critical strength locations – the process is not limited by gate locations.
- Dissimilar materials can be placed in the mold, such as glass mat or uni-directional glass to improve part strength.
- An economical choice for small (<1,000) to very large volumes using single or multiple cavity tooling.

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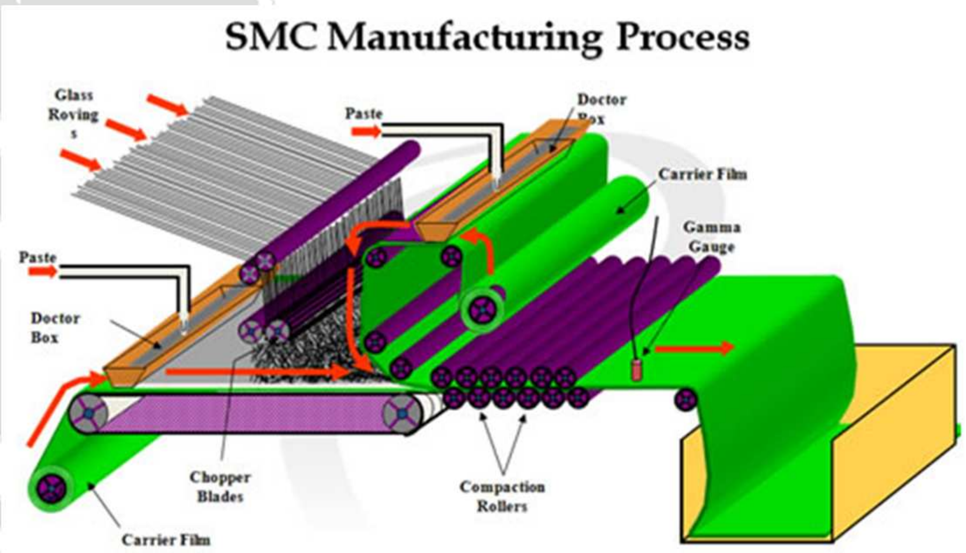
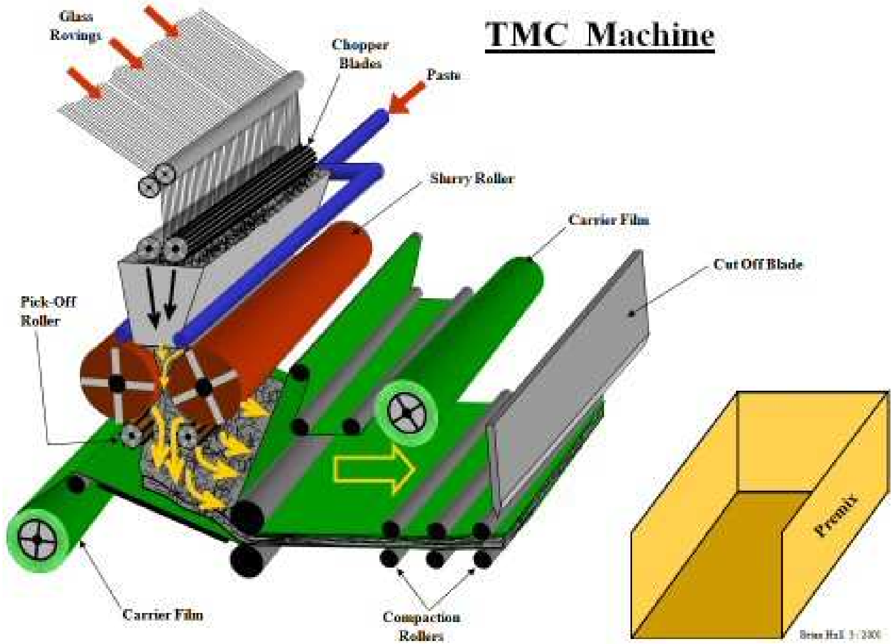
SMC and TMC manufacturing processes





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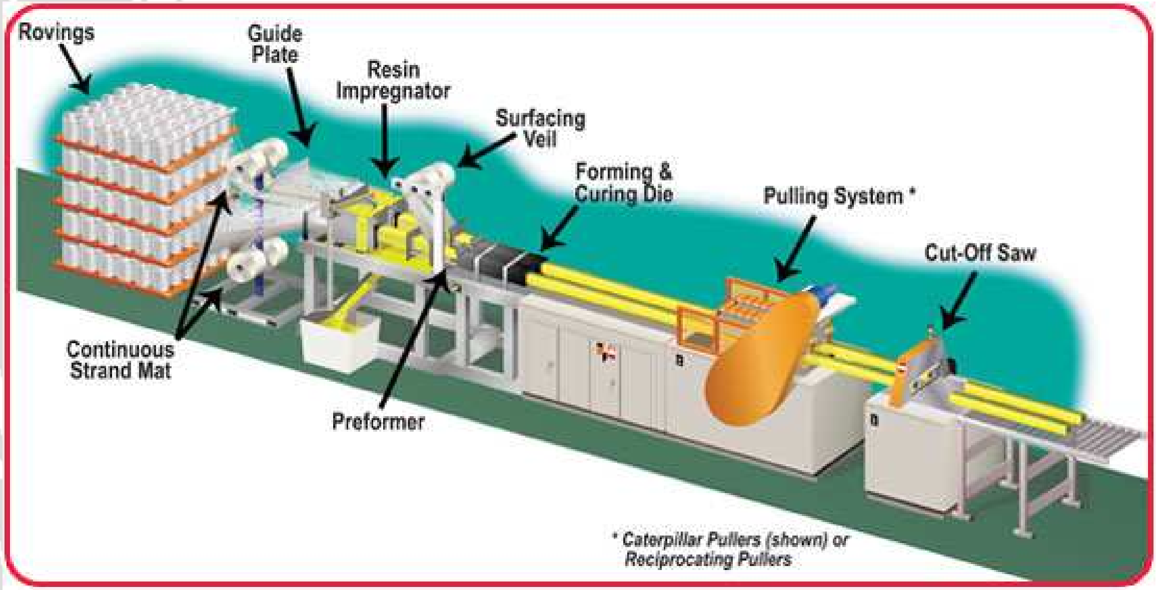
Pultrusion

- Fibre bundles and slit fabrics are pulled through a wet bath of resin and formed into the rough part shape.
- Saturated material is extruded from a heated closed die curing while being continuously pulled through die.
- Process is productive. Potential applications are: roadside reflector poles, ladder rails
- Animation link: http://www.bpf.co.uk/Data/Image/new_ani2.swf



Pultrusion Advantages:

-Increased Strength (fiber processed under tension)
-High Fiber Content
-Highly Automated
-Consistent Quality
-High Production
-Low Labor Required
-Low Cost

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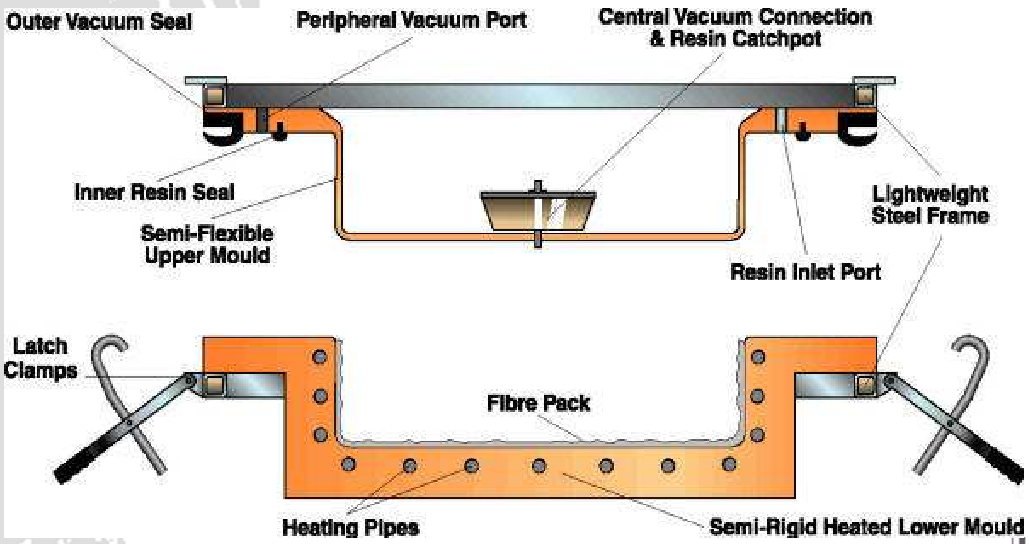
RTM process- *resin transfer moulding*

- Fabrics are placed into a mould which wet resin is then injected into. Resin is typically pressurized and forced into a cavity which is under vacuum in the RTM process.
- Resin is entirely pulled into cavity under vacuum in the VARTM process.
- This moulding process allows precise tolerances and detailed shaping but can sometimes fail to fully saturate the fabric leading to weak spots in the final shape.



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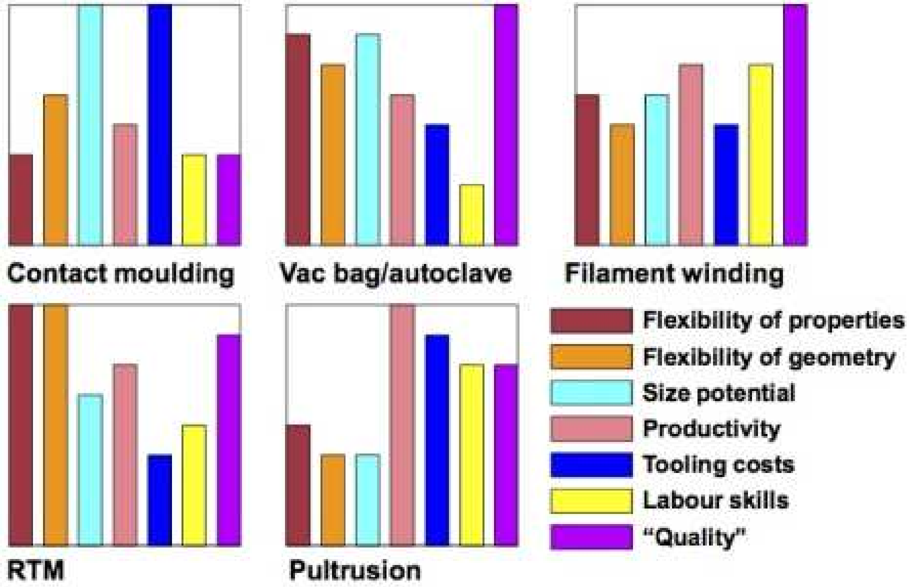
Comparision of manufacturing methods

According to Potter (1996) an ideal process can be defined as having:

- High productivity – short cycle times, low labor contents etc.
- Minimum materials cost – low value added materials, low material storage and handling cost
- Maximum geometrical flexibility – shape complexity and size of component
- Maximum property flexibility – range of matrices, range of reinforcement types, ability to control mechanical properties and tailor characteristics
- Minimum finishing requirements – net shape manufacturing
- Reliable and high quality manufacture – low reject rates, low variability etc.



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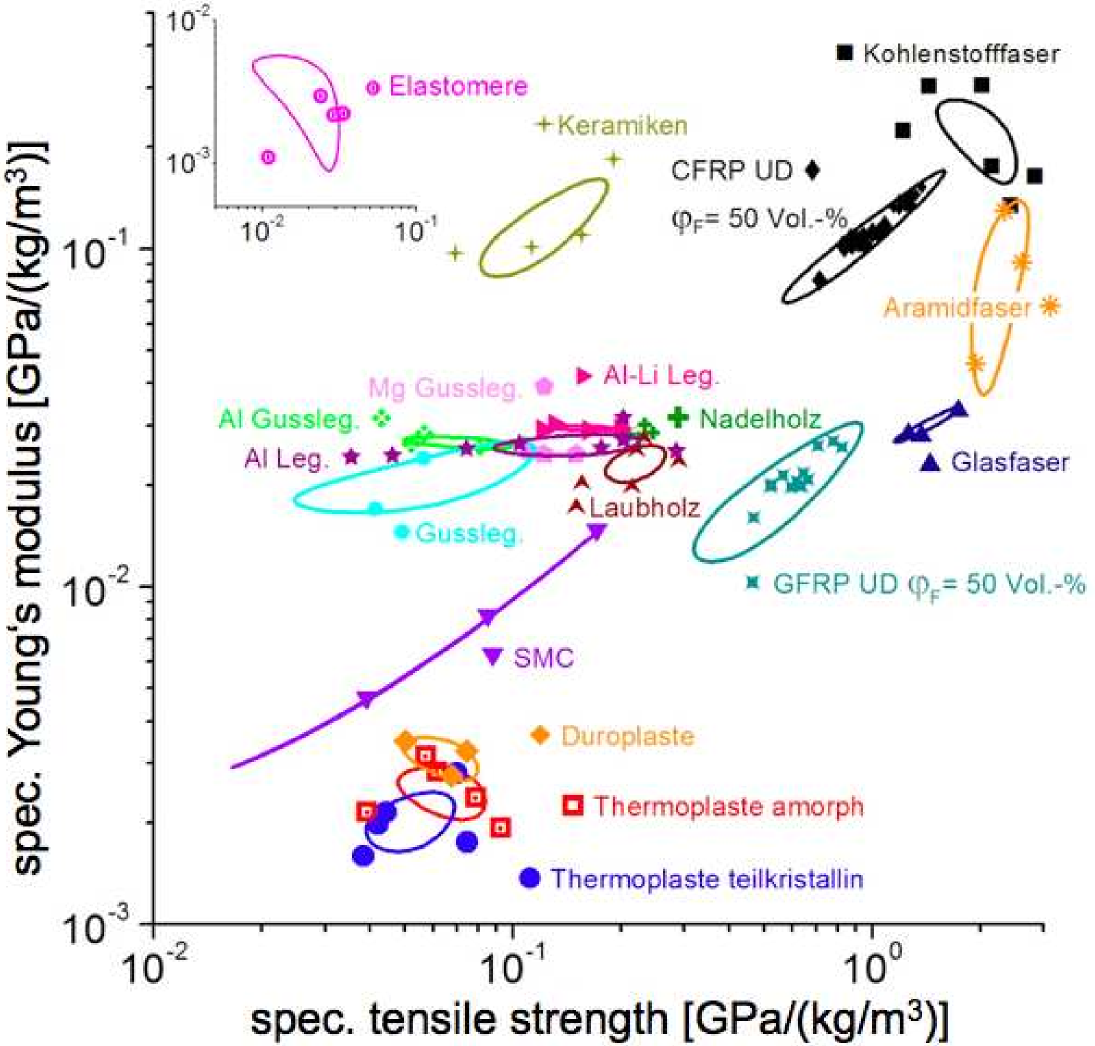
Comparision of performance



CFRP UD
carbon fiber-reinforced plastics

GFRP UD
glass fiber-reinforced plastics

SMC
sheet molding compound

Reference: Steeg, M.: Prozesstechnologie für Cyclic Butylene Terephthalate im Faser-Kunststoff-Verbund. In: Prof. Dr.-Ing. Peter Mitschang (Hrsg.): IVW Schriftenreihe Band 90. Kaiserslautern: Institut für Verbundwerkstoffe GmbH. 2010