MATERIALI COMPOSITI

Caratteristiche – Proprietà – Tecnologie di produzione

Materiali compositi

Un materiale composito consiste di due (o piu') fasi fisicamente e/o chimicamente distinte, con un'interfaccia di separazione tra di esse.

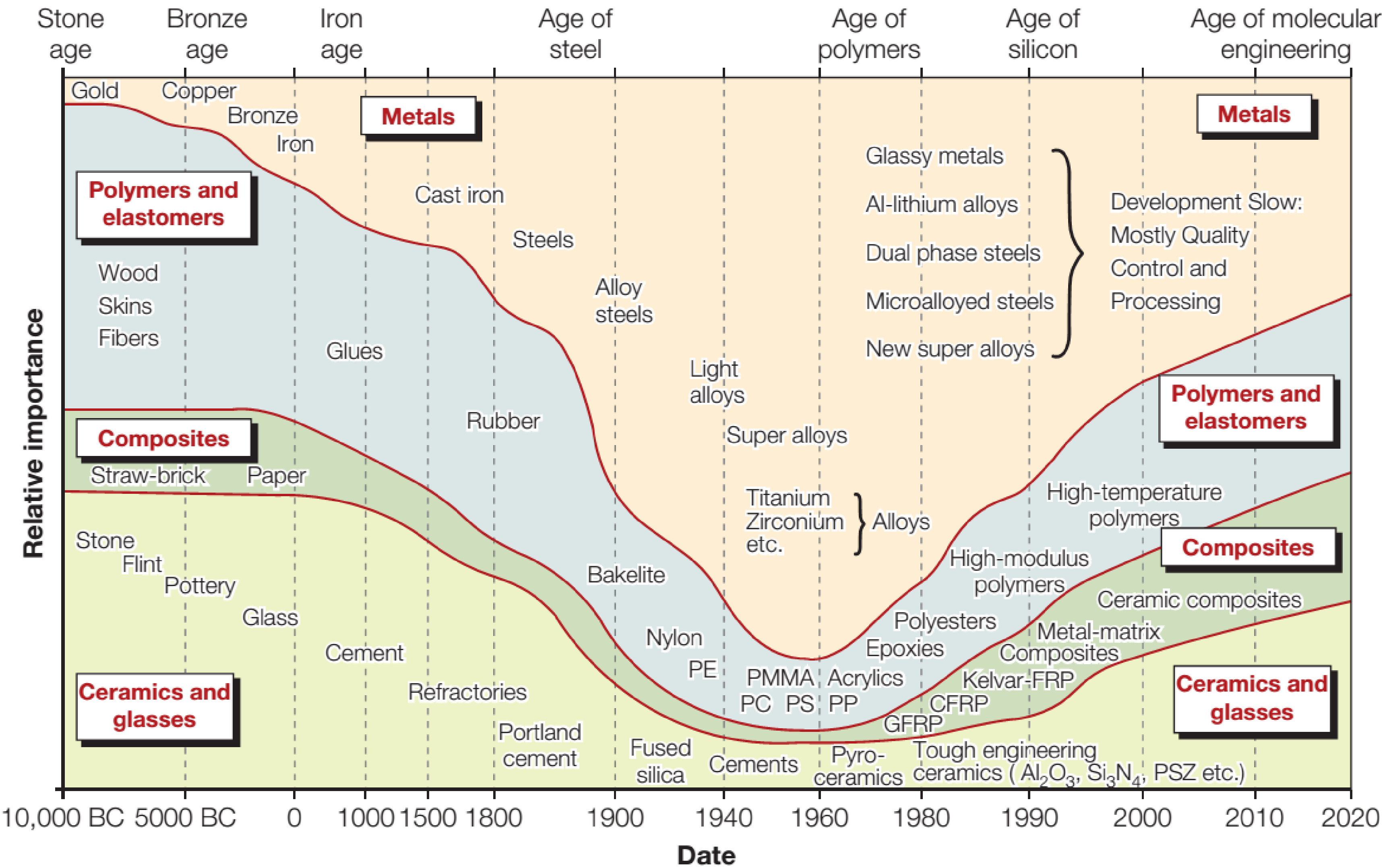
Esso presenta caratteristiche non offerte separatamente dalle due fasi costituenti.

Generalmente sono costituiti da una <u>matrice</u> (bassa rigidezza e resistenza) che ha il compito di assumere il carico e di trasferirlo al <u>rinforzo</u> che garantisce la rigidezza e resistenza.

Materiali compositi

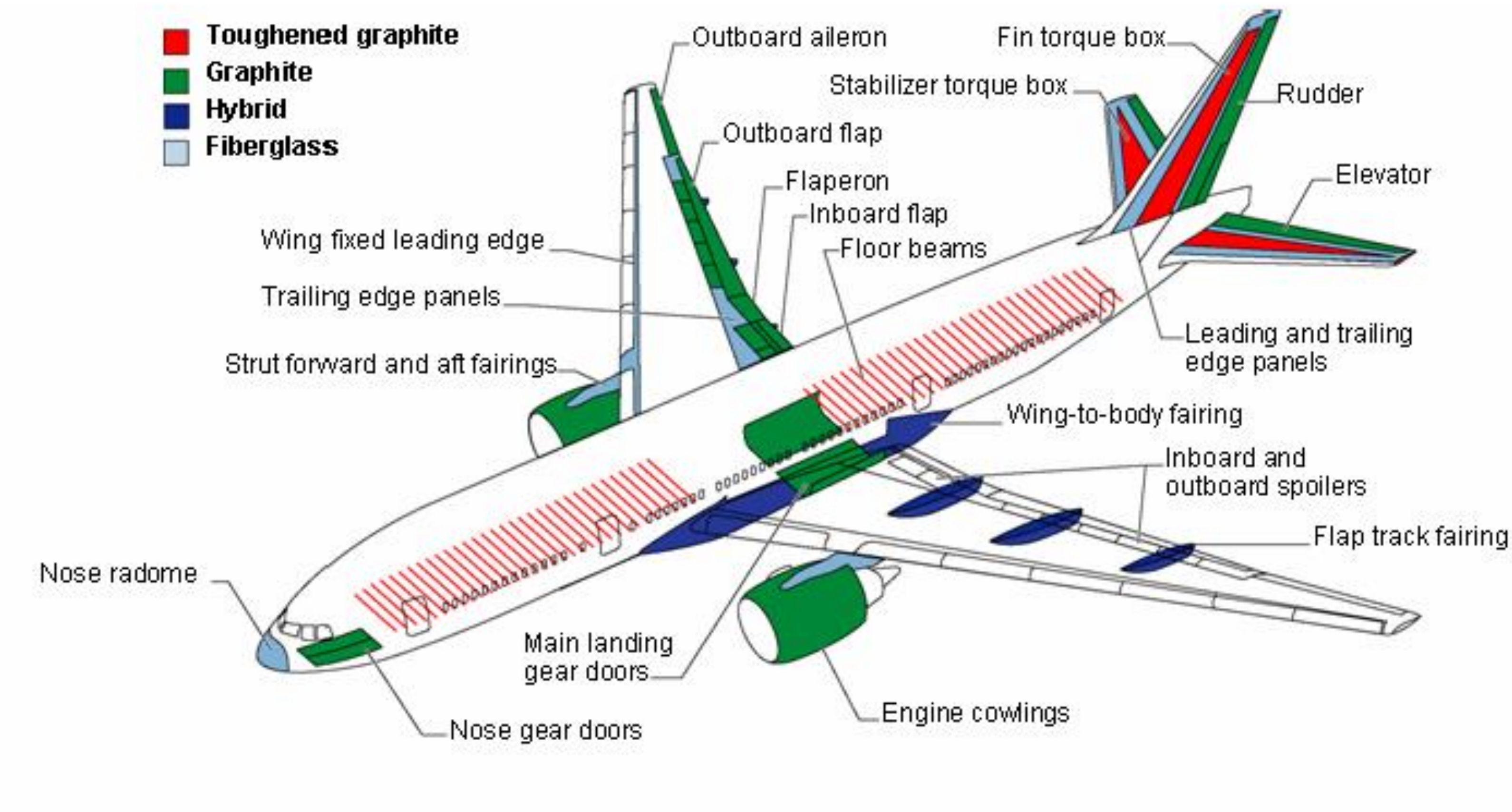
VANTAGGI PRINCIPALI

- Alta resistenza specifica (resistenza/massa)
- Alta rigidezza specifica (rigidezza/massa)
- Elevata resistenza alla corrosione
- **Il materiale (e non solo la struttura) può essere progettato**



Stone age
Bronze age
Iron age
Age of steel
Age of polymers
Age of silicon
Age of molecular engineering
Gold
Copper
Bronze
Iron
Metals
Metals
Polymers and elastomers
Cast iron
Steels
Alloy steels
Glassy metals
Al-lithium alloys
Dual phase steels
Microalloyed steels
New super alloys
Development Slow: Mostly Quality Control and Processing
Wood
Skins
Fibers
Glues
Light alloys
Super alloys
Rubber
Polymers and elastomers
Composites
Straw-brick
Paper
Titanium
Zirconium
etc.
Alloys
High-temperature polymers
Stone
Flint
Pottery
Glass
Bakelite
High-modulus polymers
Composites
Cement
Nylon
Polyesters
Ceramic composites
PE
Epoxies
Metal-matrix Composites
Refractories
PMMA
Acrylics
Kelvar-FRP
PC
PS
PP
CFRP
Ceramics and glasses
GFRP
Ceramics and glasses
Portland cement
Fused silica
Cements
Pyro-ceramics
Tough engineering ceramics (Al_2O_3, Si_3N_4, PSZ etc.)
Relative importance
10,000 BC
5000 BC
0
1000
1500
1800
1900
1940
1960
1980
1990
2000
2010
2020
Date

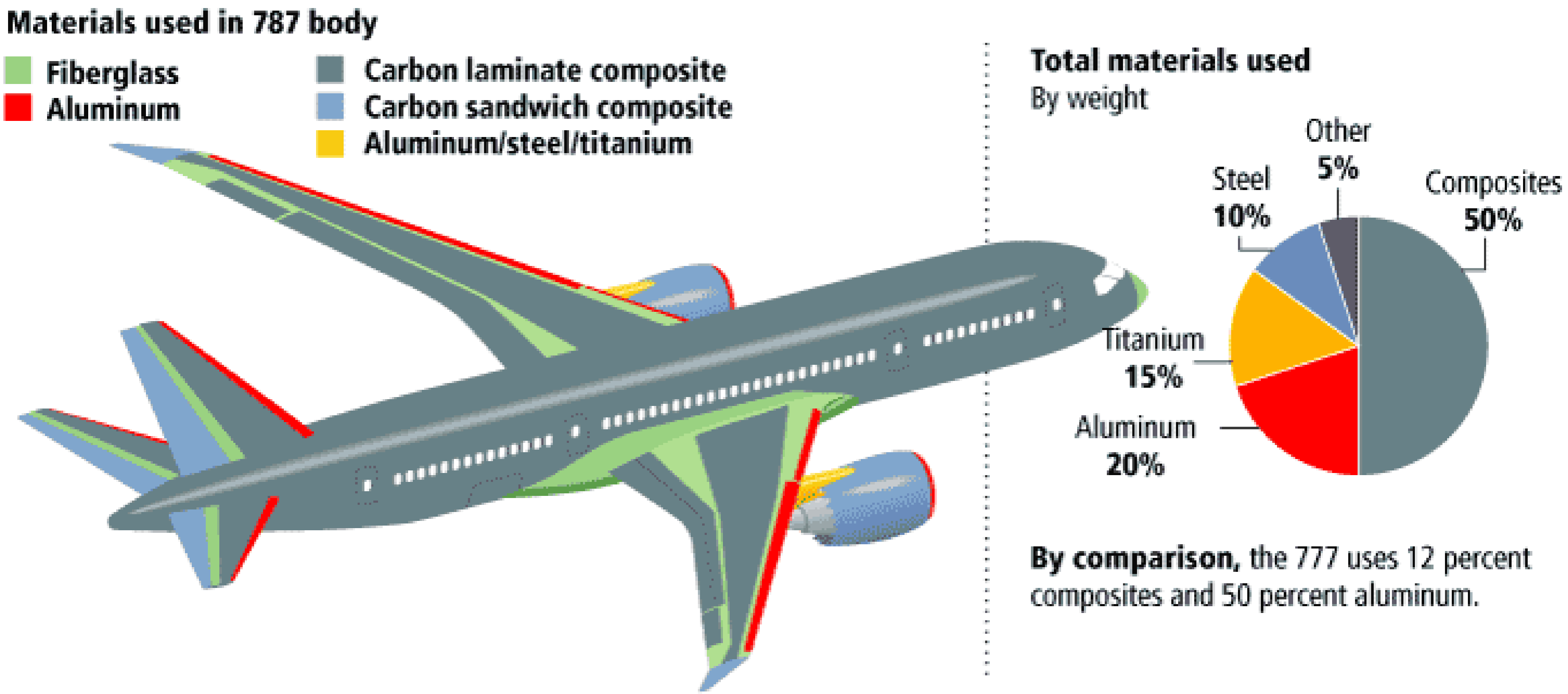
1990
(BOEING 777)



50% Alluminio - **12**% Compositi

2009

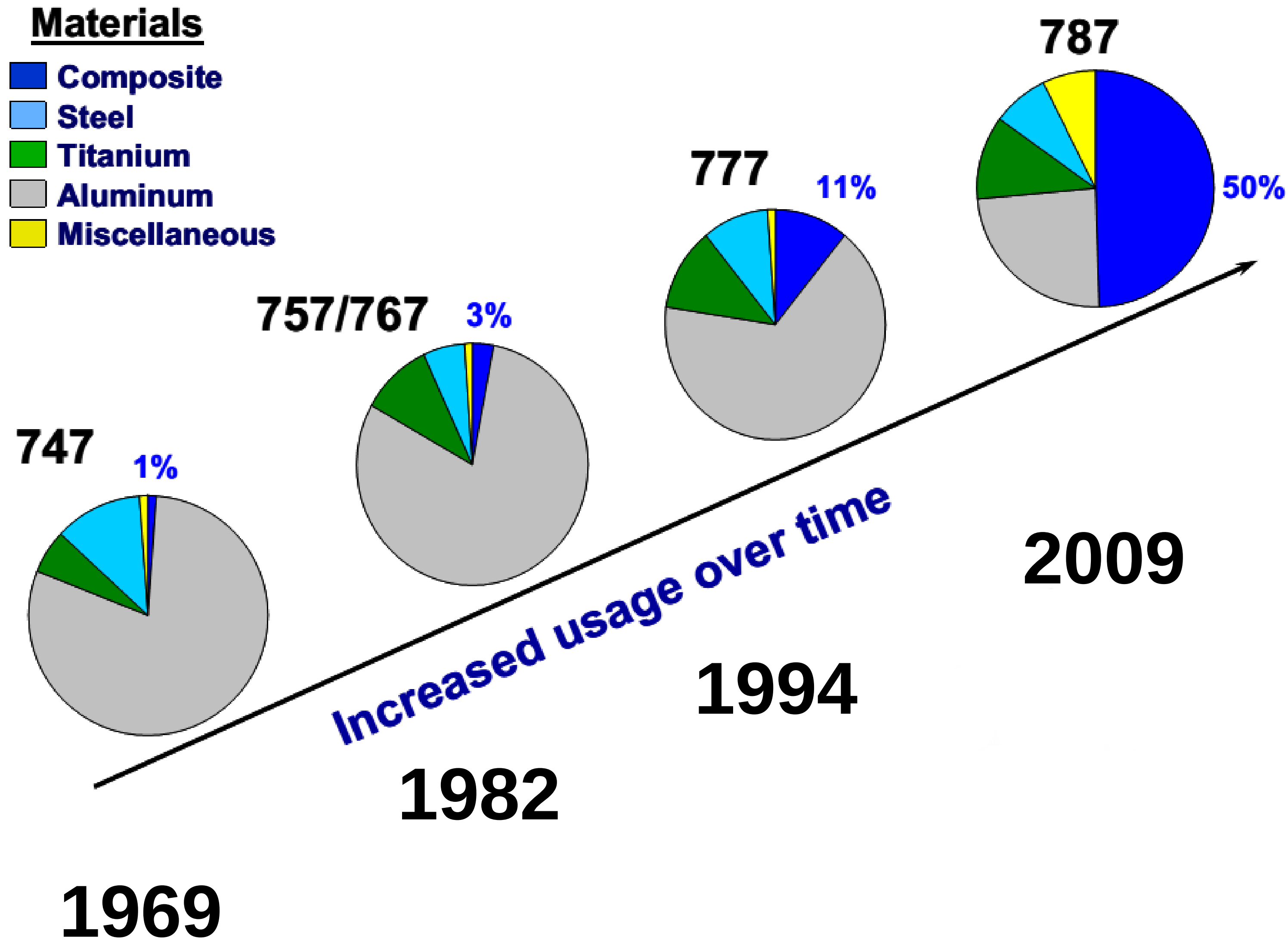
(BOEING 787)



50% Compositi - **20**% Alluminio

(Compositi 80% in volume)

Percentuale materiali (in peso) in velivoli civili (Boeing)



Tipi di composito

MATRICE / RINFORZO	Metallica	Ceramica	Polimerica
Metallico	Metallurgia delle polveri – (Metalli immiscibili)	Cermets (compositi ceramica - metallo)	
Ceramico	Fibre di vetro/matrice metallica	SiC /Al2O3 Fibre in Carburo di Silicio/Allumina) (Utensili)	**Fibre di vetro/resina poliestere**
Polimerico			**Fibre di kevlar/Resina epossidica**
Singolo elemento (Boro, Carbonio)	Metalli fibrorinforzati (campo aerospaziale)		Fibre di carbonio/Resina epossidica

MMC
Metal Matrix Composite

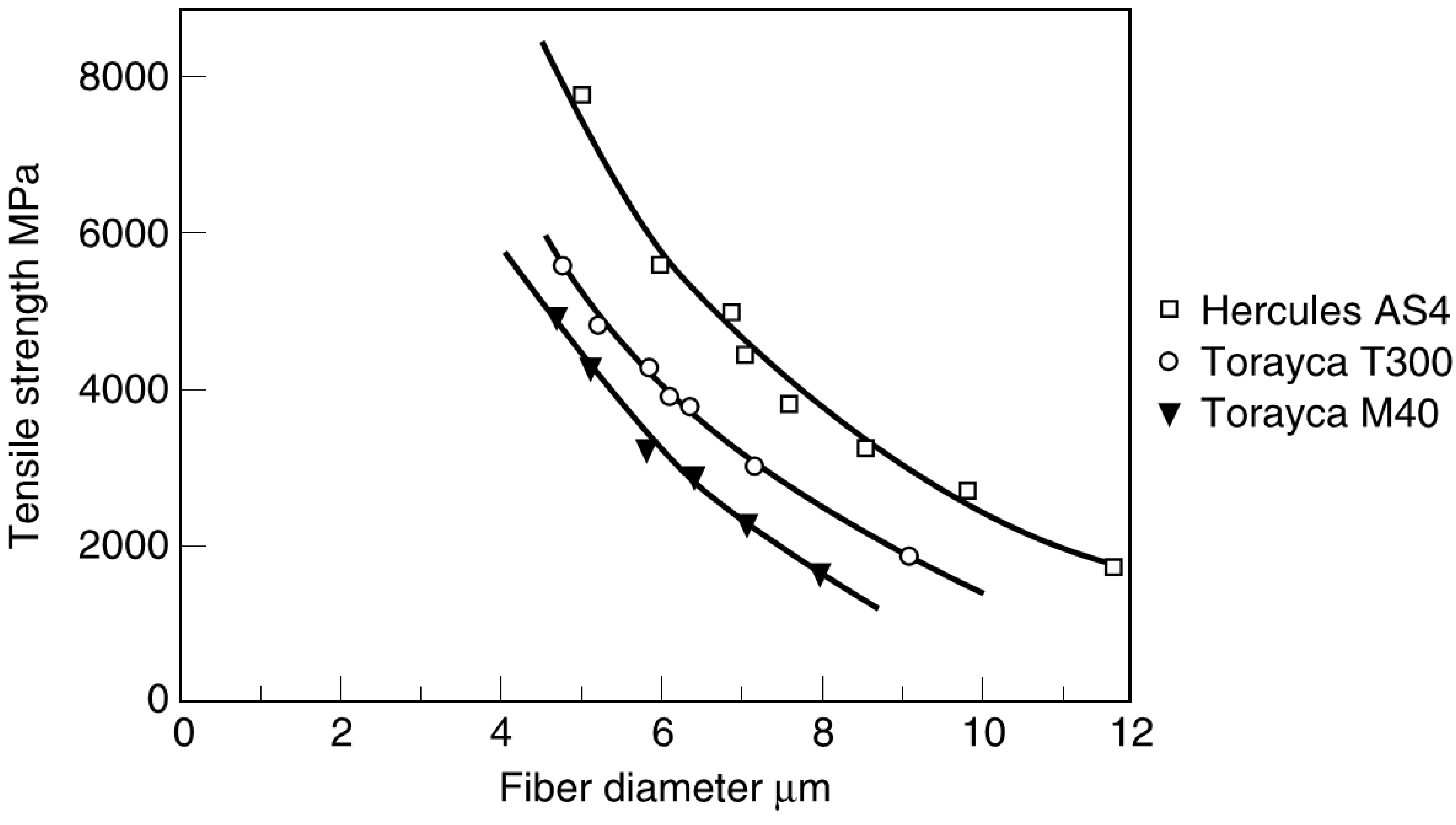
CMC
Ceramic Matrix Composite

PMC
Polymer Matrix Composite

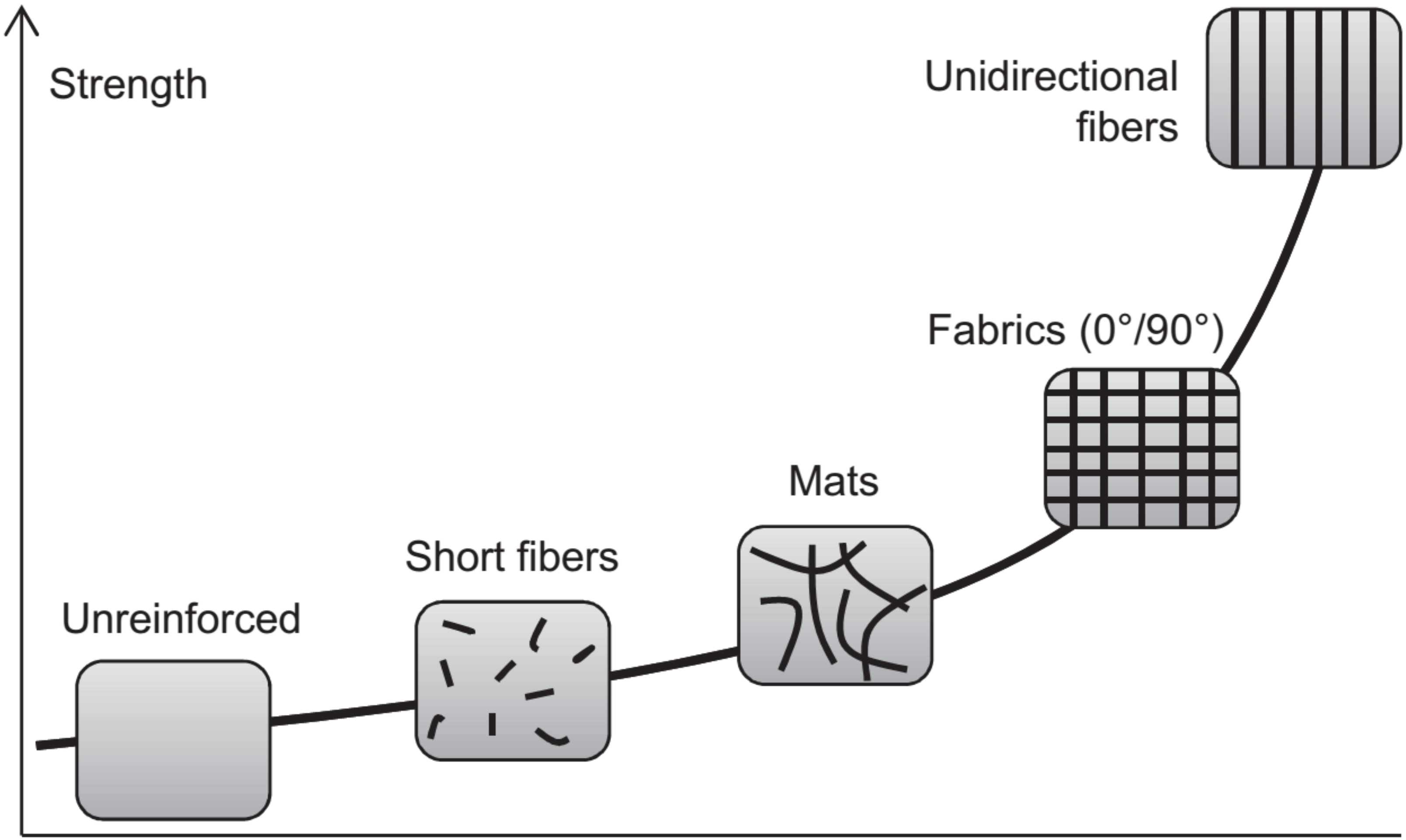
Fattori di forma del rinforzo

- Fibre
  - sezione circolare, quadrata, esagonale, etc.
  - diametro → 1 µm ÷ 150 µm
  - Rapporti L/D (Lunghezza/Diametro)
    - ≈ 100 per fibre corte
    - $> 10^5$ per fibre continue
- Particelle
  - piccole particelle (≈ 1 mm) che impediscono movimenti di dislocazione (nei metalli) o di propagazione di fratture e aumentano la resistenza della matrice
- Lamine (flakes)
  - lamelle piatte (≈ 1 mm)

Relazione tra resistenza e diametro delle fibre



Relazione tra resistenza e architetture del rinforzo



Fibre di Vetro

- Usi: tubi, serbatoi, imbarcazioni, articoli sportivi, pale aerogeneratori
- Vantaggi
  - basso costo
  - resistenza alla corrosione
  - trasparente alle radiofrequenze
- Svantaggi
  - Resistenza medio-bassa
  - Bassa rigidezza
  - Densità relativamente alta (2500 kg/m^3)
- Tipi:
  - **E-Glass – economico/bassa resistenza**
  - S-Glass – migliore resistenza/rigidezza meccanica
  - C-Glass – resistenza alla corrosione da ambienti acidi

Fibre aramidiche (aromatic polyamide) - Kevlar, Twaron -

- Usi:
  - Indumenti protettivi, resistenza balistica, articoli sportivi, pneumatici.
- Vantaggi:
  - Elevata resistenza specifica rispetto alle fibre di vetro
  - Più duttili e flessibili (minore modulo di Young) delle fibre di carbonio.
- Svantaggi:
  - Scadenti proprietà a compressione
  - Sensibilità a radiazioni UV

Fibre di carbonio (graphite)

- Usi
  - aeronautica ed aerospazio, trasporti, articoli sportivi.

- Vantaggi
  - elevata resistenza e rigidezza
  - bassa densità

Vari tipi di fibre di carbonio con diversi rapporti rigidezza/resistenza

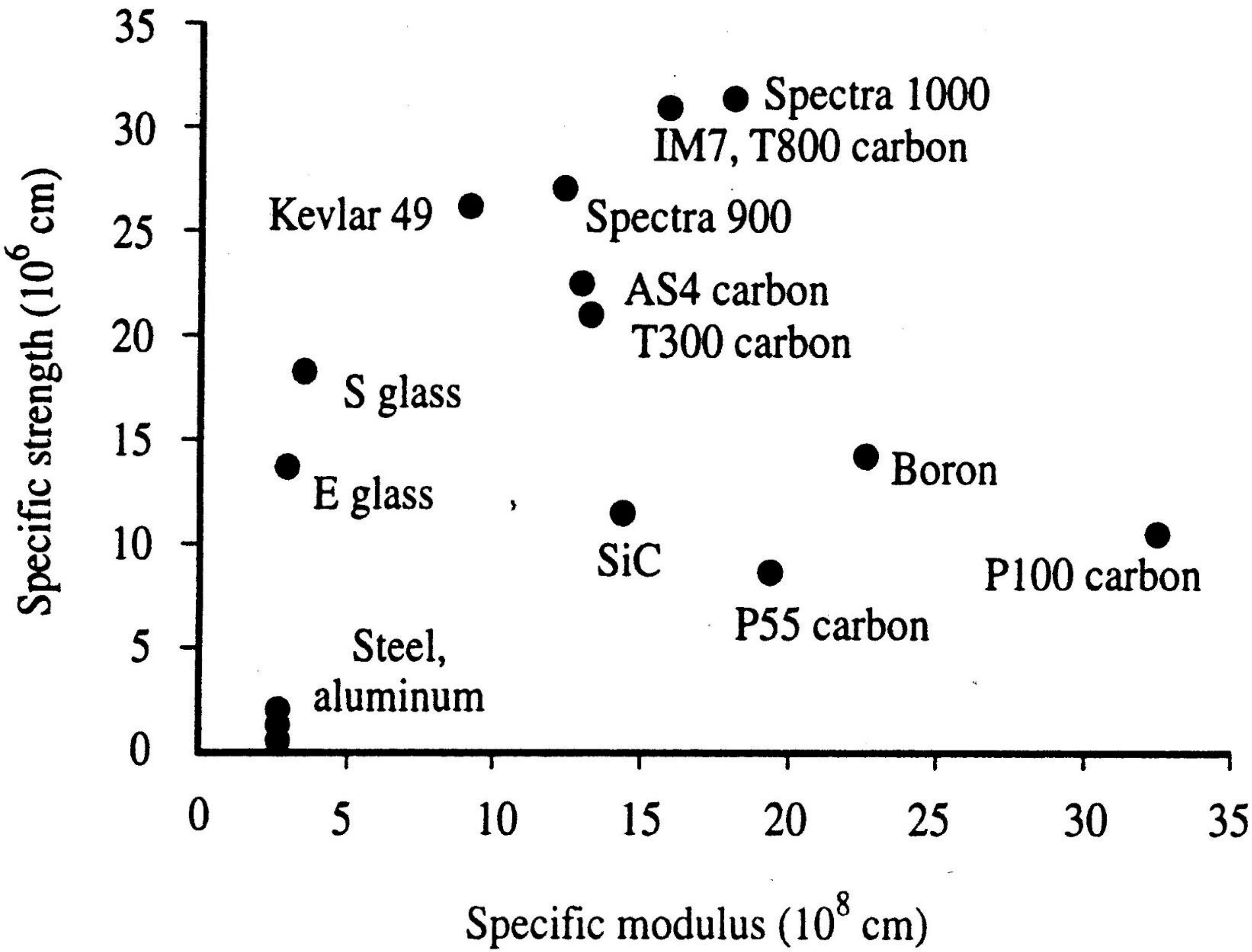
- Svantaggi
  - Comportamento relativamente fragile
  - Costo

Altri tipi di fibre

- Boro (boro depositato su filo in tungsteno)
  - Alta rigidezza, altissimo costo
  - Diametro ≈ 200 μm
  - Buona resistenza alla compressione
- Polietilene (Spectra/Dyneema)
  - Industria tessile
  - Alta resistenza
  - Bassa densità (<1000 kg/m^3)
  - Si degrada a temperature superiori a 150°C
- Ceramiche
  - Alte temperature (utilizzo con matrici ceramiche)
  - Fragili

FIBRE

Resistenza specifica vs. Rigidezza specifica



Matrice

- Funzioni della matrice
  - Trasmettere e distribuire il carico alle fibre
  - Mantenere le fibre nell'orientazione desiderata
  - Proteggere le fibre dall'ambiente

- Requisiti della matrice
  - Resistenza a taglio
  - Tenacità (resistenza alla frattura)
  - Resistenza umidità e ad ambienti corrosivi
  - Resistenza a temperature di esercizio

Matrici Polimeriche

- **Termoindurenti (Thermoset)**
  - induriscono per reazione chimica (reticolazione)
  - Indurimento irreversibile

- Poliestere, vinilestere
  - Comuni, basso costo, resistenza ambiente aggressivo
- Epoxy (resina epossidica)
  - Proprietà meccaniche elevate; costosa

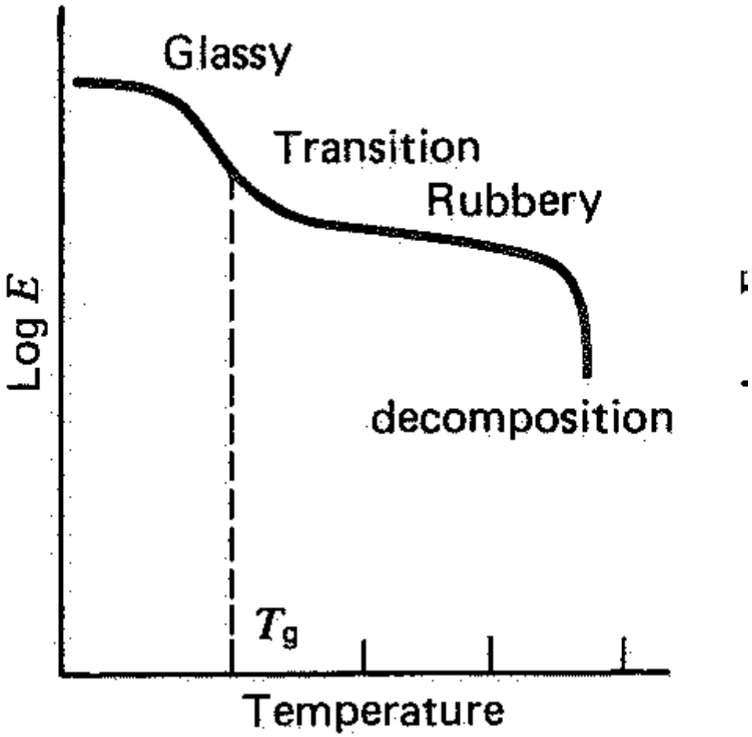
Matrici Polimeriche

- **Termoplastiche (Thermoplastic)**
  - Messe in forma riscaldando il materiale
  - Reazione reversibile
  - Può essere riscaldata e rimessa in forma (Patch)
  - Temperature di esercizio fino a 150°C circa

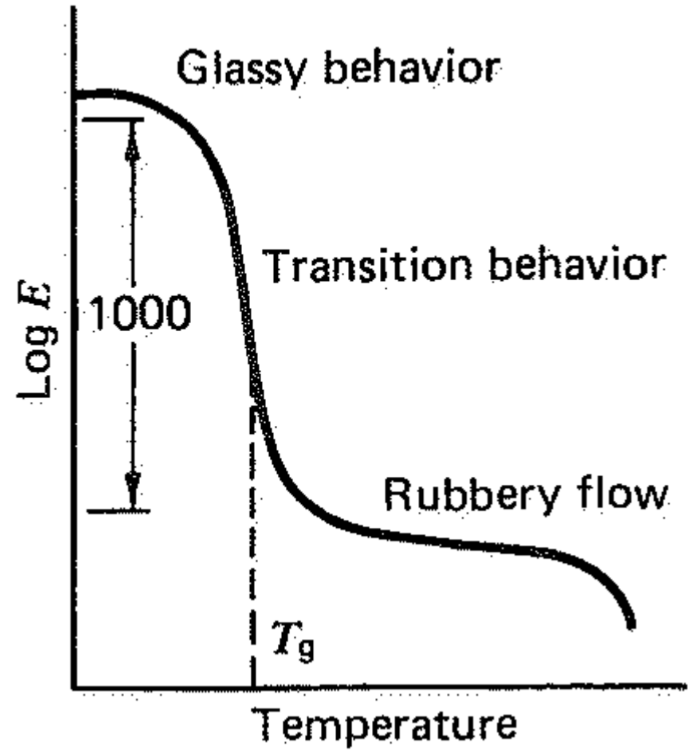
    - Polipropilene
      - accoppiata con fibre di nylon o di vetro
      - può essere iniettata (economica)
      - Il composito può essere stampato combinando strati di fibre e films di resina

Matrici Polimeriche

Matrici termoindurenti



Matrici termoplastiche



Tg = Temperatura di transizione vetrosa (glass transition temperature)

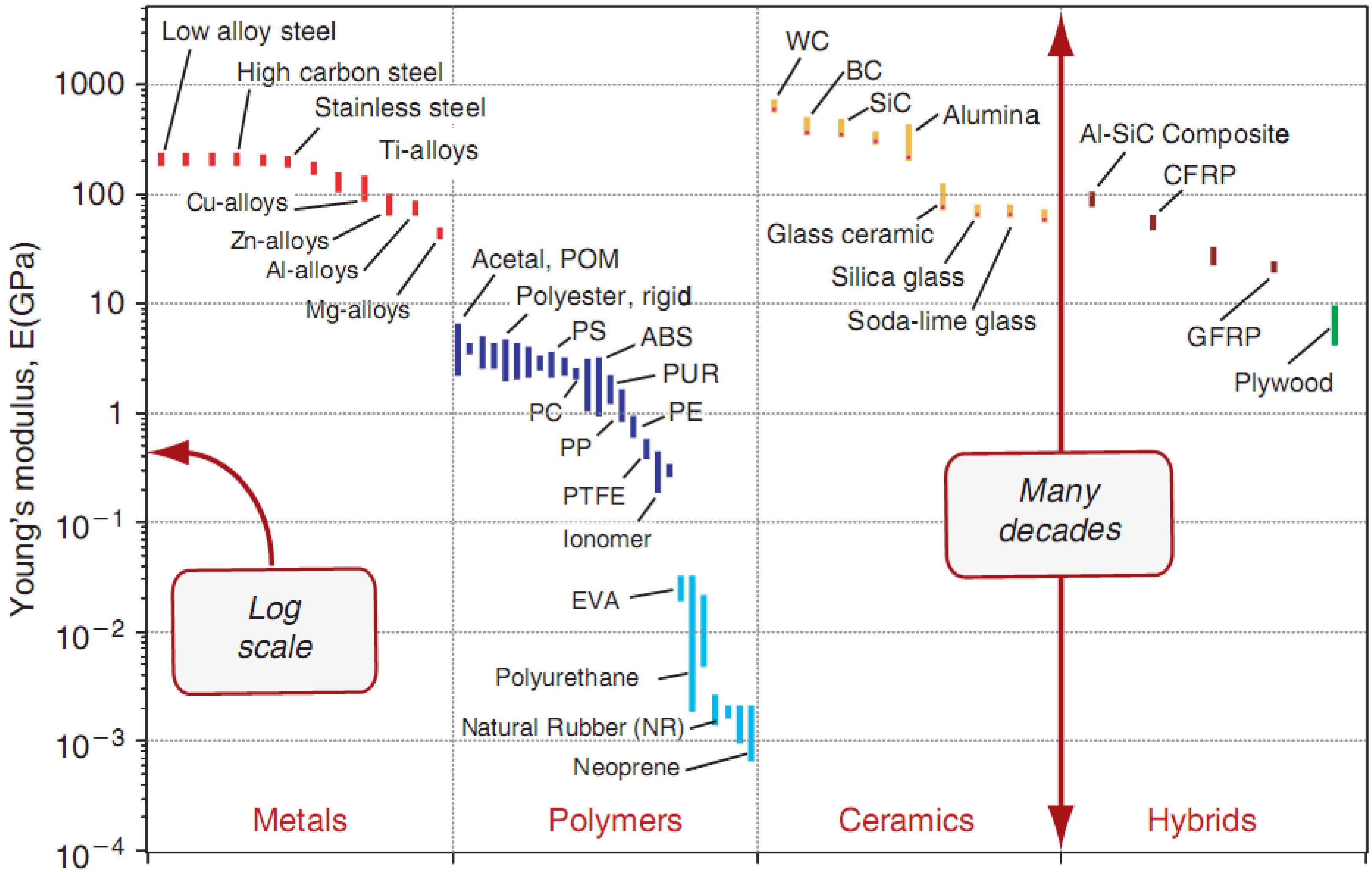
Altre matrici

- **Matrici metalliche**
  - Alta temperatura
  - p.e.: Alluminio con fibre di boro o carbonio
- **Matrici ceramiche**
  - Altissima temperatura
  - Le fibre aumentano la tenacità (crack resistance), non necessariamente la resistenza

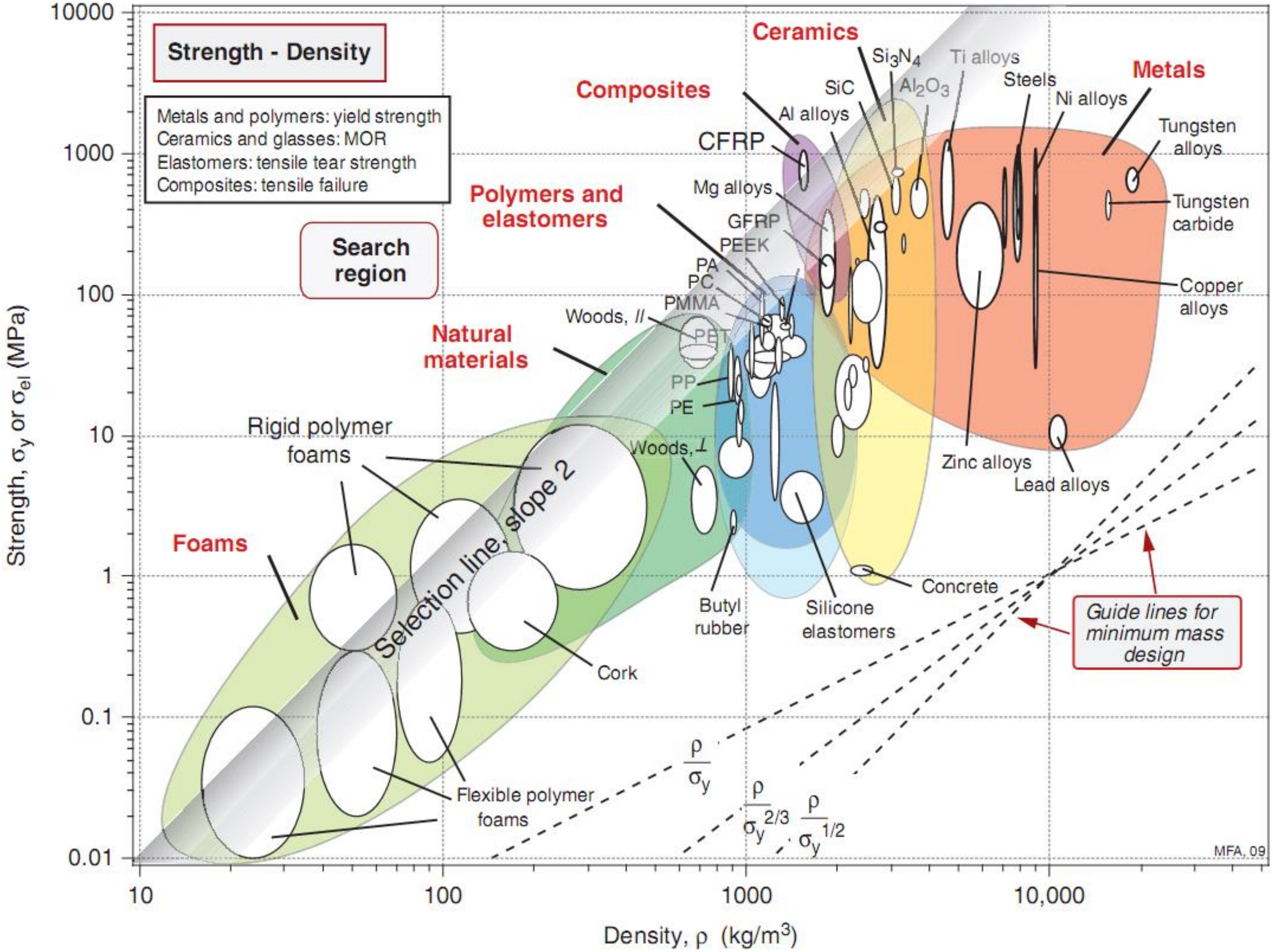
PROPRIETA' BASE DI MATERIALI INGEGNERISTICI PER USO STRUTTURALE

Class	Property	Symbol and Units
General	Density	ρ (kg/m^3 or Mg/m^3)
	Price	C_m ($/kg)
Mechanical	Elastic moduli (Young's, shear, bulk)	E, G, K (GPa)
	Yield strength	σ_y (MPa)
	Tensile (ultimate) strength	σ_{ts} (MPa)
	Compressive strength	σ_c (MPa)
	Failure strength	σ_f (MPa)
	Hardness	H *(Vickers)*
	Fatigue endurance limit	σ_e (MPa)
	Fracture toughness	K_{1c} (MPa.m$^{1/2}$)
	Loss coefficient (damping capacity)	η (–)
	Wear rate (Archard) constant	K_AMPa^{-1}
Thermal	Melting point	T_m (°C or K)
	Glass temperature	T_g (°C or K)
	Maximum service temperature	T_{max} (°C or K)
	Minimum service temperature	T_{min} (°C or K)
	Thermal expansion coefficient	α (K^{-1})

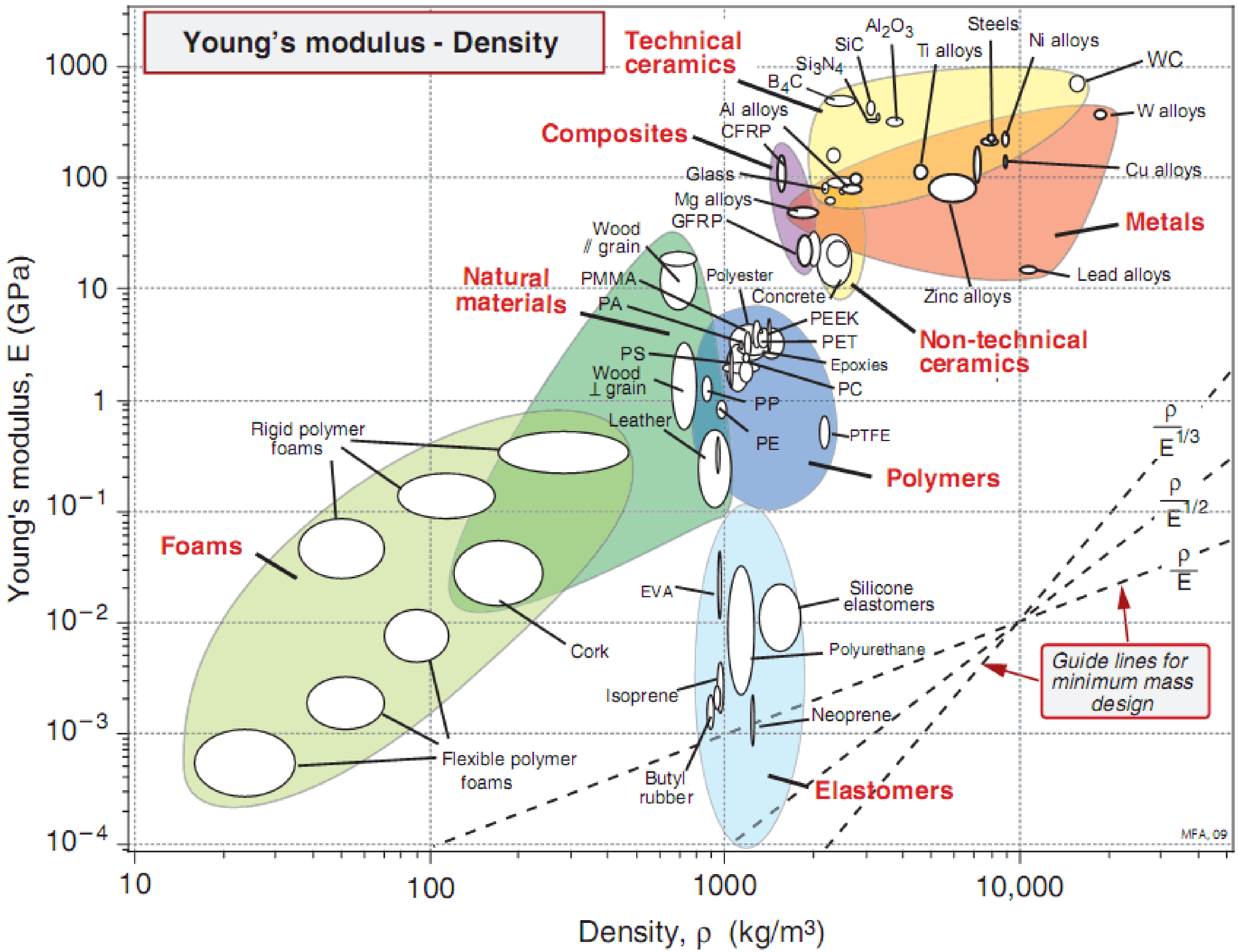
MATERIALI INGEGNERISTICI



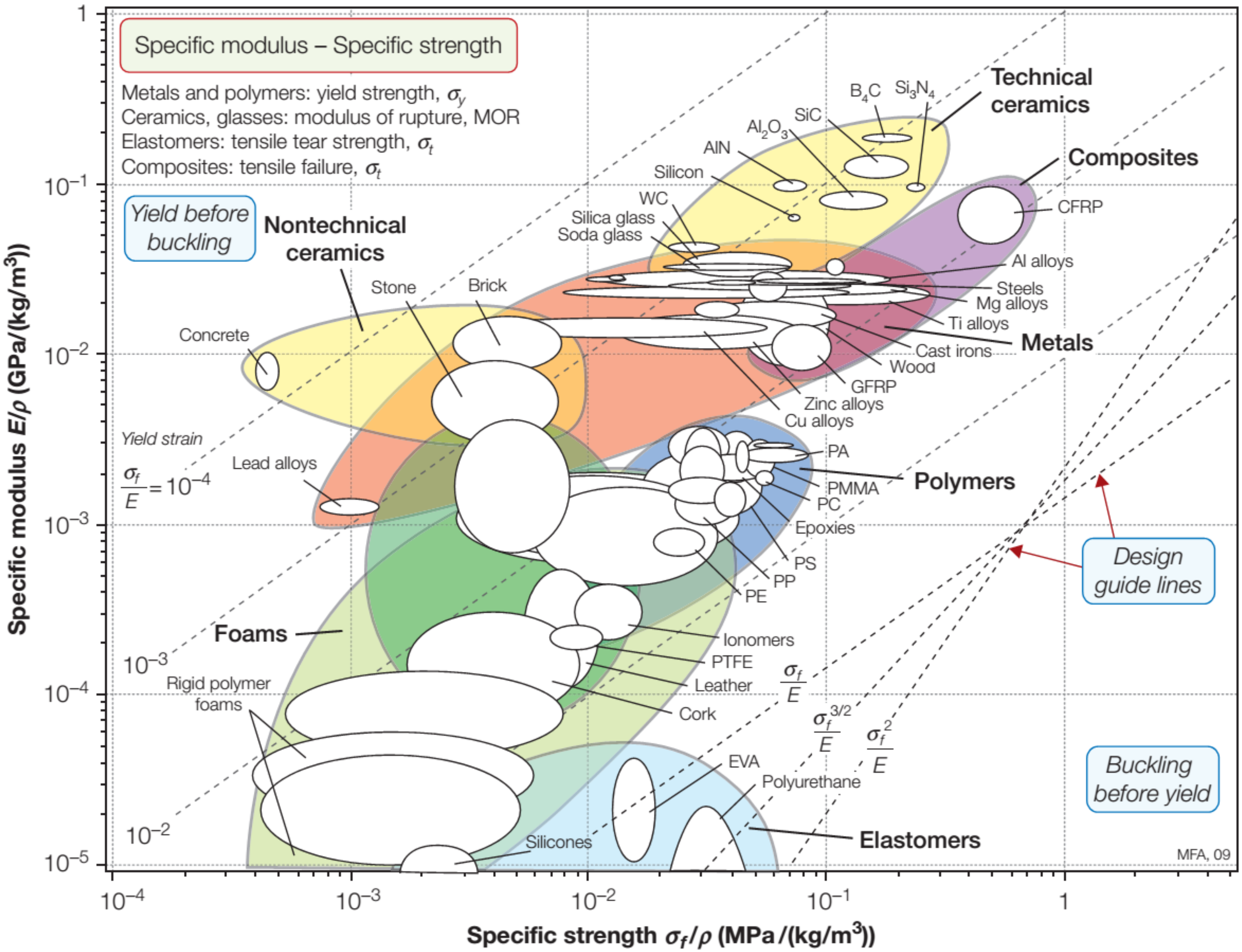
Proprietà assolute



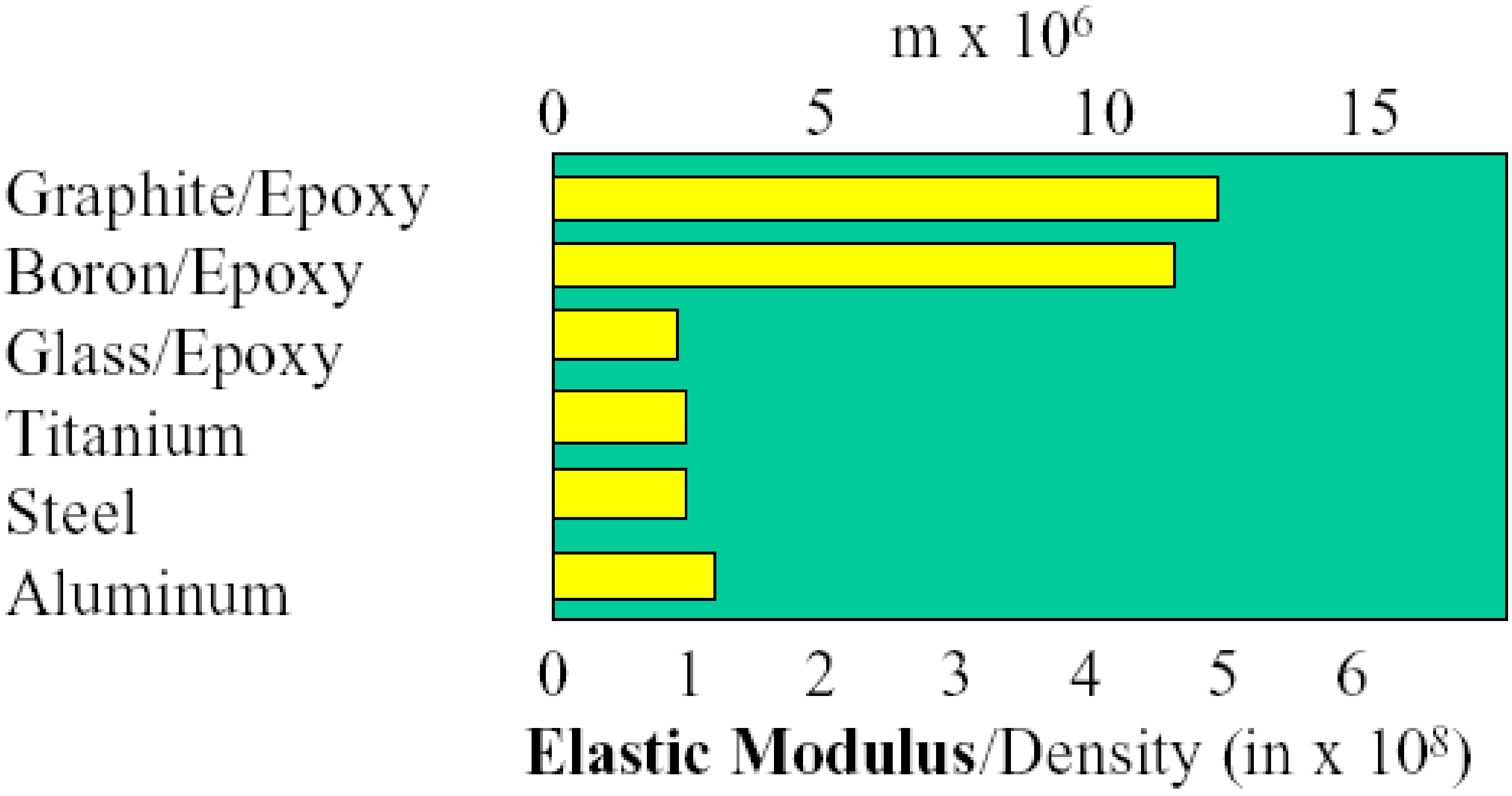
Proprietà assolute



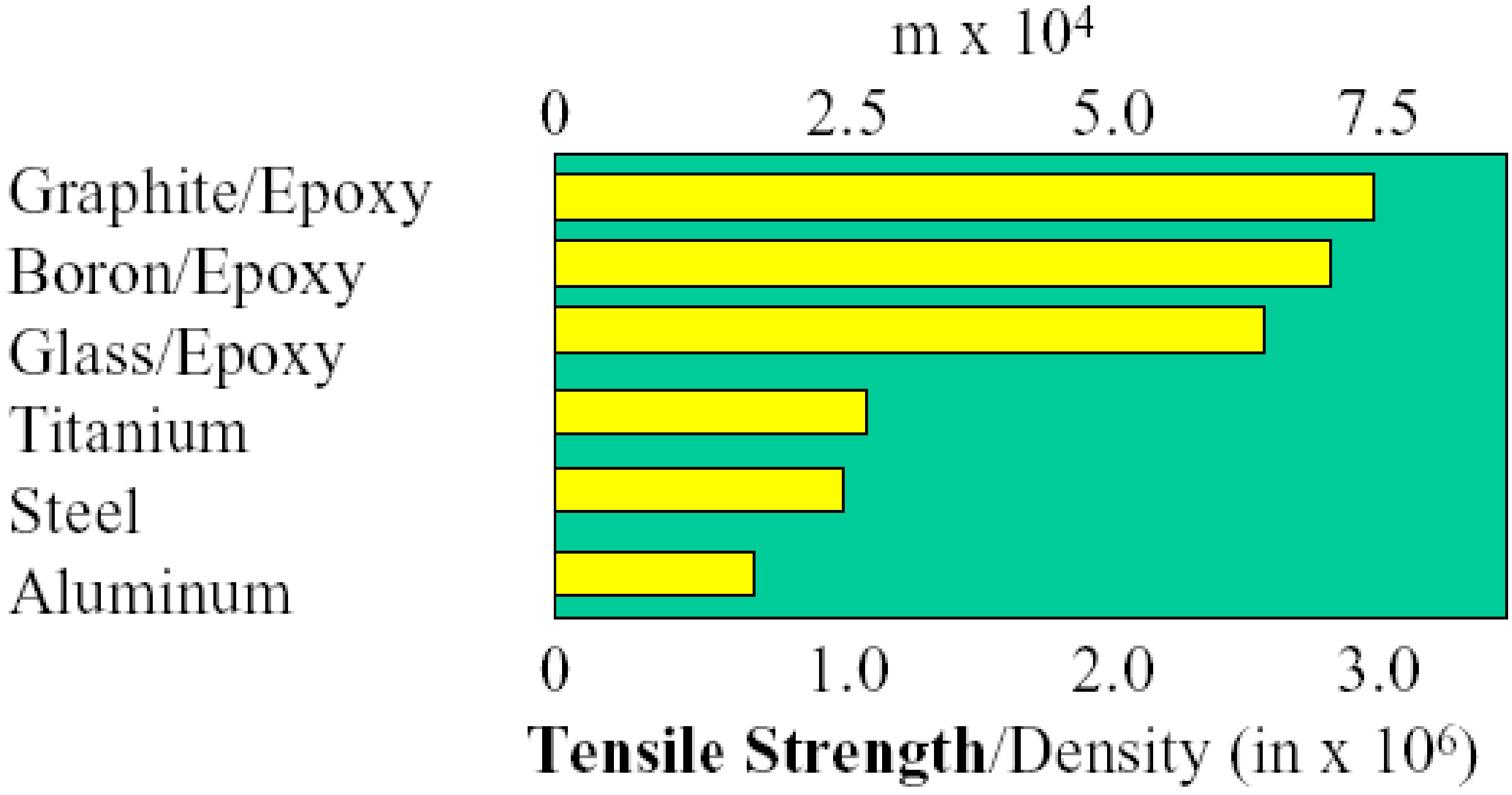
Proprietà specifiche

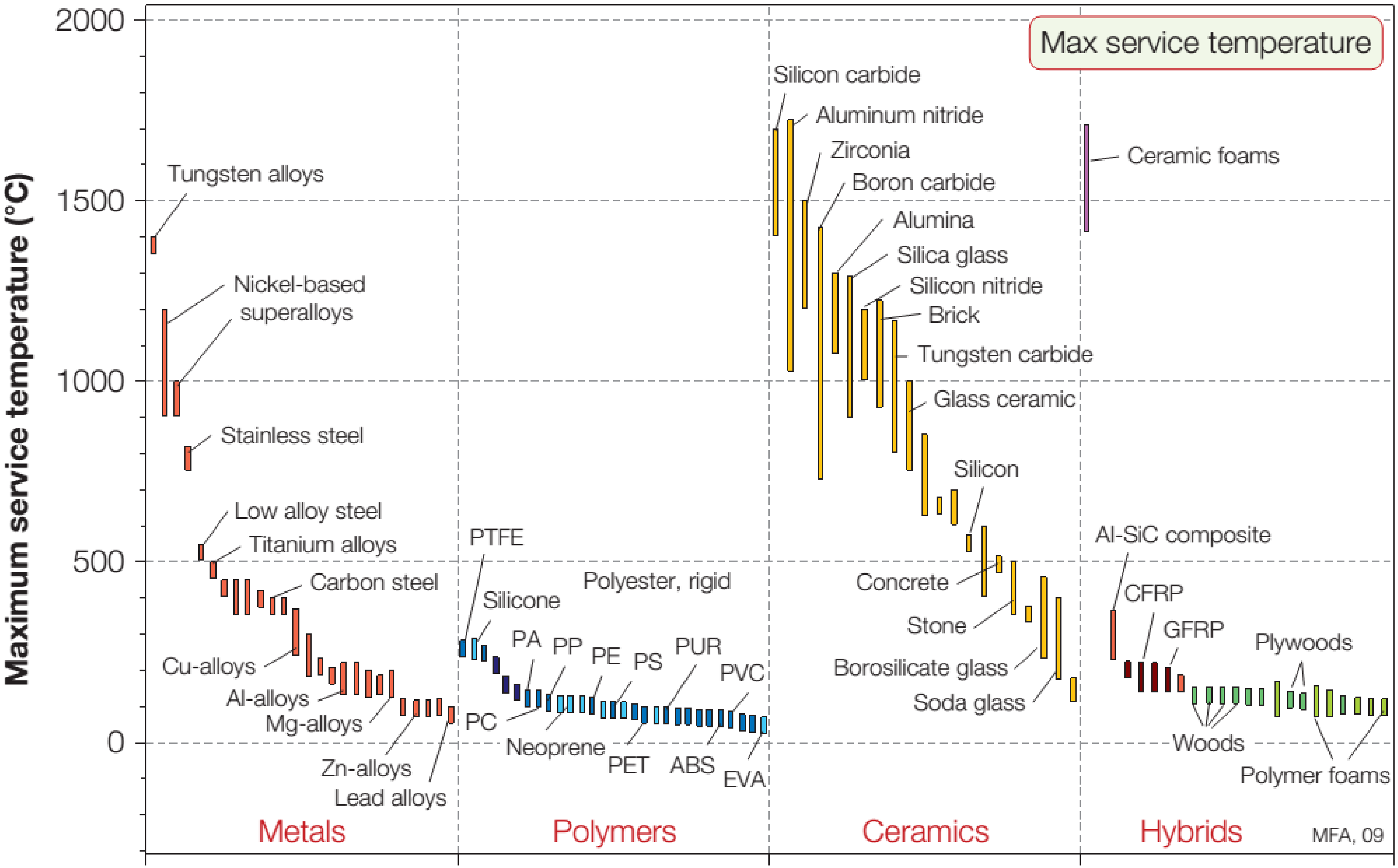


COMPOSITI
Rigidezza specifica

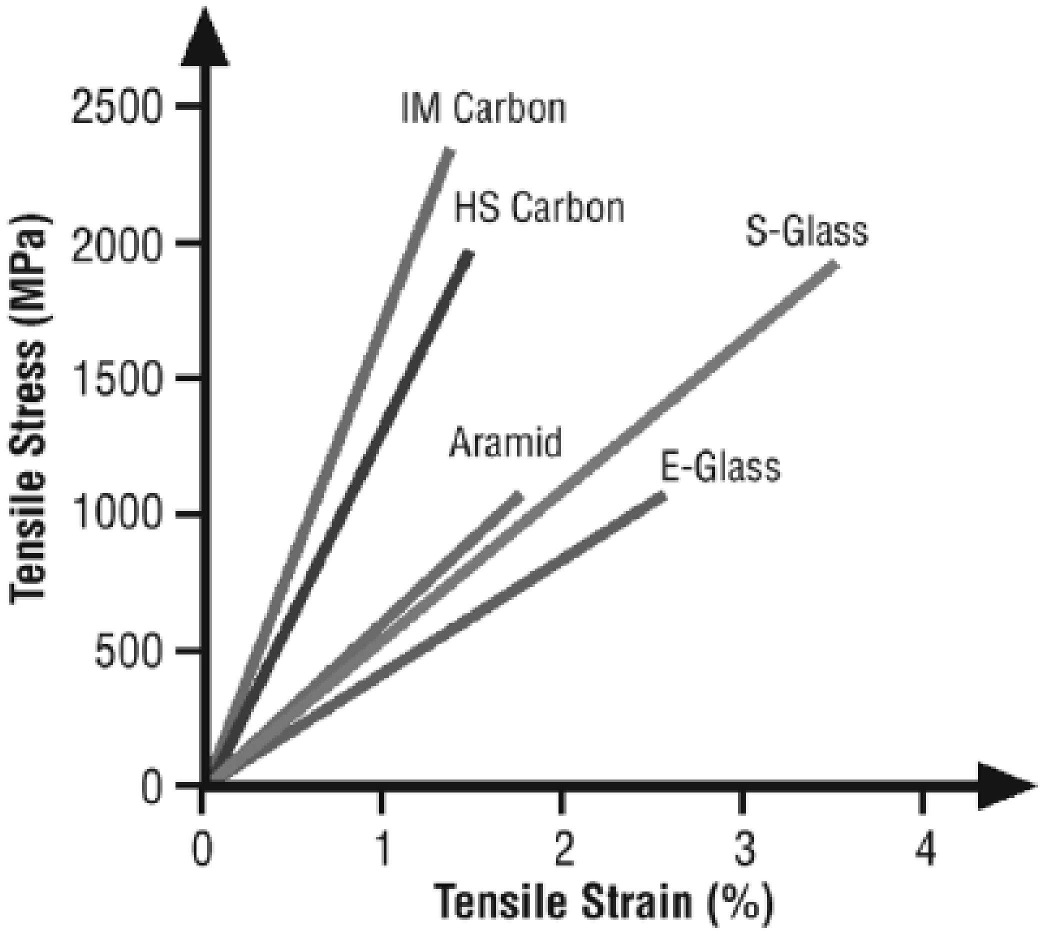


COMPOSITI
Resistenza specifica

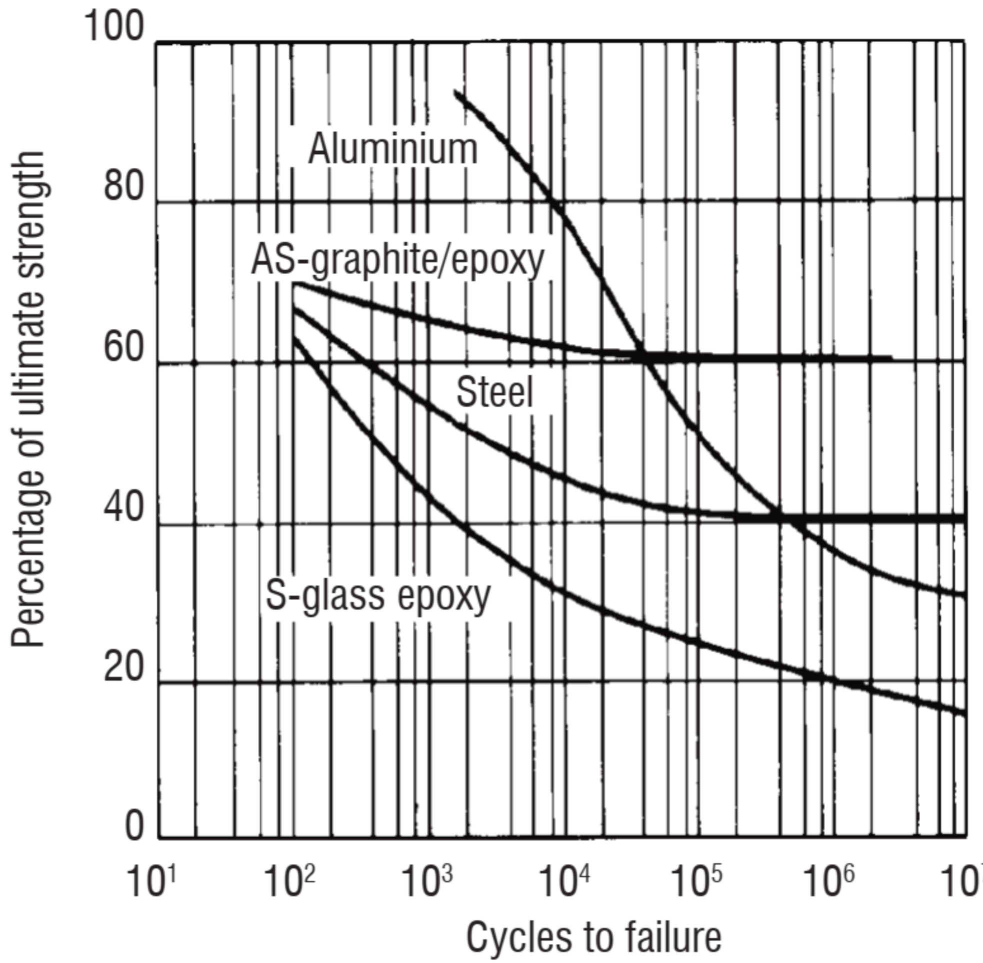



Max service temperature
Maximum service temperature (°C)
2000
1500
1000
500
0
Tungsten alloys
Nickel-based superalloys
Stainless steel
Low alloy steel
Titanium alloys
Carbon steel
Cu-alloys
Al-alloys
Mg-alloys
Zn-alloys
Lead alloys
PTFE
Silicone
Polyester, rigid
PA
PP
PE
PS
PUR
PVC
PC
Neoprene
PET
ABS
EVA
Silicon carbide
Aluminum nitride
Zirconia
Boron carbide
Alumina
Silica glass
Silicon nitride
Brick
Tungsten carbide
Glass ceramic
Silicon
Concrete
Stone
Borosilicate glass
Soda glass
Ceramic foams
Al-SiC composite
CFRP
GFRP
Plywoods
Woods
Polymer foams
Metals
Polymers
Ceramics
Hybrids
MFA, 09

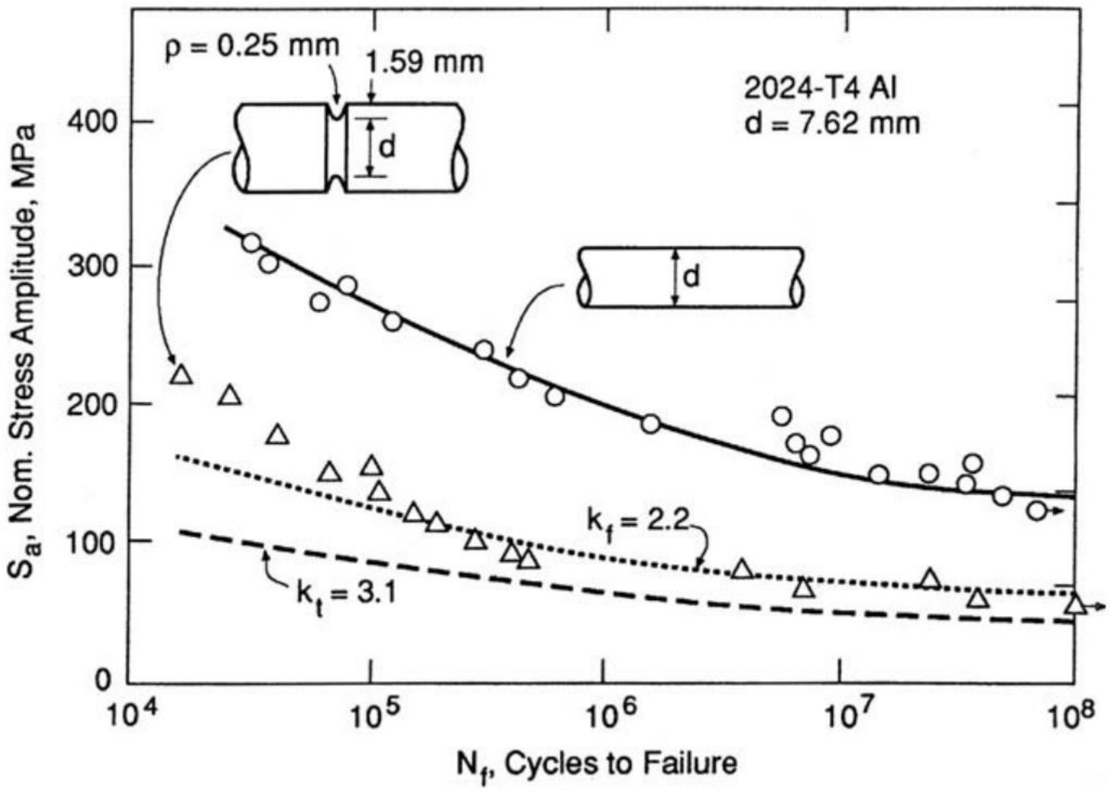
COMPOSITI
Curve a trazione



COMPOSITI vs METALLI
Comportamento a fatica

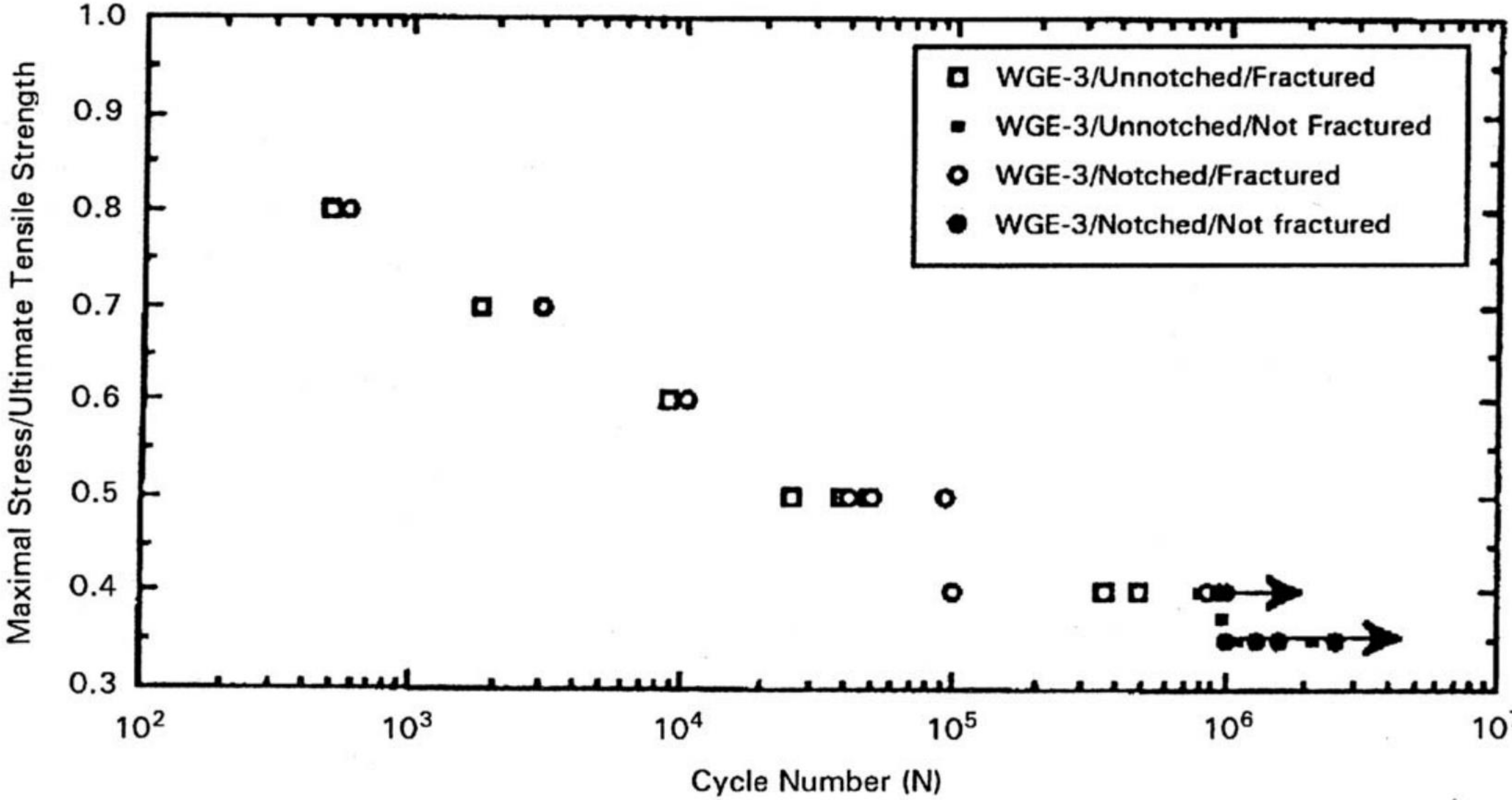


COMPOSITI vs METALLI
Comportamento a fatica con intagli



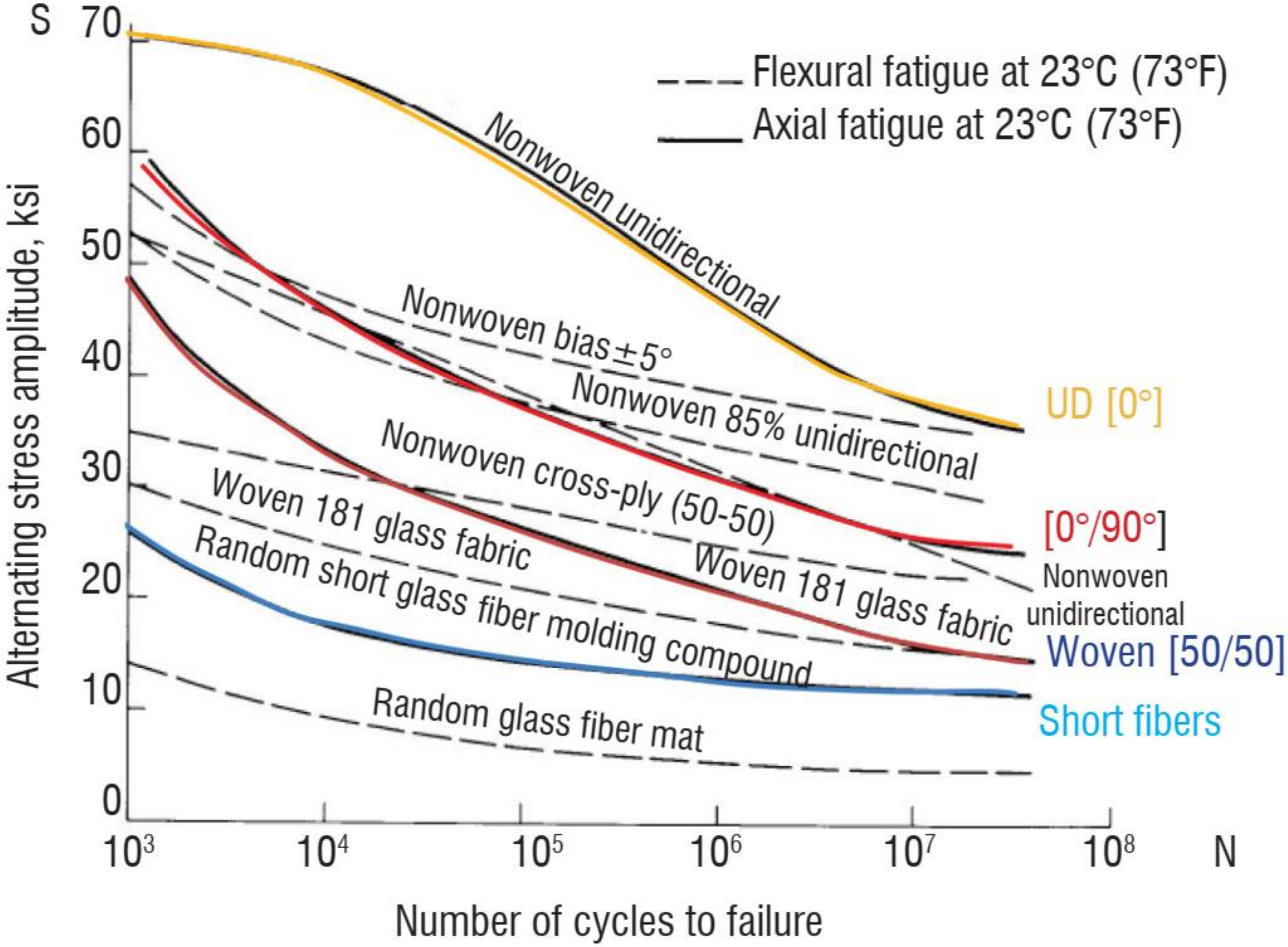
ALLUMINIO

COMPOSITI vs METALLI
Comportamento a fatica con intagli



GLASSFIBRE

COMPOSITI
Comportamento a fatica



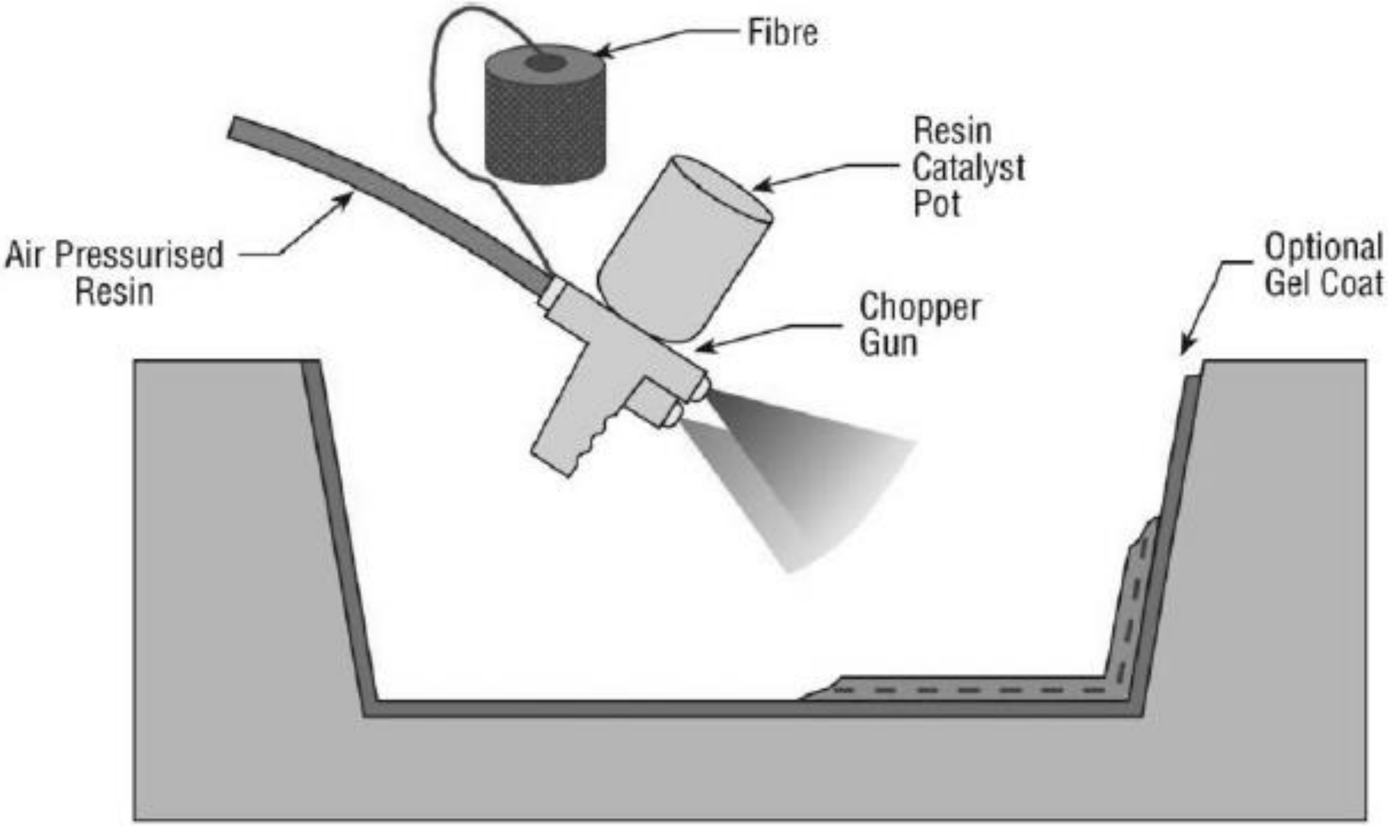
Tecnologie di produzione

Tecniche a stampo aperto (Open mould)

Tecnologie *wet resin*

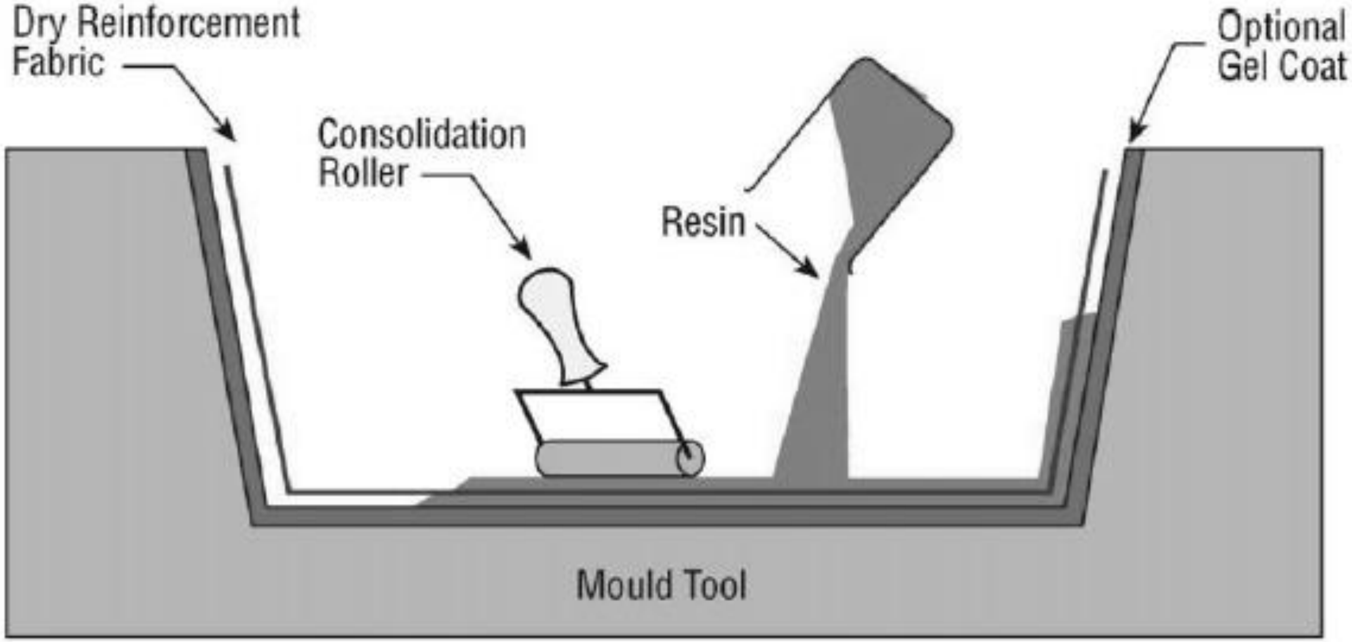
- **Fasi principali**
  - Disposizione delle fibre sullo stampo.
  - Impregnazione del rinforzo con la resina.
  - Trattamento della resina (curing)

Spray Lay-up


Fibre
Resin
Catalyst
Pot
Air Pressurised
Resin
Chopper
Gun
Optional
Gel Coat

Spray Lay-up

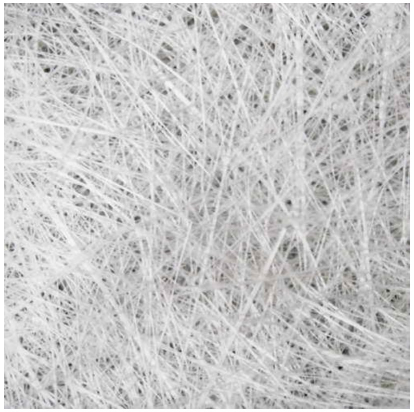
Hand lay-up



Dry Reinforcement
Fabric
Consolidation
Roller
Resin
Optional
Gel Coat
Mould Tool

Hand lay-up

Rinforzo

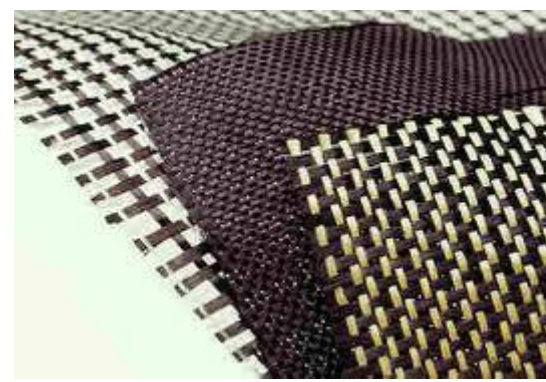


Mat
(CSM: chopped strand mat)

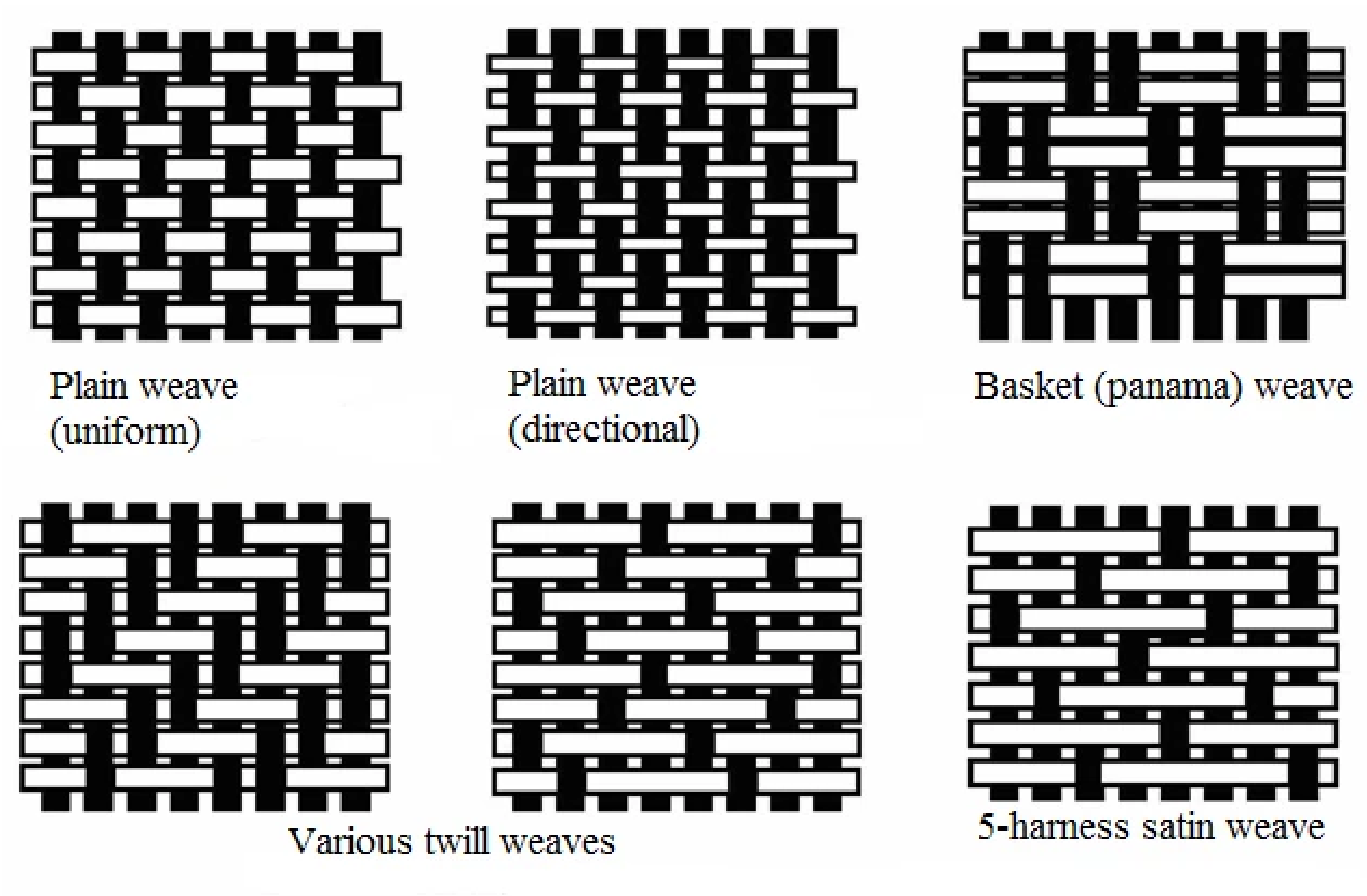
Uniweave

Tessuto

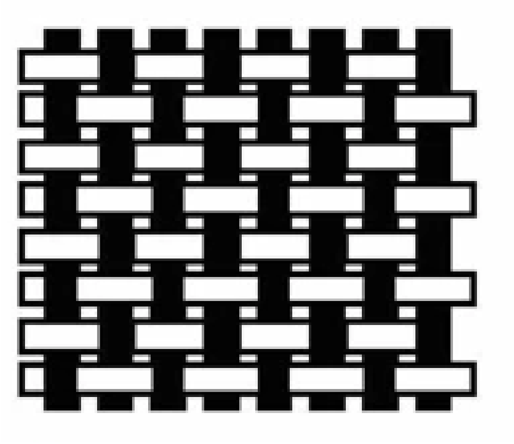
Tessuto ibrido



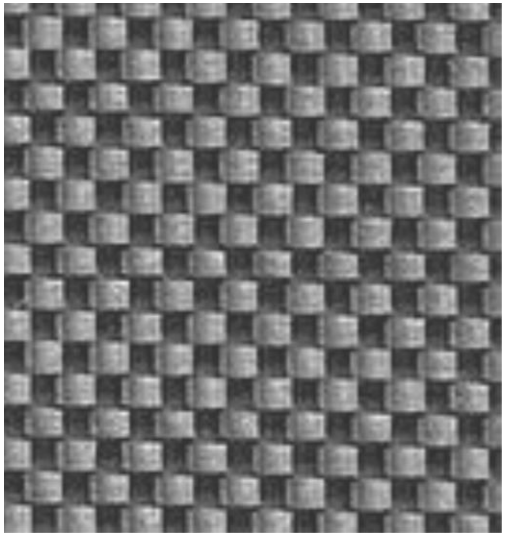
Rinforzo intrecciato (tessuto)

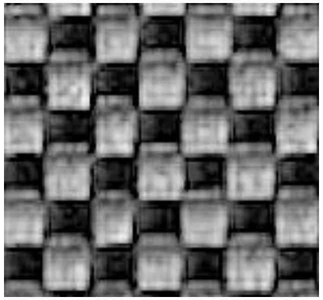


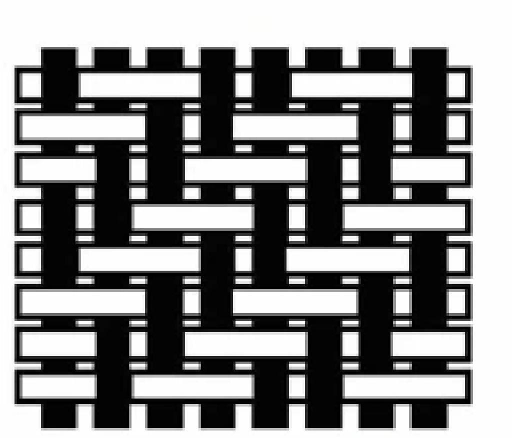
Rinforzo intrecciato (tessuto)



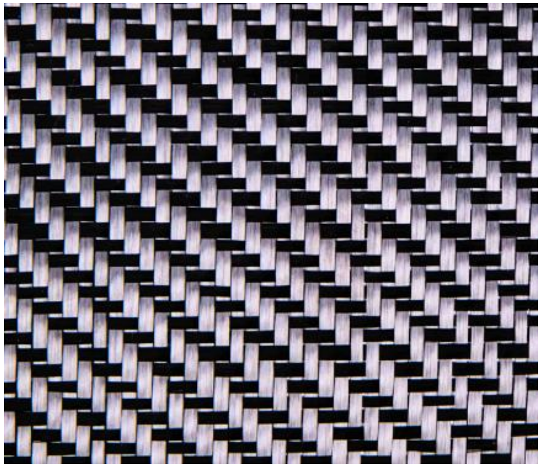
PLAIN WEAVE (1x1)

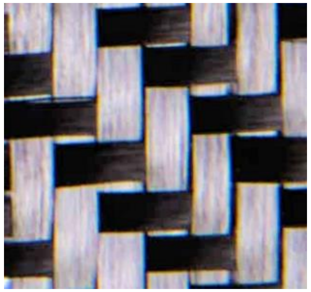






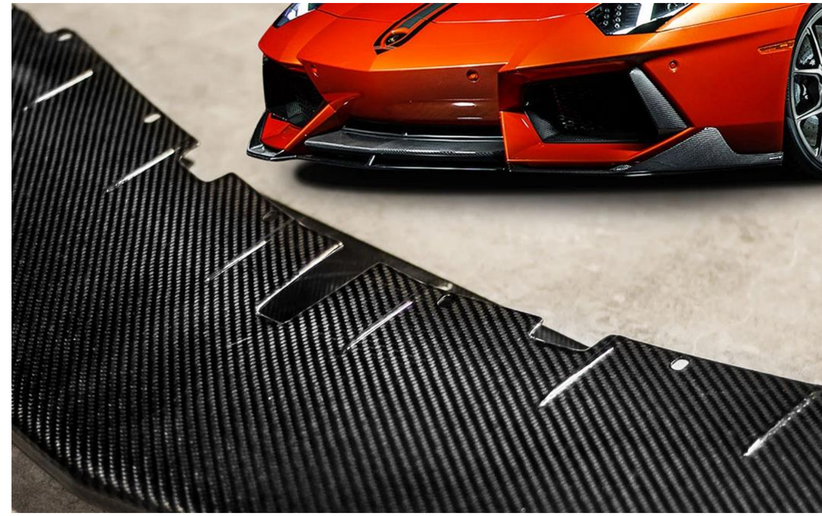
TWILL WEAVE (2x2)





FERRARI 458

LAMBORGHINI AVENTADOR



- PLAIN WEAWE -

FERRARI

- TWILL WEAWE

LAMBORGHINI
ALFA ROMEO
MCLAREN
BMW
PORSCHE

- PLAIN WEAWE -

DUCATI
MV AGUSTA

- TWILL WEAWE

APRILIA
BMW
YAMAHA
KAWASAKI

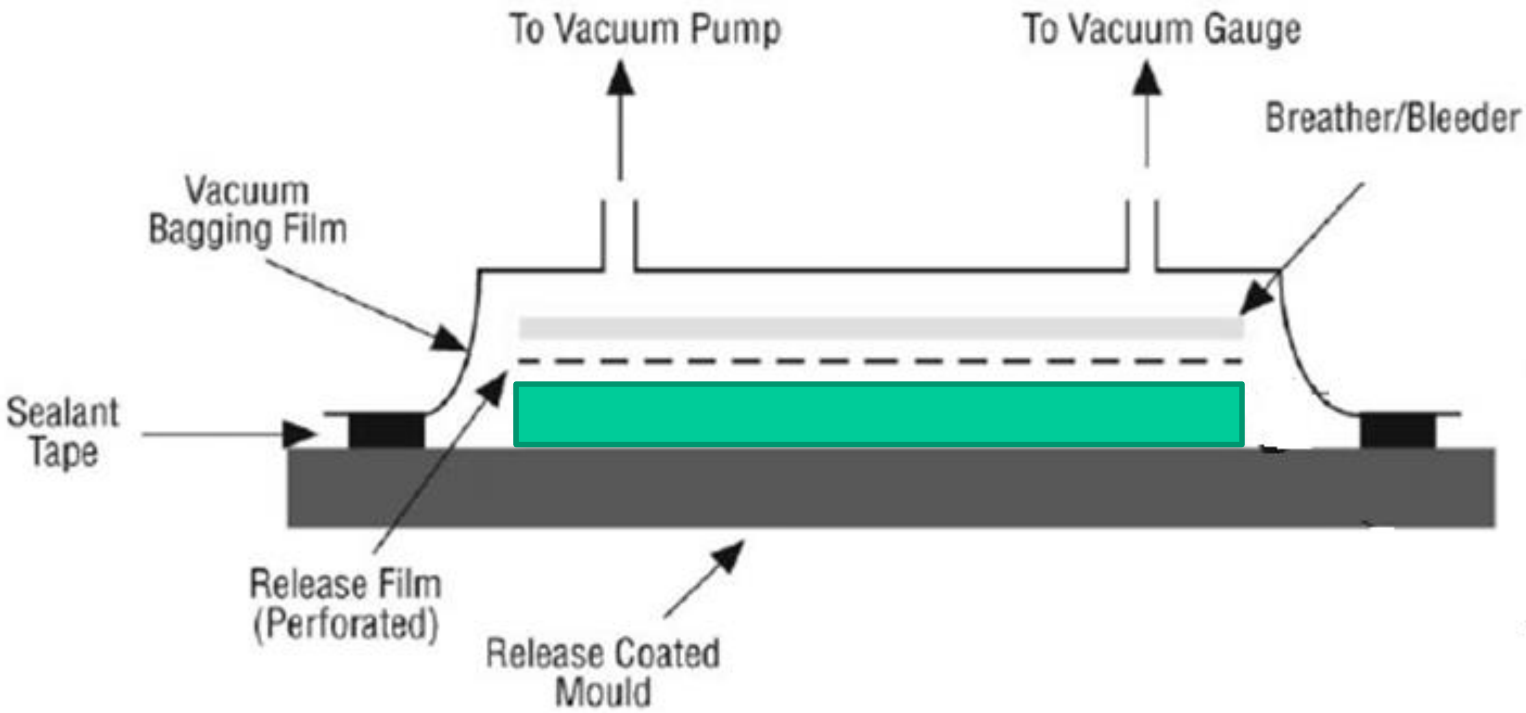
UNIDIREZIONALE

TESSUTO PLAIN WEAVE(3k TOW SIZE)

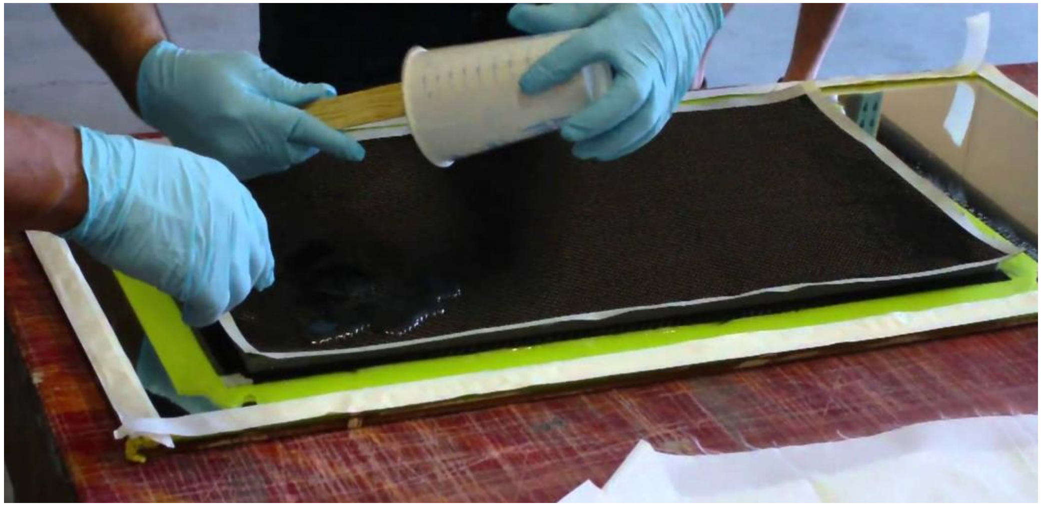
TESSUTO PLAIN WEAVE (3k TOW SIZE)

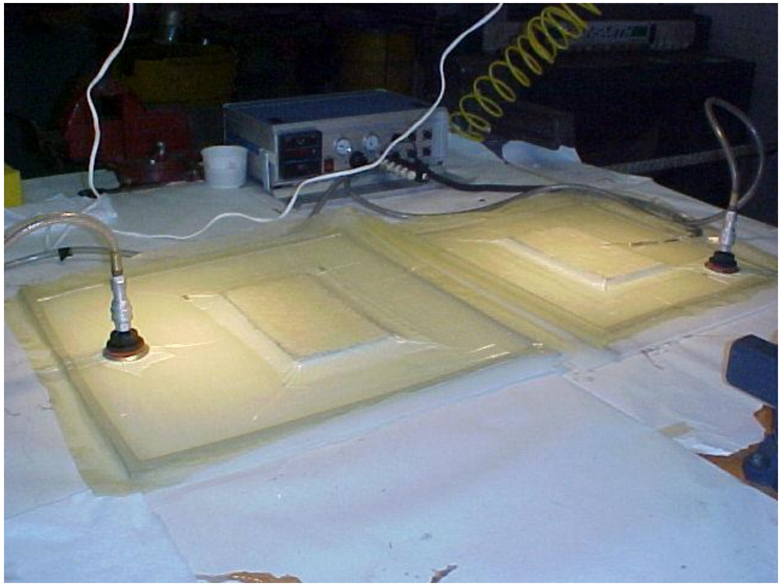
TESSUTO PLAIN WEAVE (12k TOW SIZE)

Vacuum bagging (sacco a vuoto)

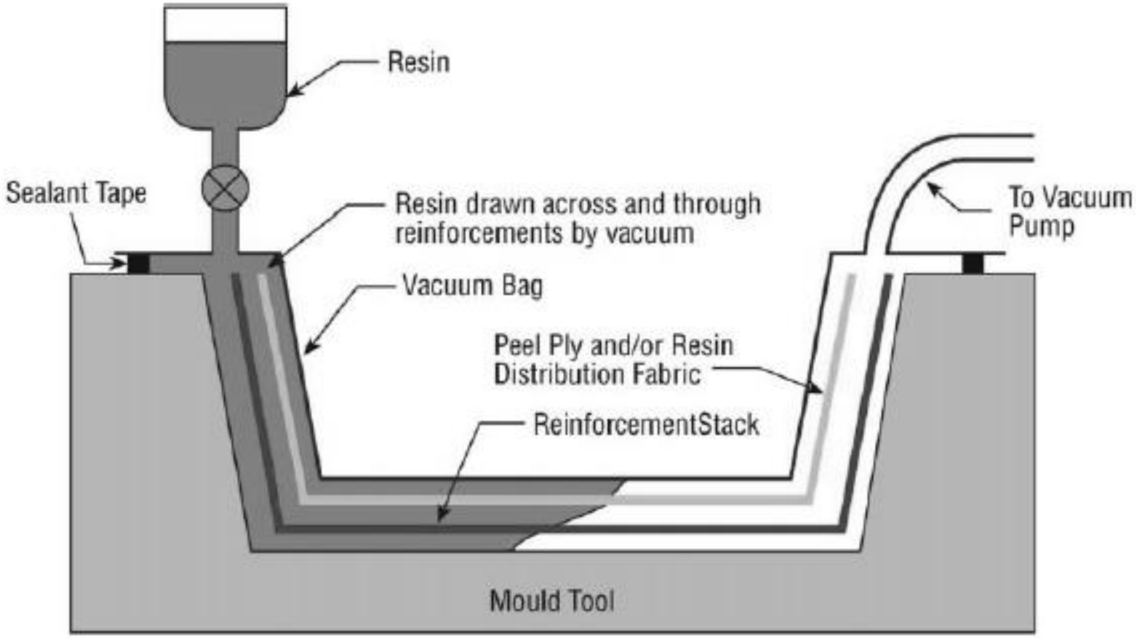


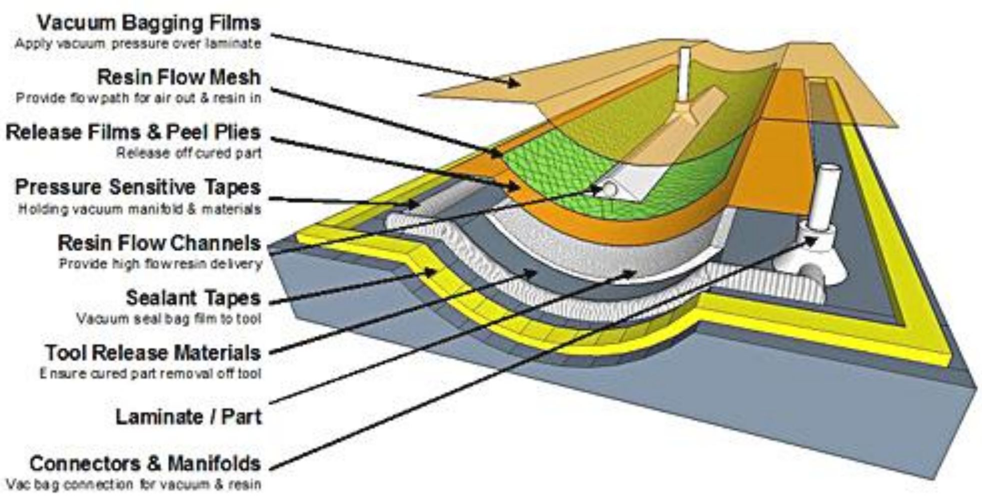
Vacuum bagging





Resin Infusion

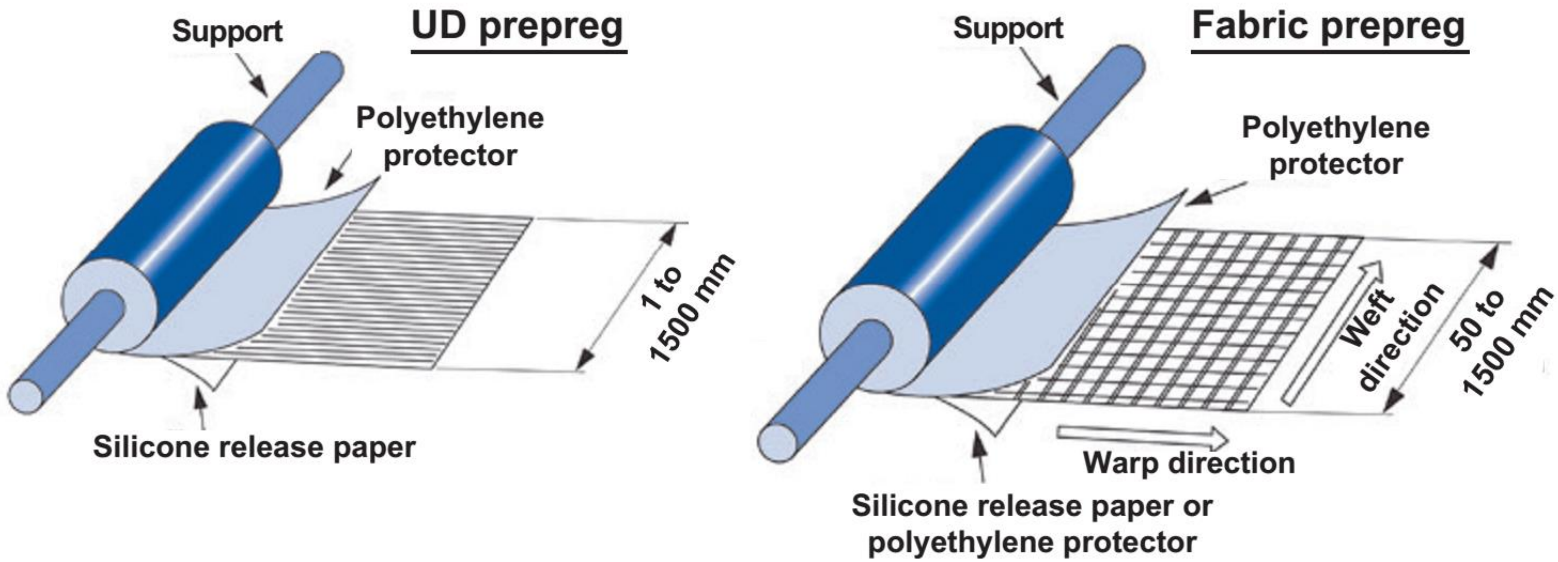






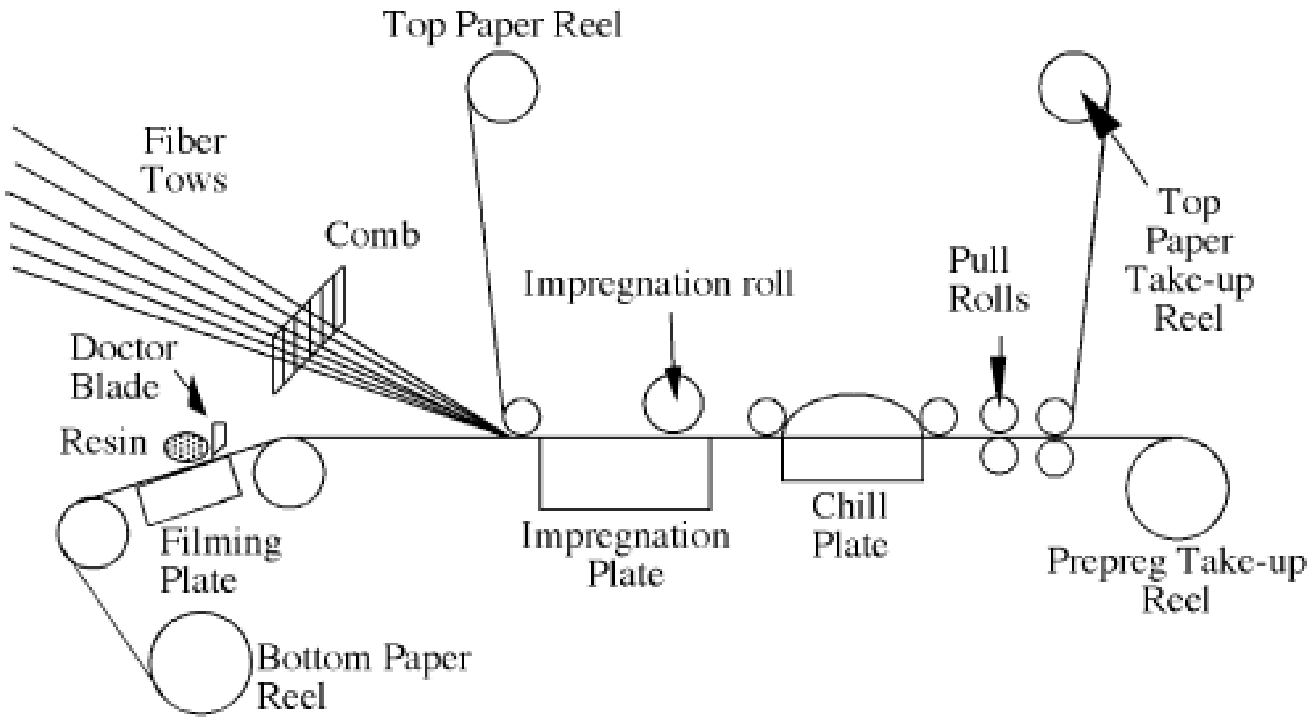
Tecnologie con Prepregs (Preimpregnati)

Pre-pregs


UD prepreg
Support
Polyethylene protector
1 to 1500 mm
Silicone release paper
Fabric prepreg
Support
Polyethylene protector
Weft direction
50 to 1500 mm
Warp direction
Silicone release paper or polyethylene protector

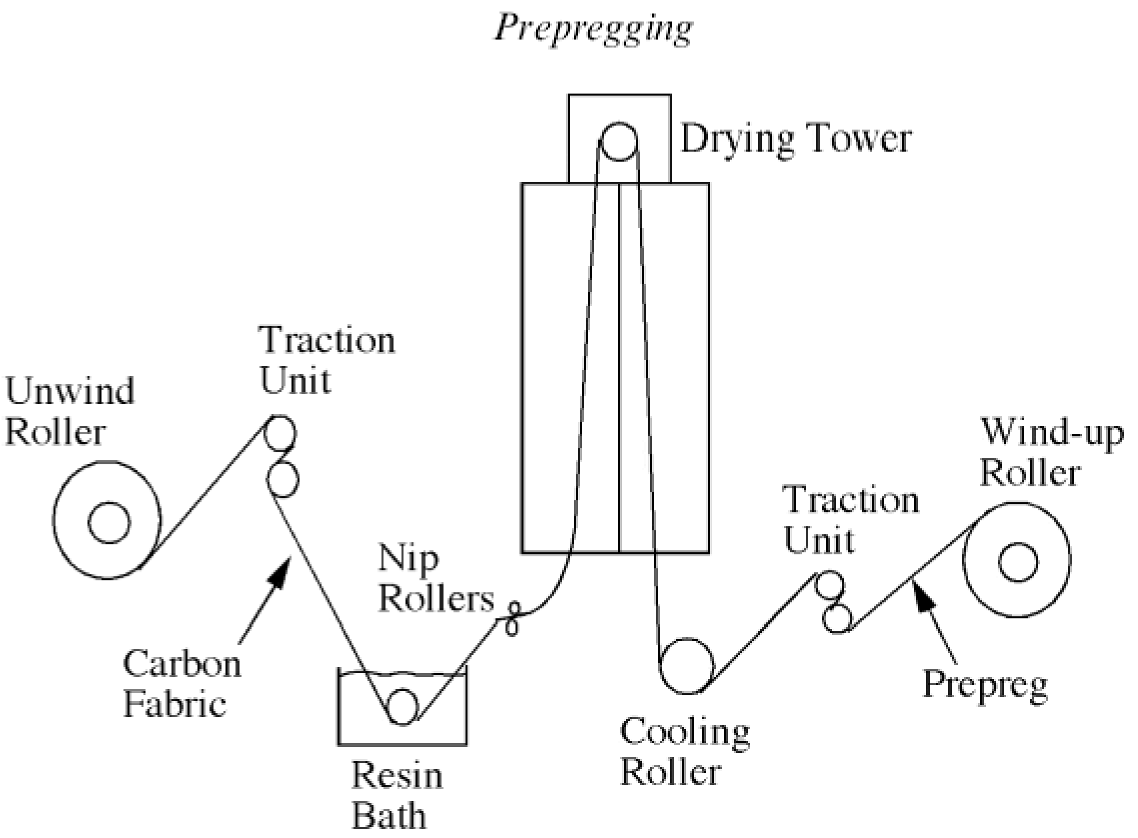
Pre-pregs

Prepregging
(**hot melt**)



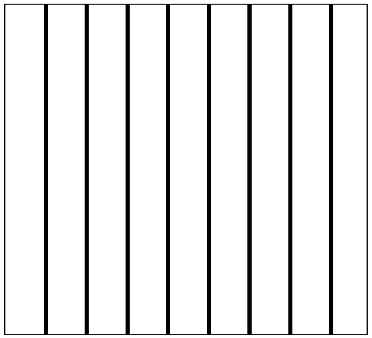
La viscosità della resina è ridotta con il riscaldamento

Prepregging
(**solution dip**)

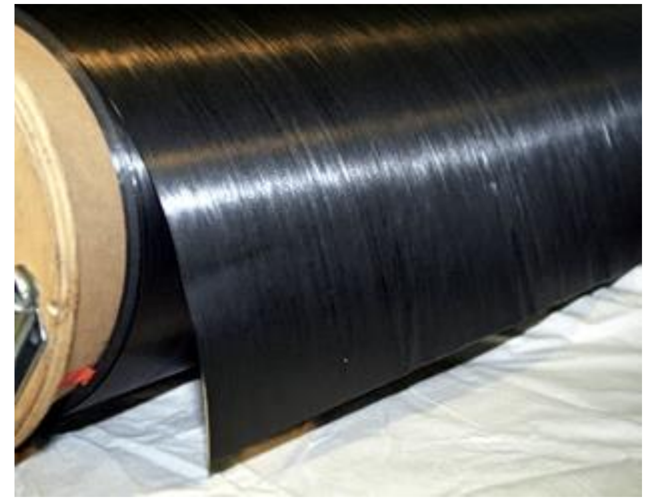


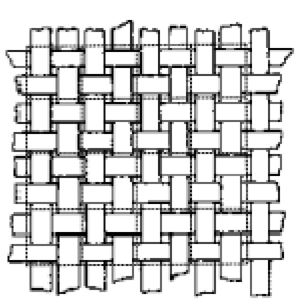
La viscosità della resina è ridotta con l’uso di solventi

Lamine prepreg

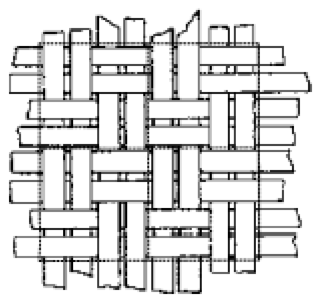


Unidirezionale



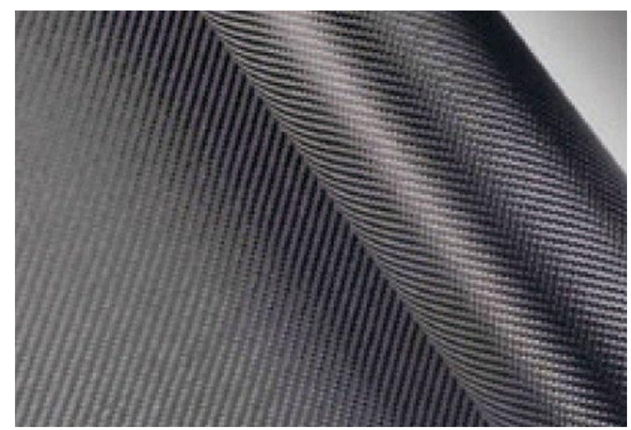


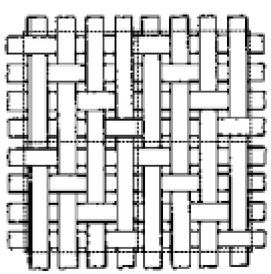
a. plain weave



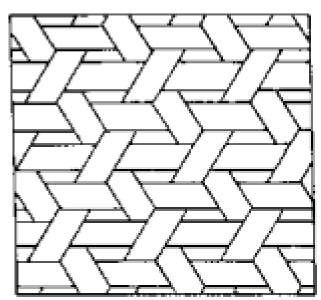
b. 2x2 basket weave

Tessuto



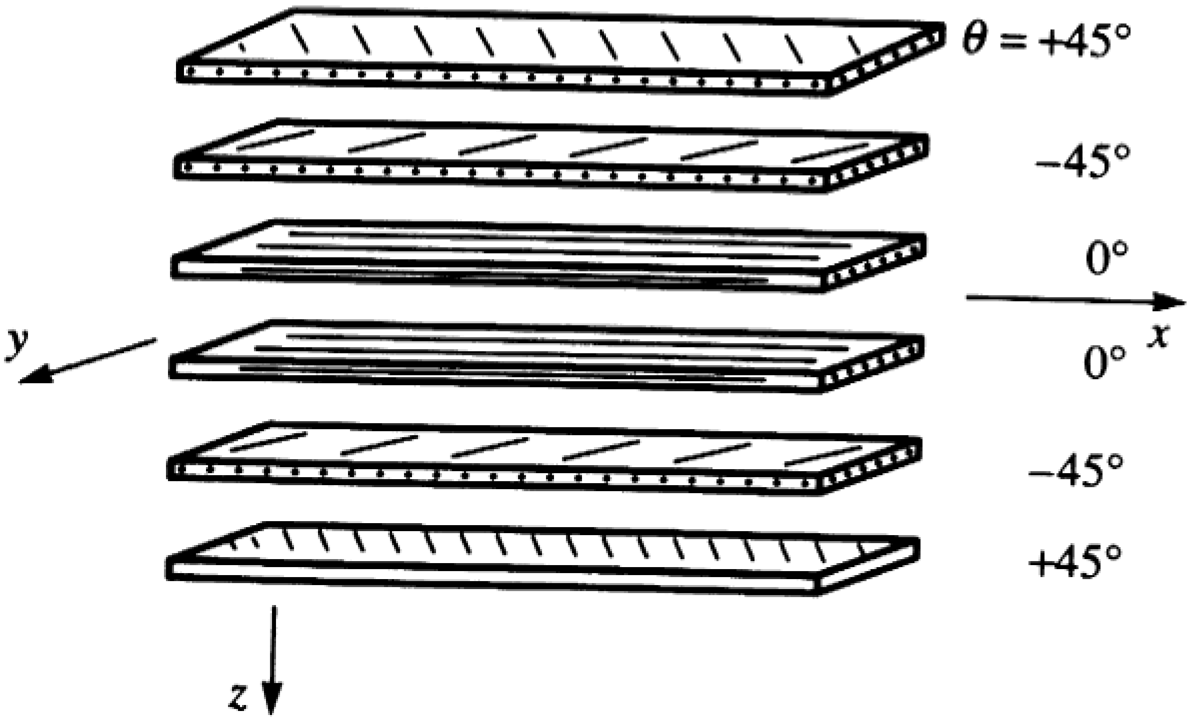


d. 3/1 Twill (left handed)

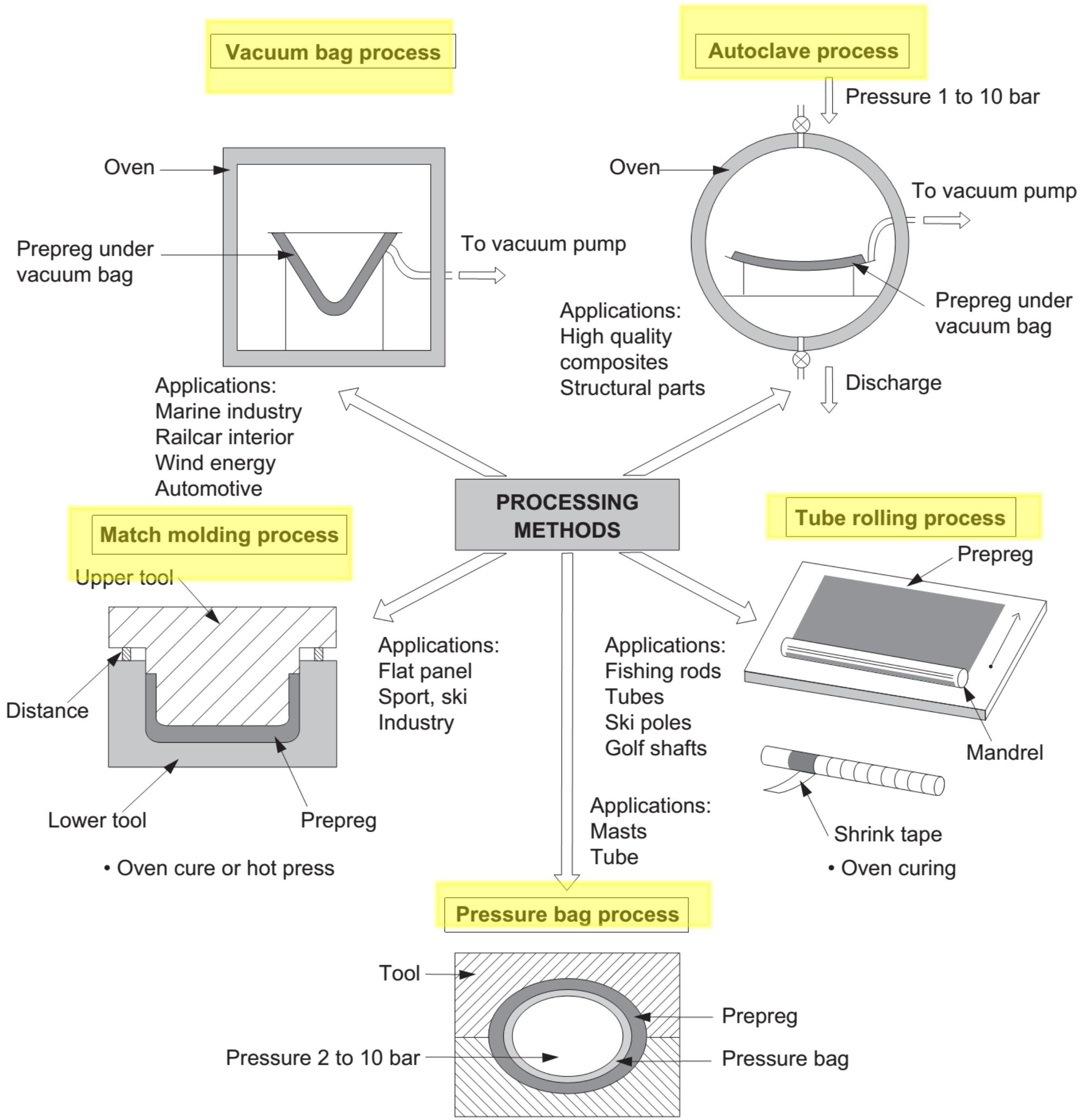


a. Basic triaxial weave

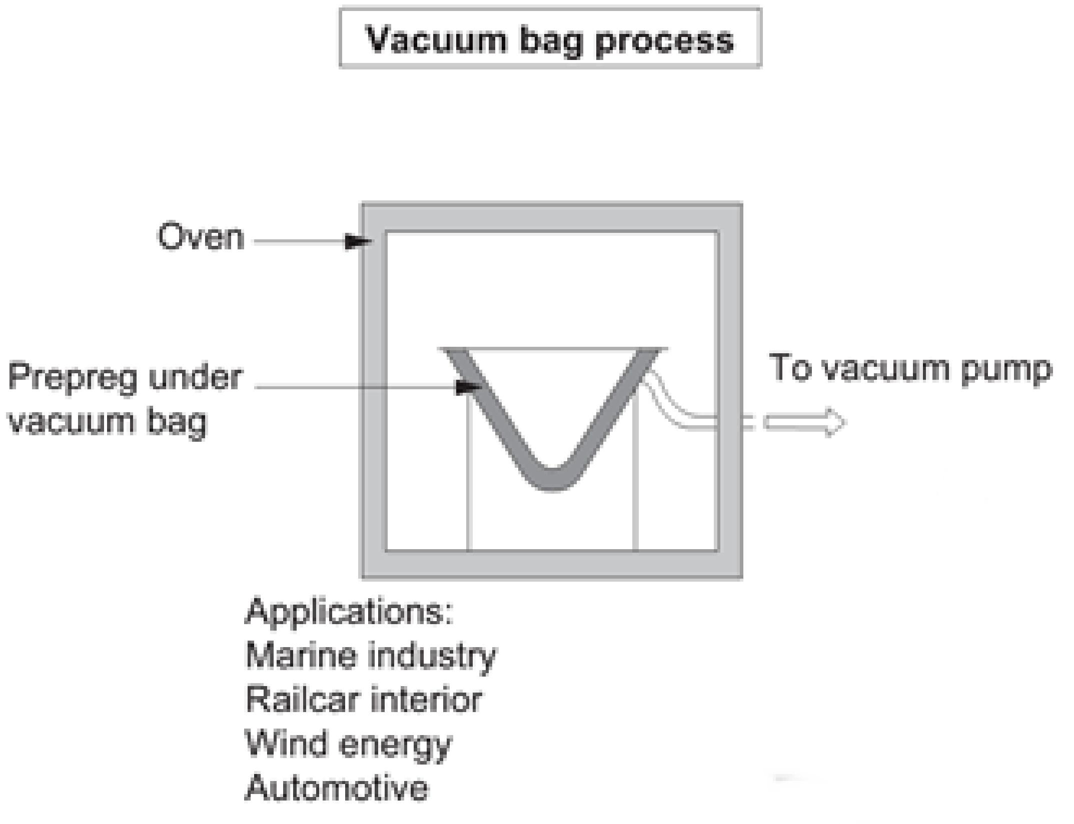
Laminati



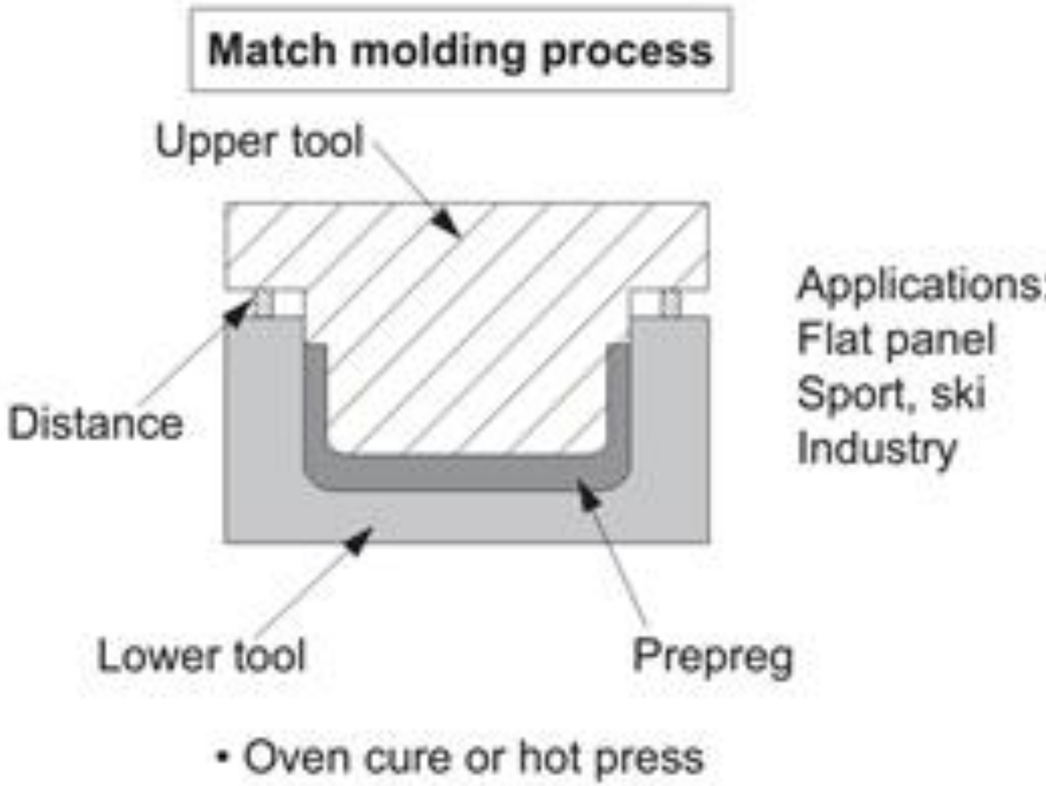
Tecnologie di produzione con Prepreg



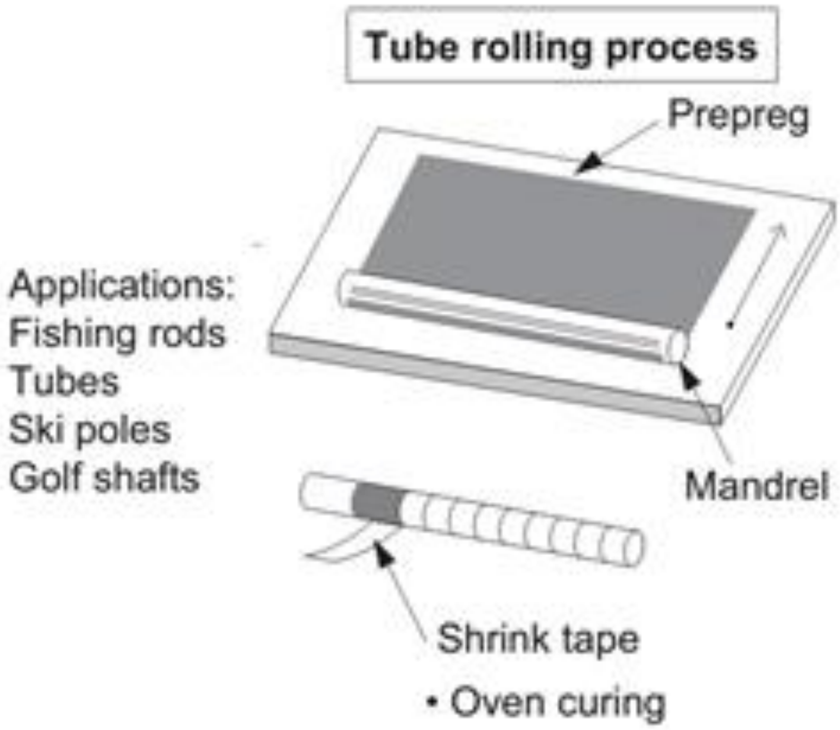
Tecnologie di produzione con Prepreg



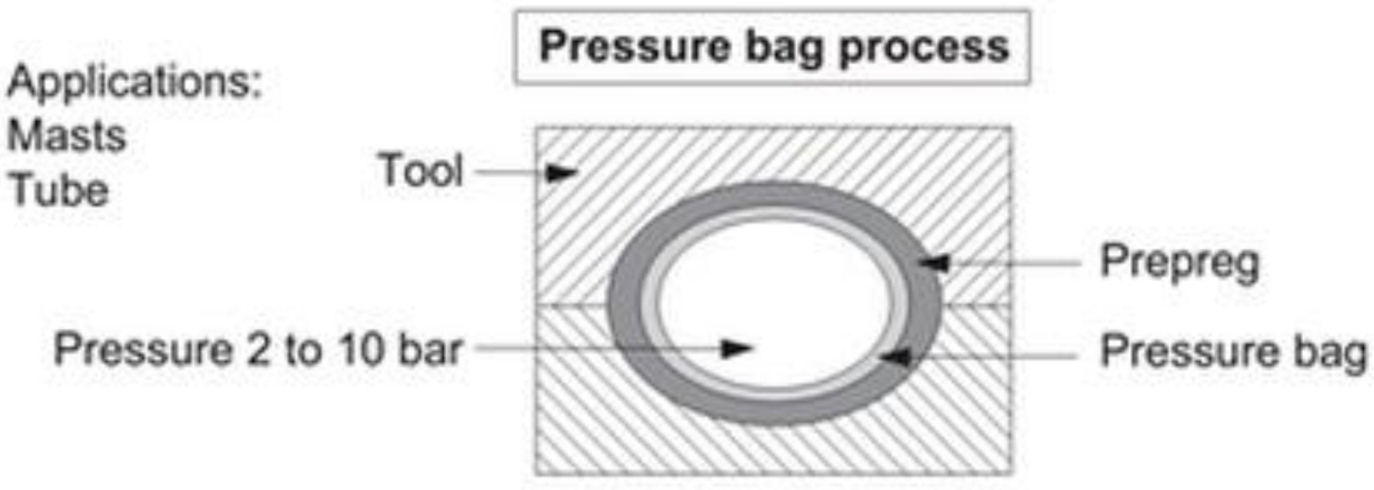
Tecnologie di produzione con Prepreg



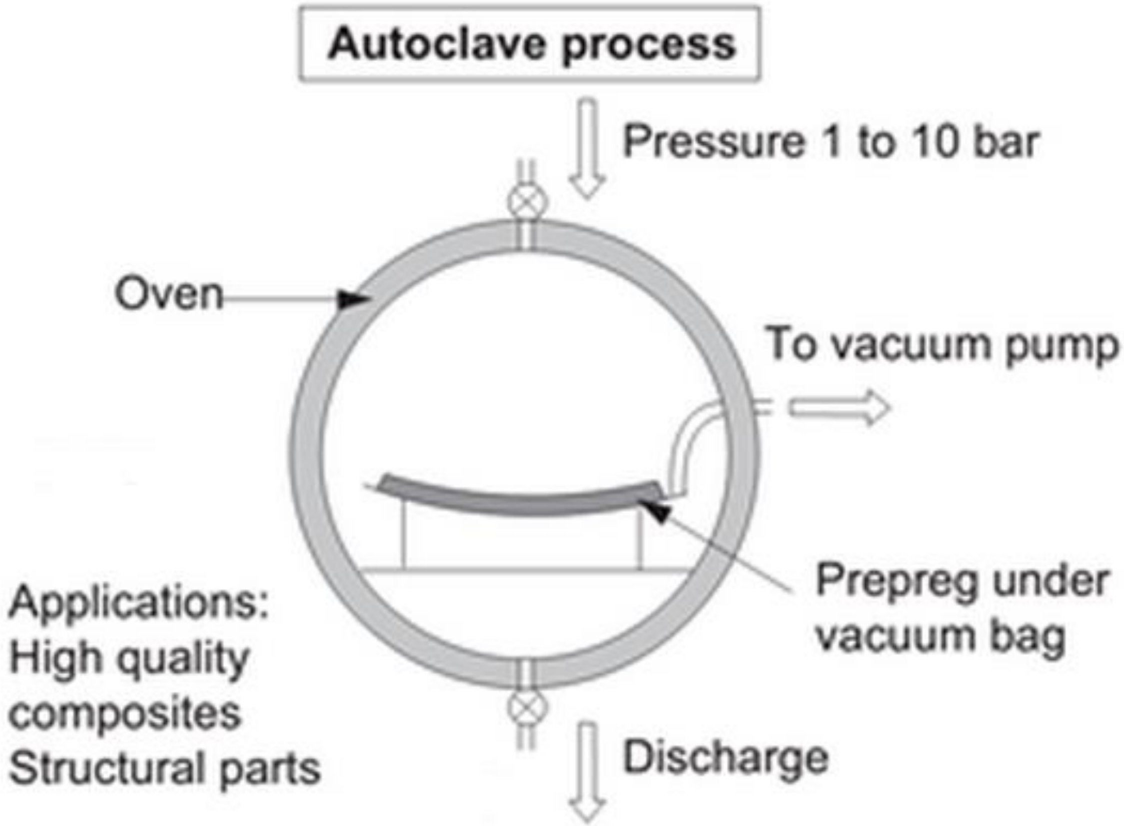
Tecnologie di produzione con Prepreg



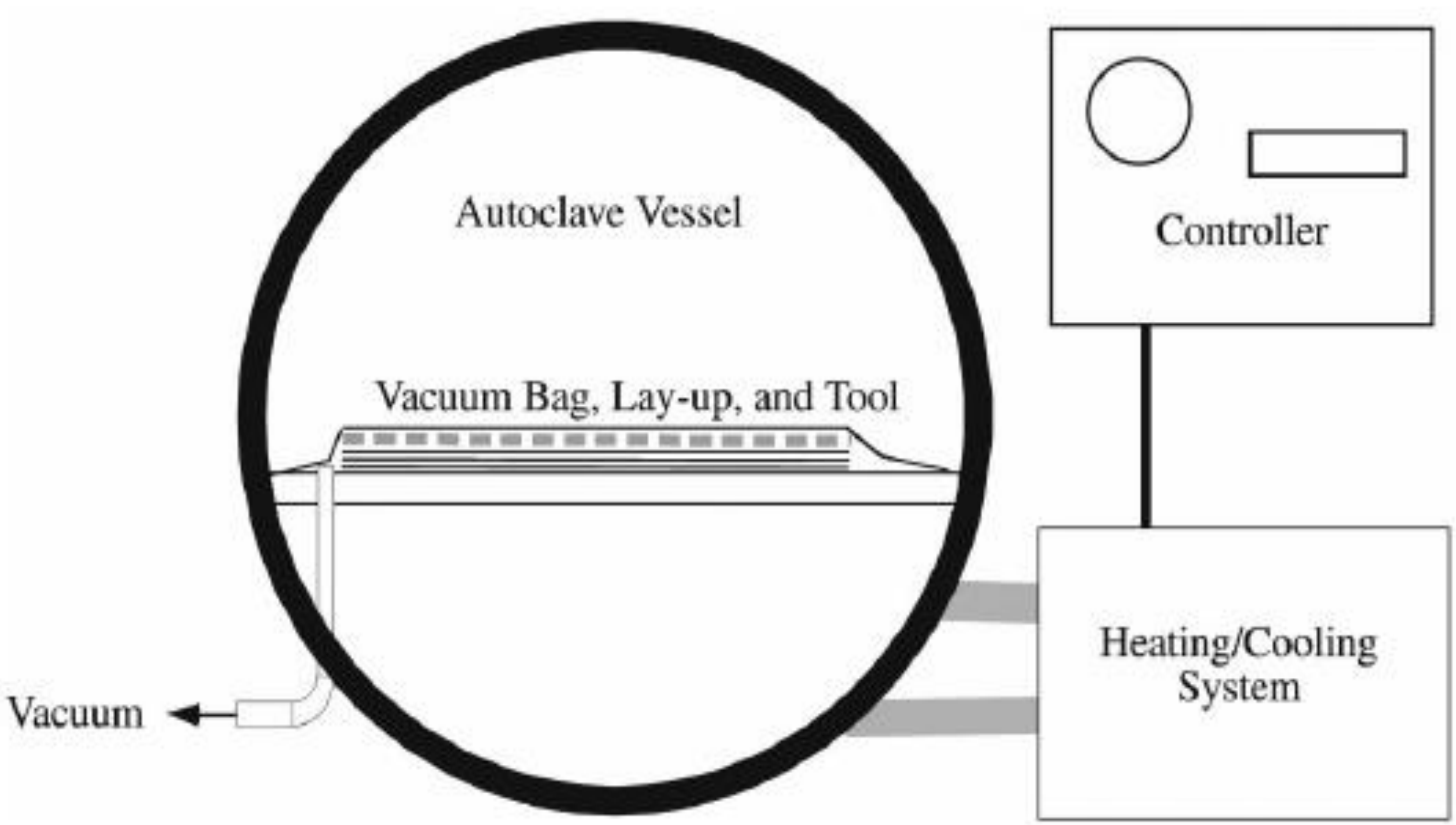
Tecnologie di produzione con Prepreg



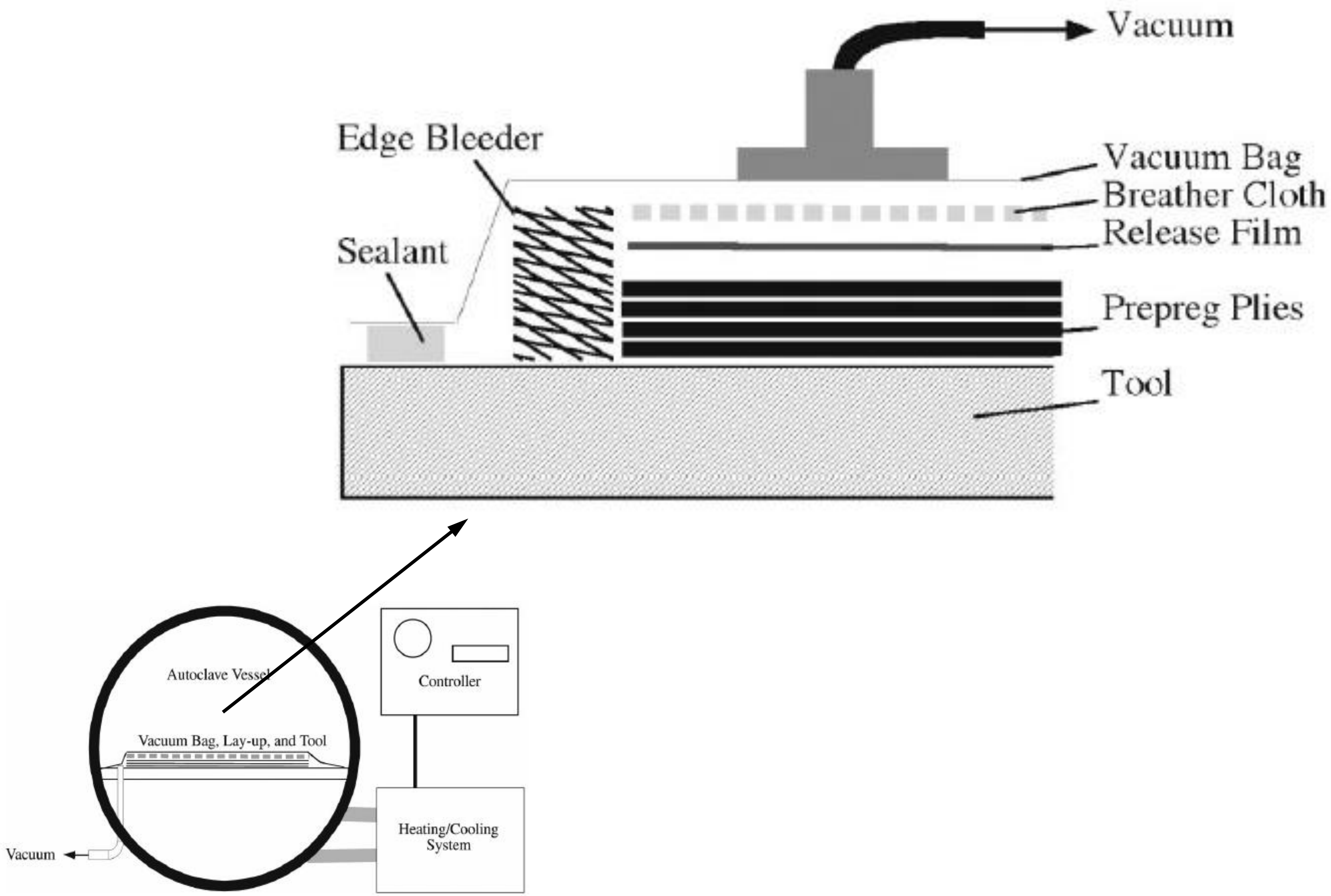
Tecnologie di produzione con Prepreg



Consolidamento in autoclave



Consolidamento in autoclave (vacuum bag)



Consolidamento in autoclave

D = 10 m - Lunghezza = 30 m

Consolidamento in autoclave

Consolidamento in autoclave di prepregs

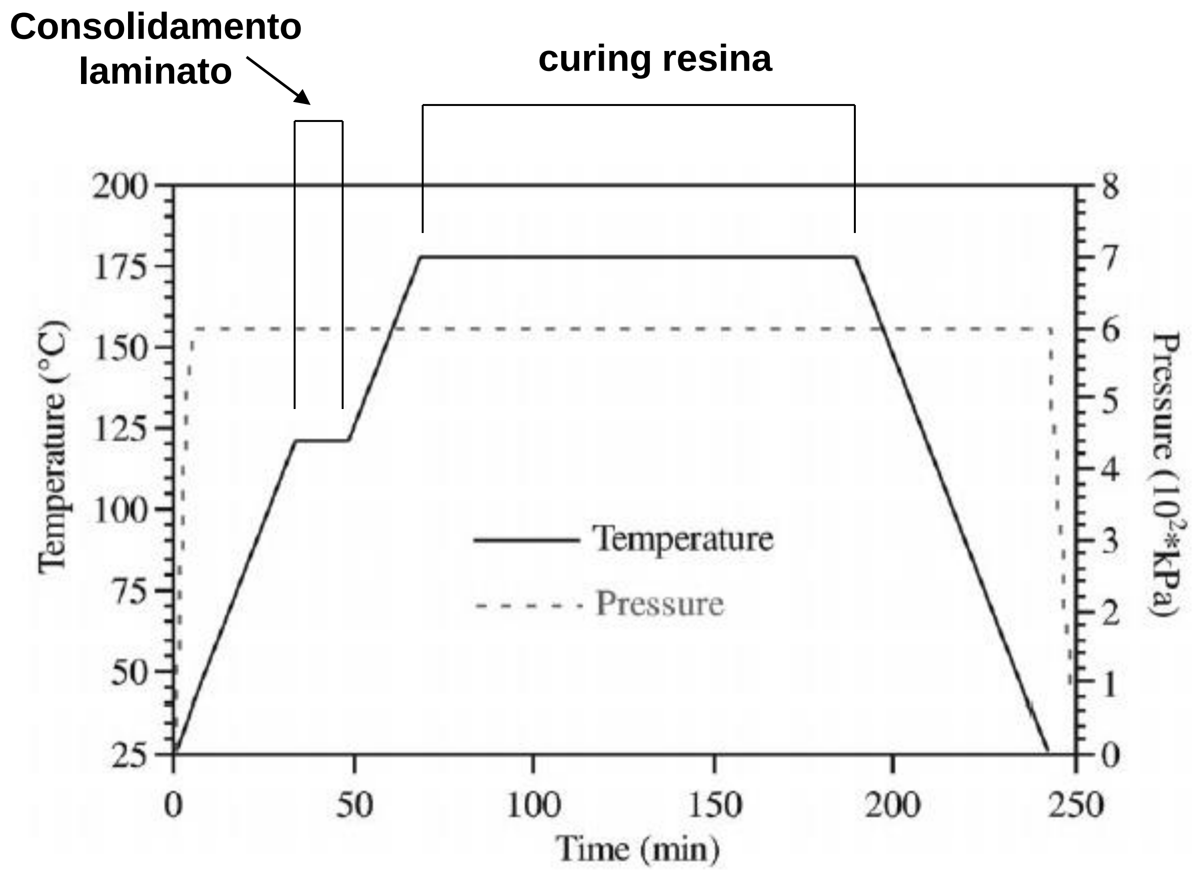
Lay-up

Vacuum bagging

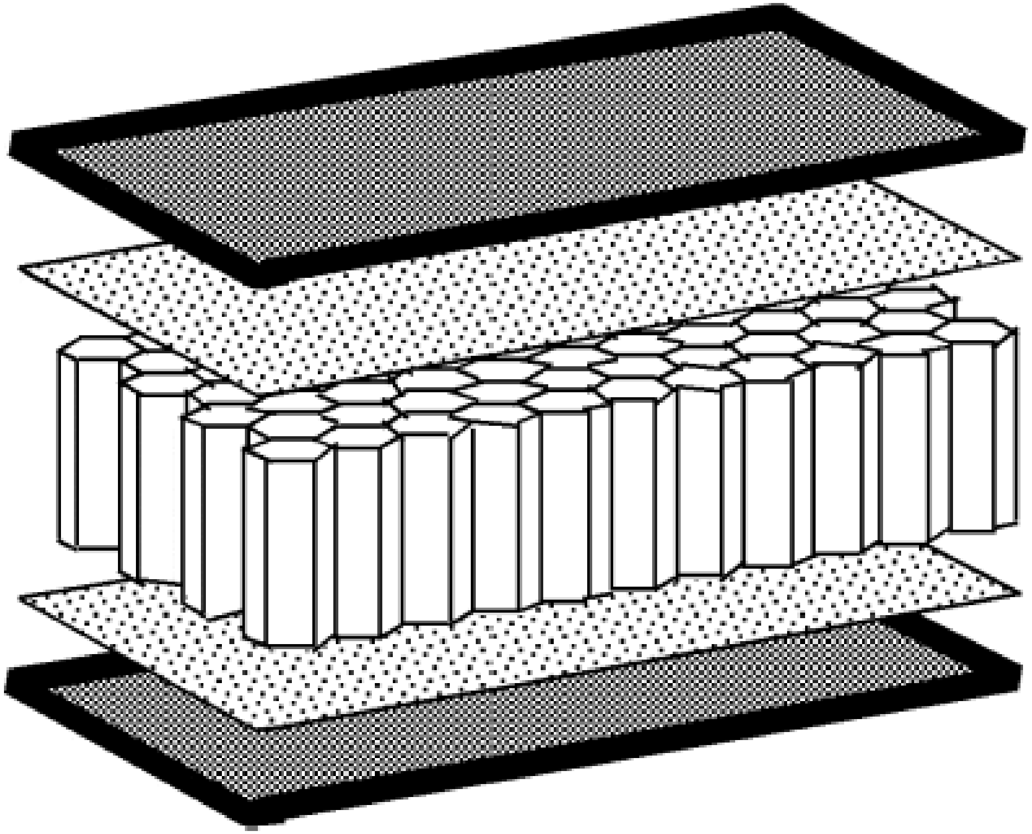
Autoclave

Componente finale

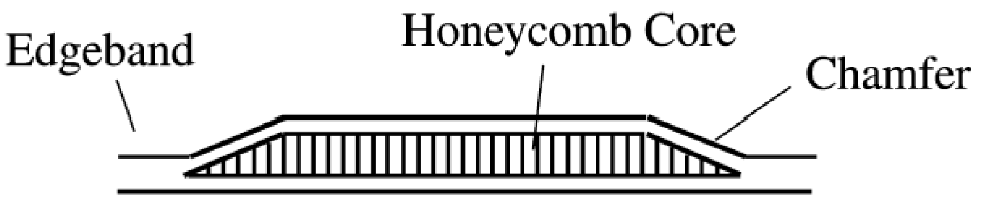
Tipico ciclo di autoclave

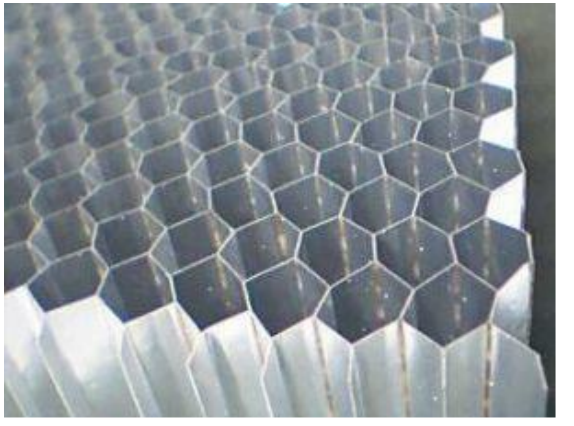


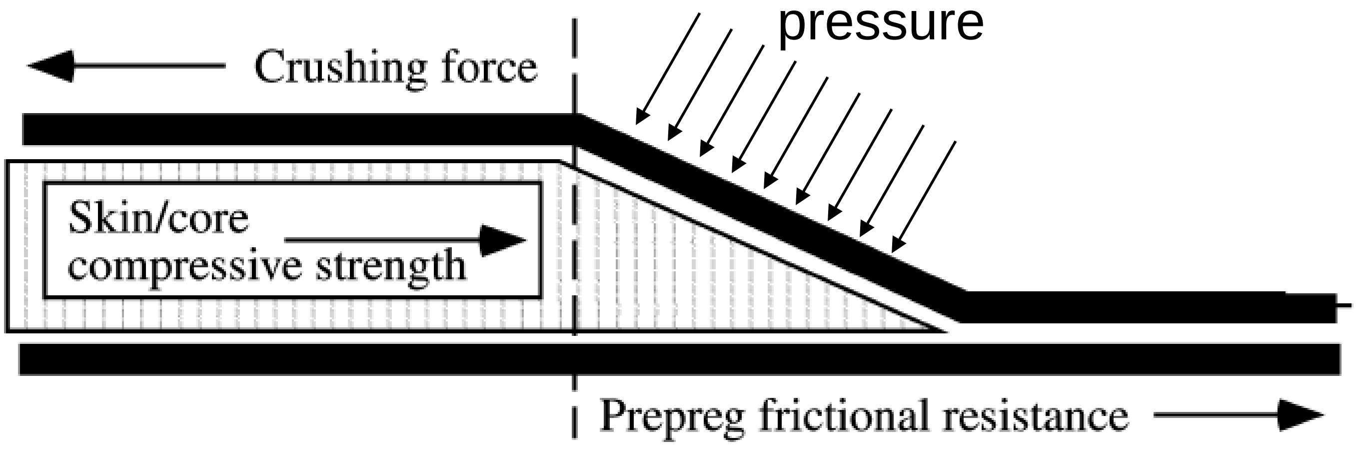
Realizzazione sandwich



Core crushing (honeycomb)

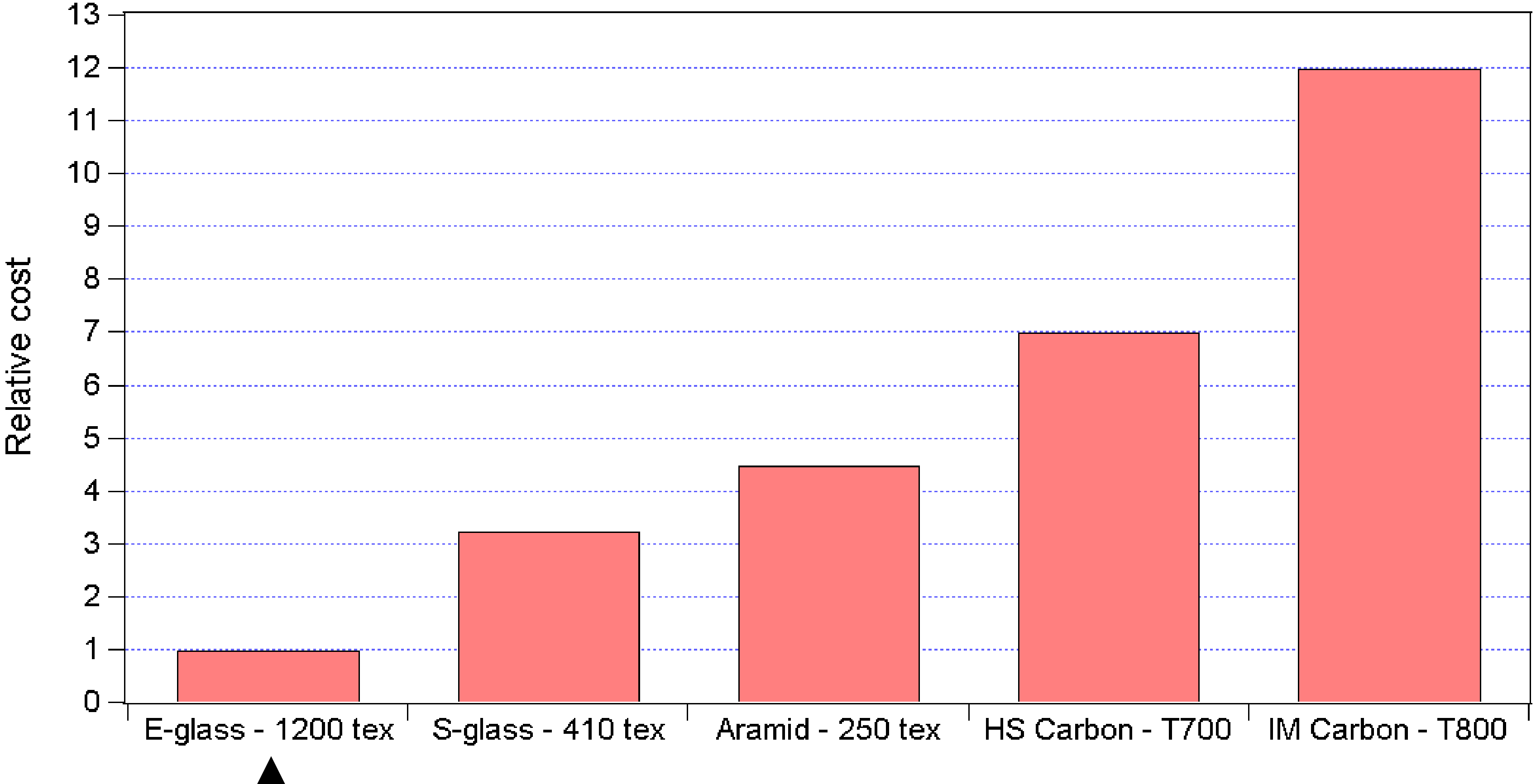






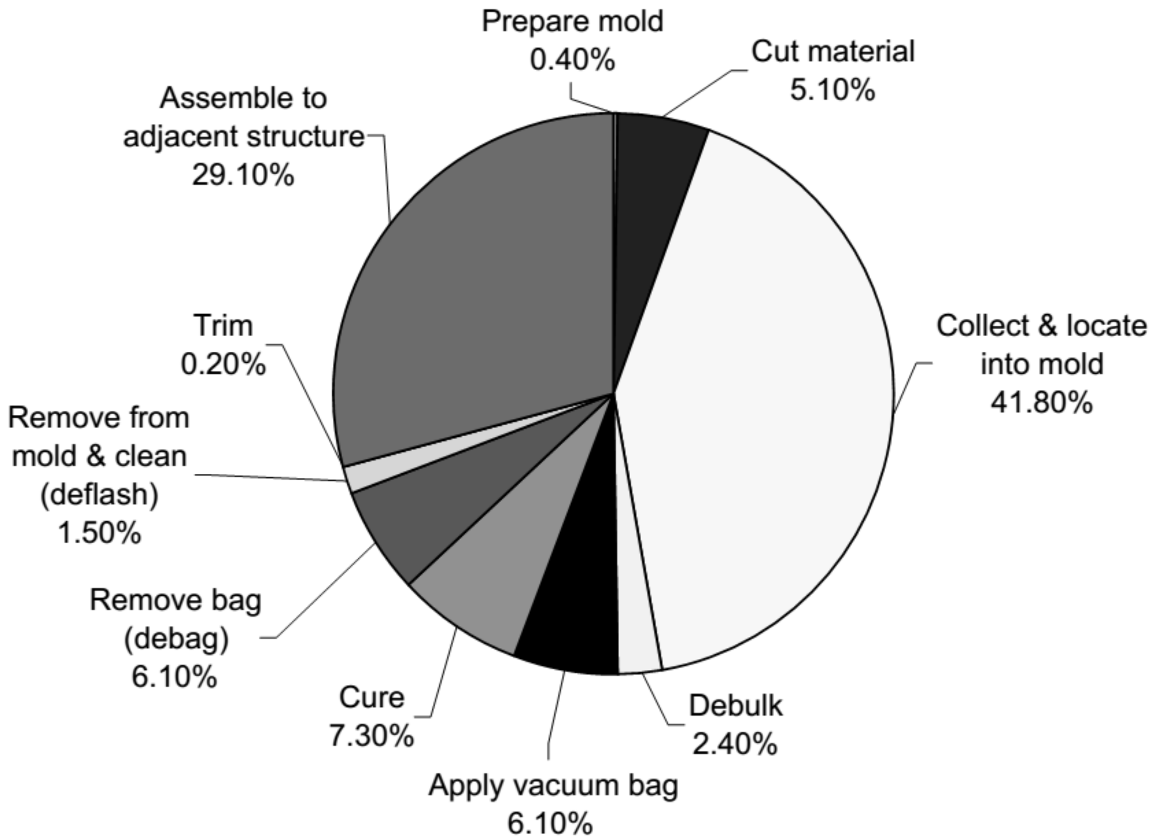
Costo delle fibre

Confronto per tessuti di grammatura 300 g/m^2

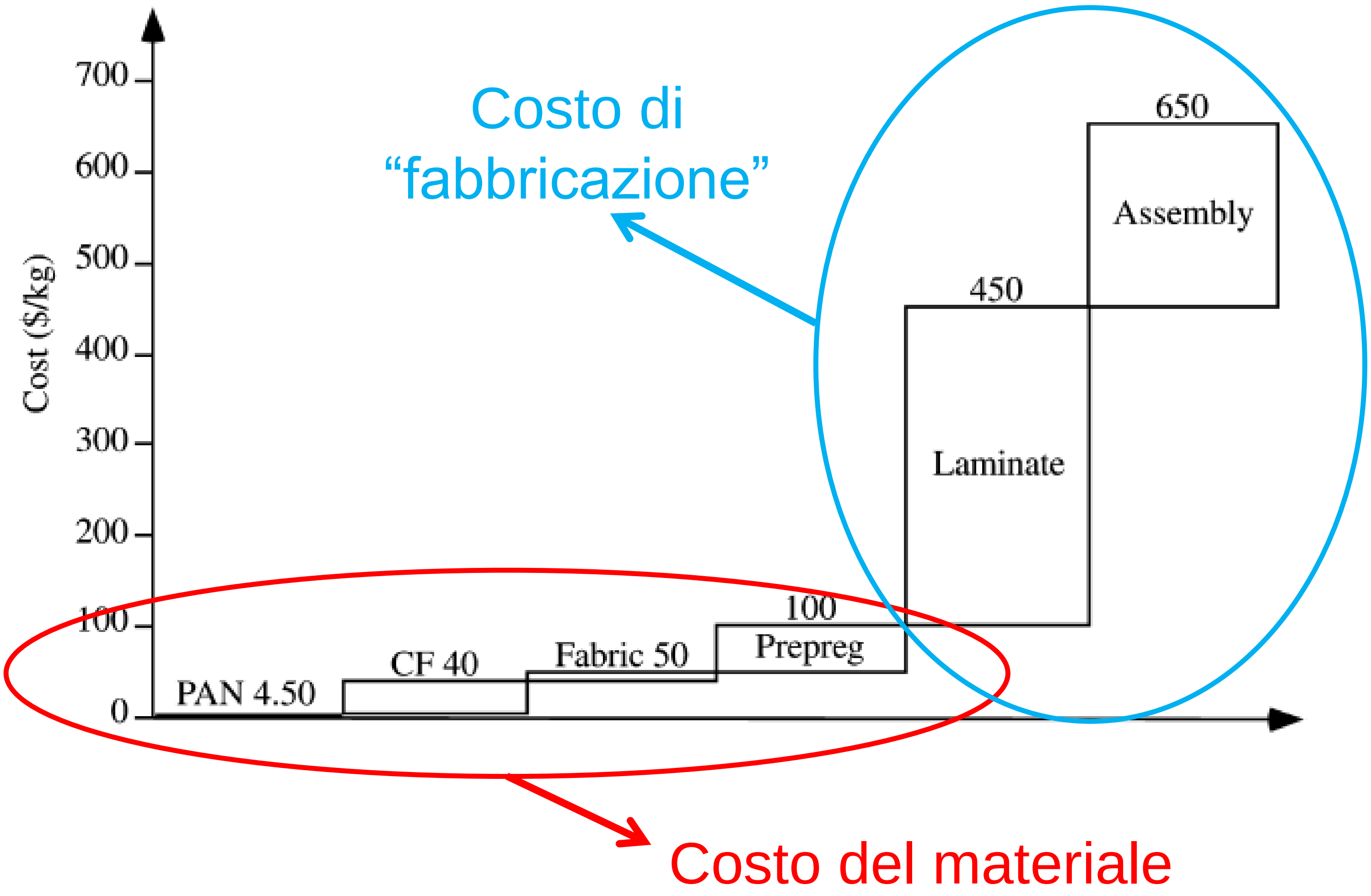


Materiale di riferimento: Costo E- glass = ~ 2.5 Euro/m^2)

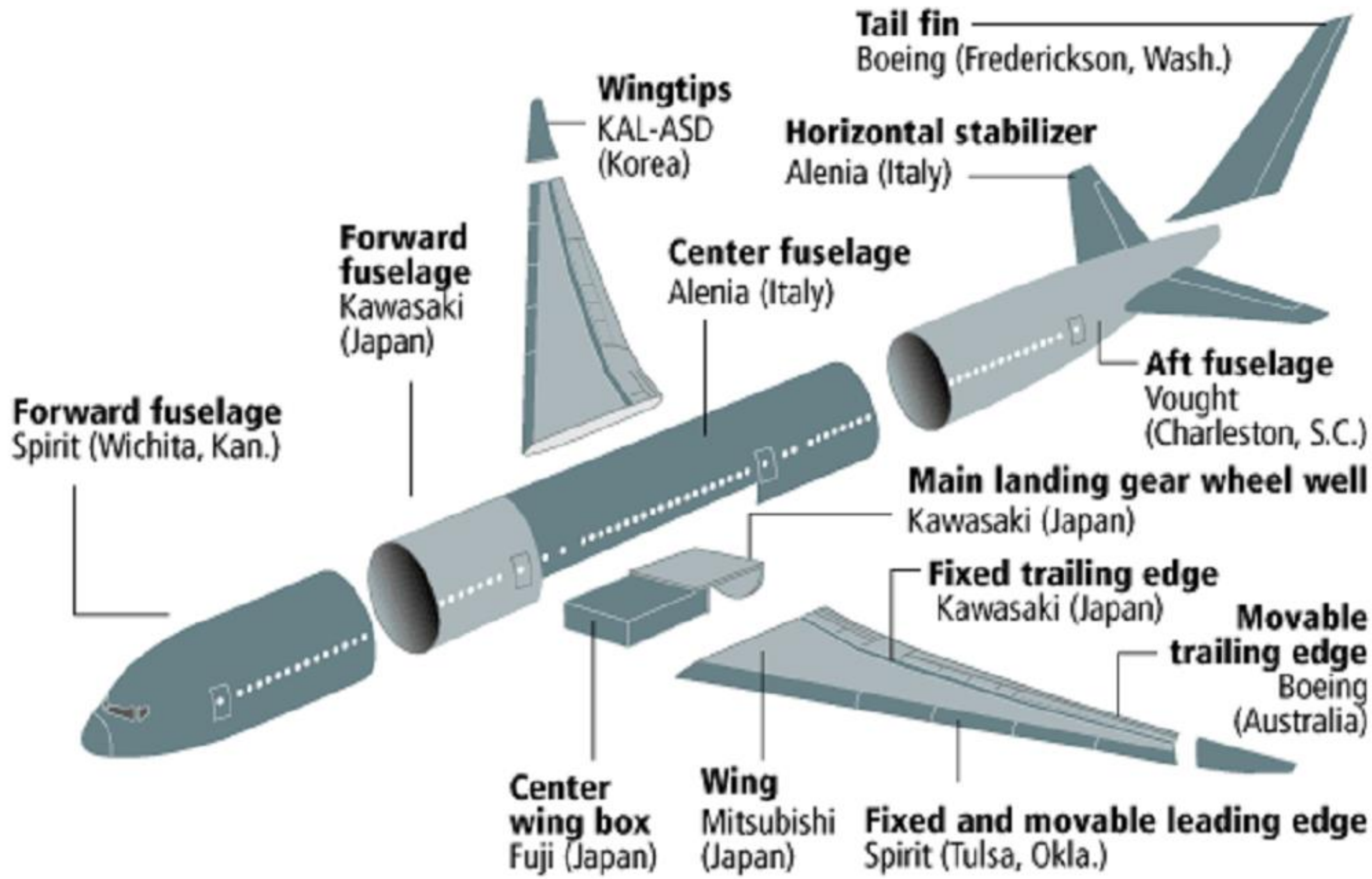
Percentuali di costo e montaggio di un componente realizzato in prepreg (escluso costo del materiale)

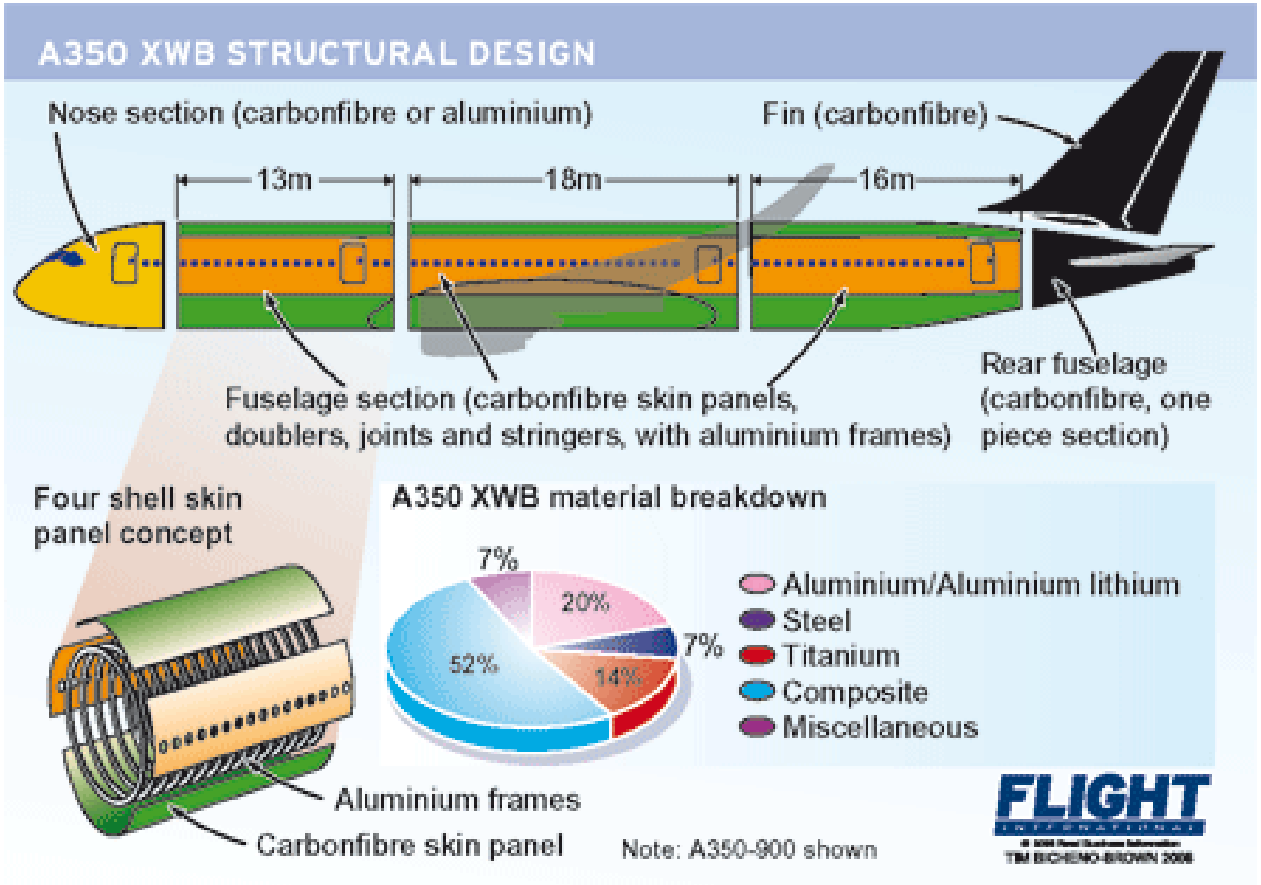


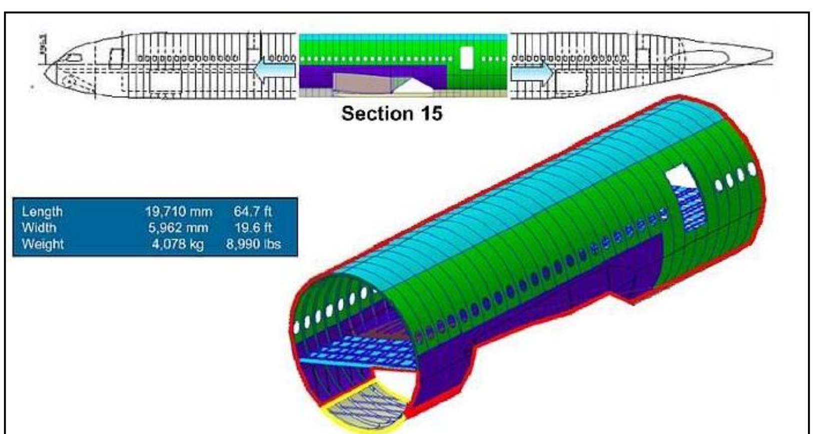
Costi realizzazione componenti in laminato da prepreg (1999)

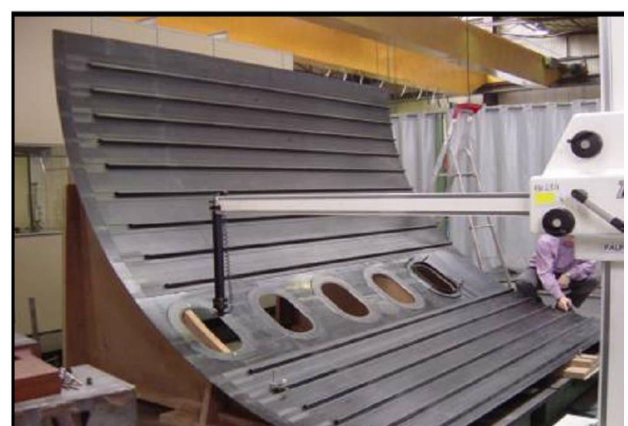


Boeing 787 Dreamliner Parts Suppliers




A350 XWB STRUCTURAL DESIGN
Nose section (carbonfibre or aluminium)
Fin (carbonfibre)
13m
18m
16m
Fuselage section (carbonfibre skin panels, doublers, joints and stringers, with aluminium frames)
Rear fuselage (carbonfibre, one piece section)
Four shell skin panel concept
A350 XWB material breakdown
7%
20%
7%
52%
14%
Aluminium/Aluminium lithium
Steel
Titanium
Composite
Miscellaneous
Aluminium frames
Carbonfibre skin panel
Note: A350-900 shown
FLIGHT INTERNATIONAL
TIM BICHENO-BROWN 2006

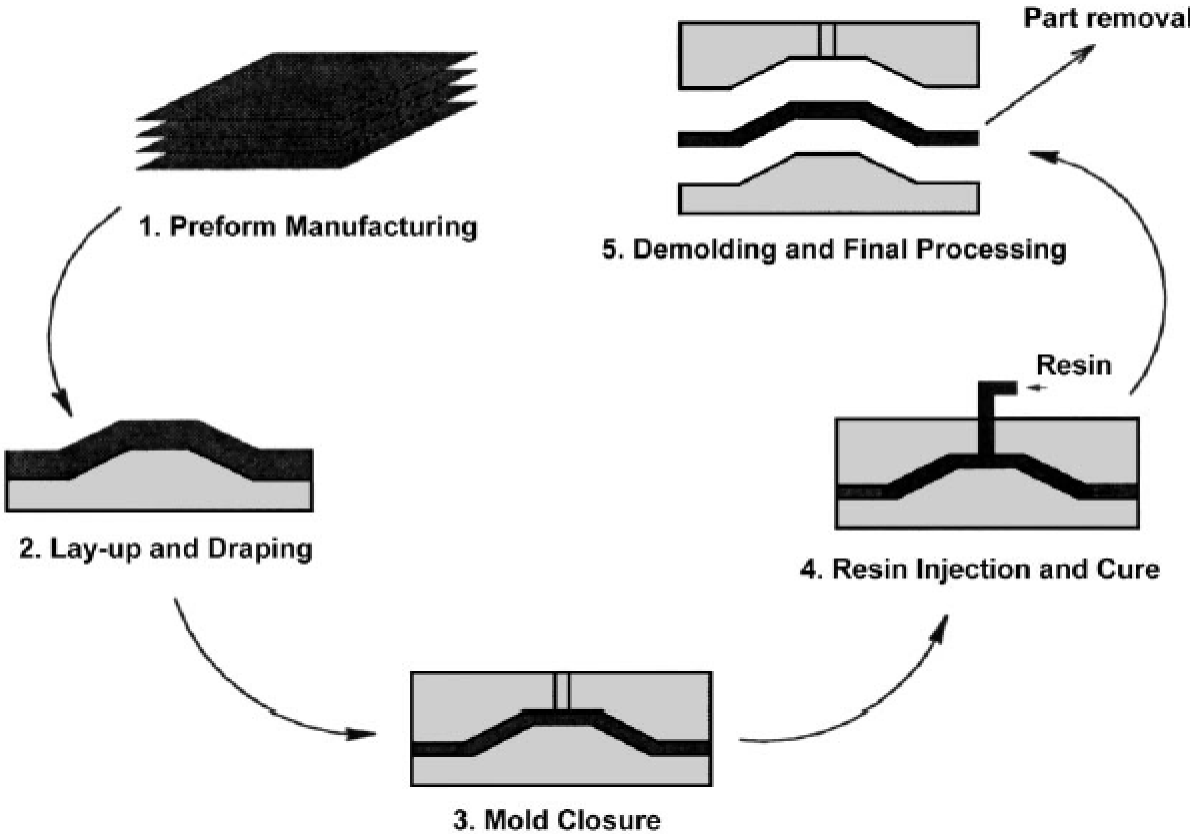

Section 15
Length 19,710 mm 64.7 ft
Width 5,962 mm 19.6 ft
Weight 4,078 kg 8,990 lbs



Processi per volumi di produzione medio-alti (Stampo chiuso)

Liquid Moulding

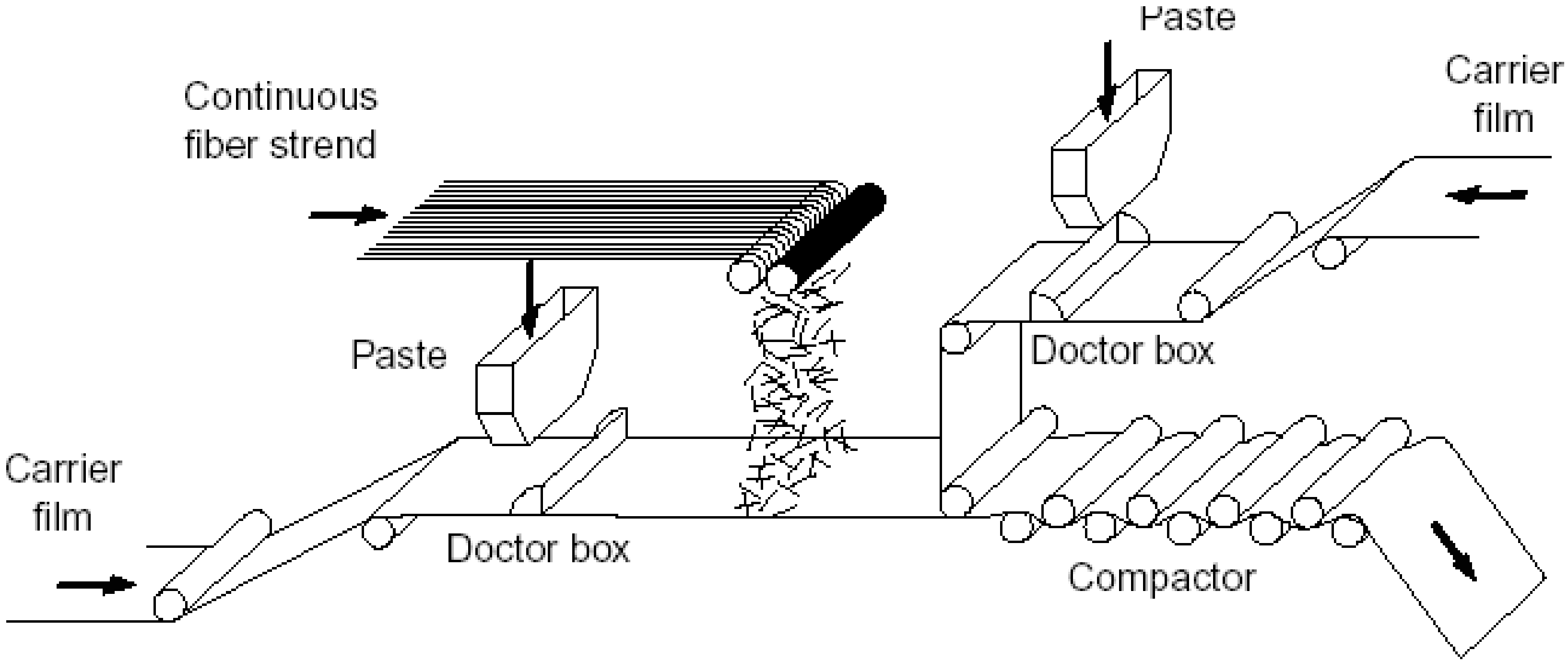
Schema del processo RTM (Resin Transfer Moulding)



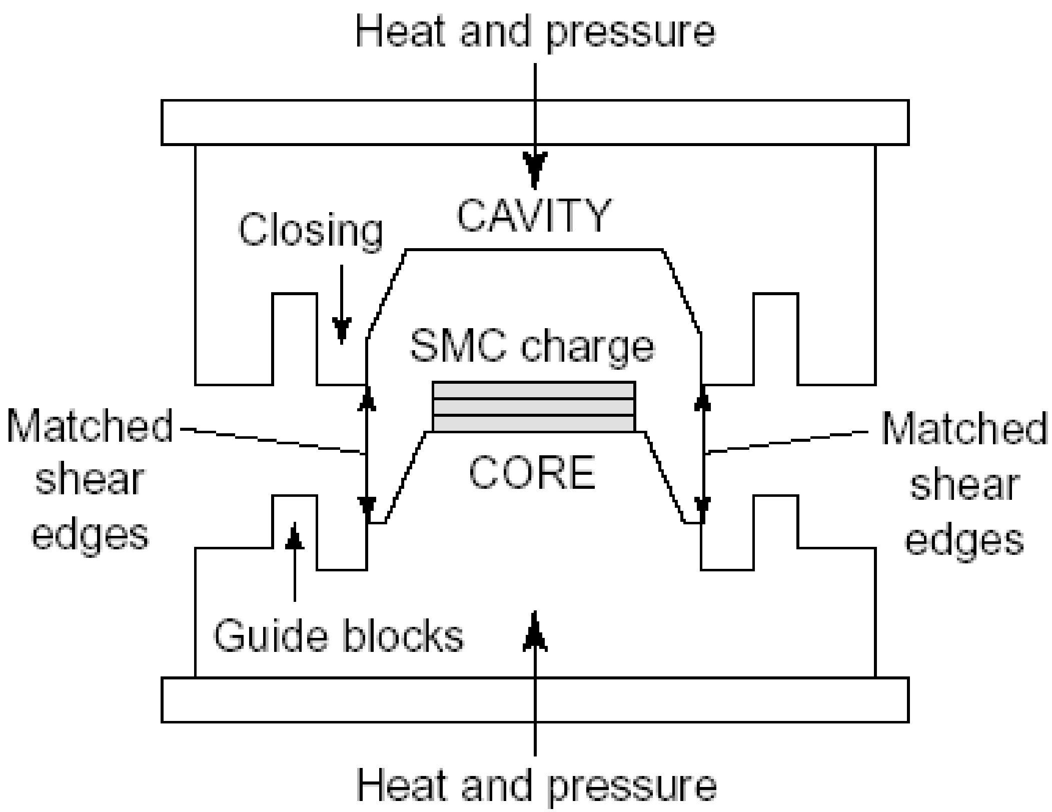
RTM
(Resin Transfer Moulding)

SMC/BMC
(Sheet Moulding Compound)
(Bulk Moulding Compound)

Produzione dell’ SMC
(resina termoindurente + fibre di vetro)

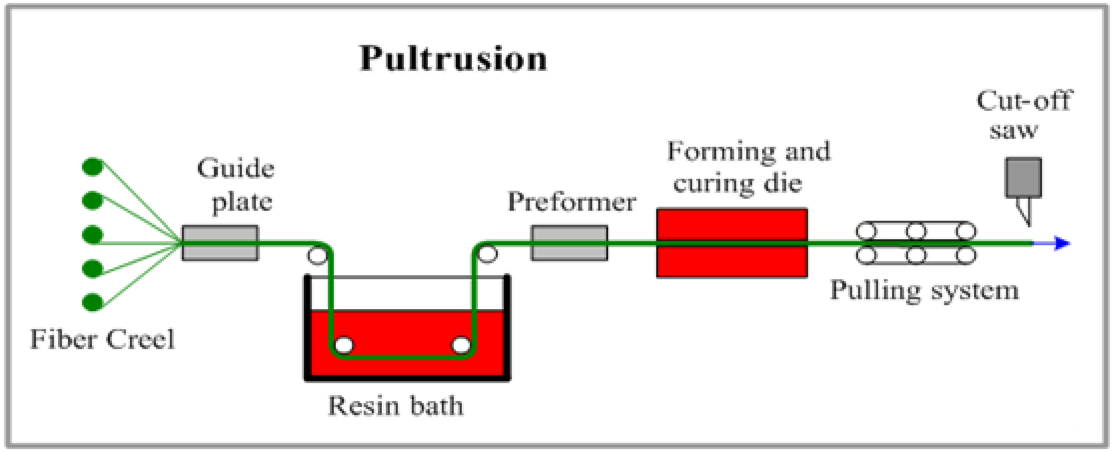


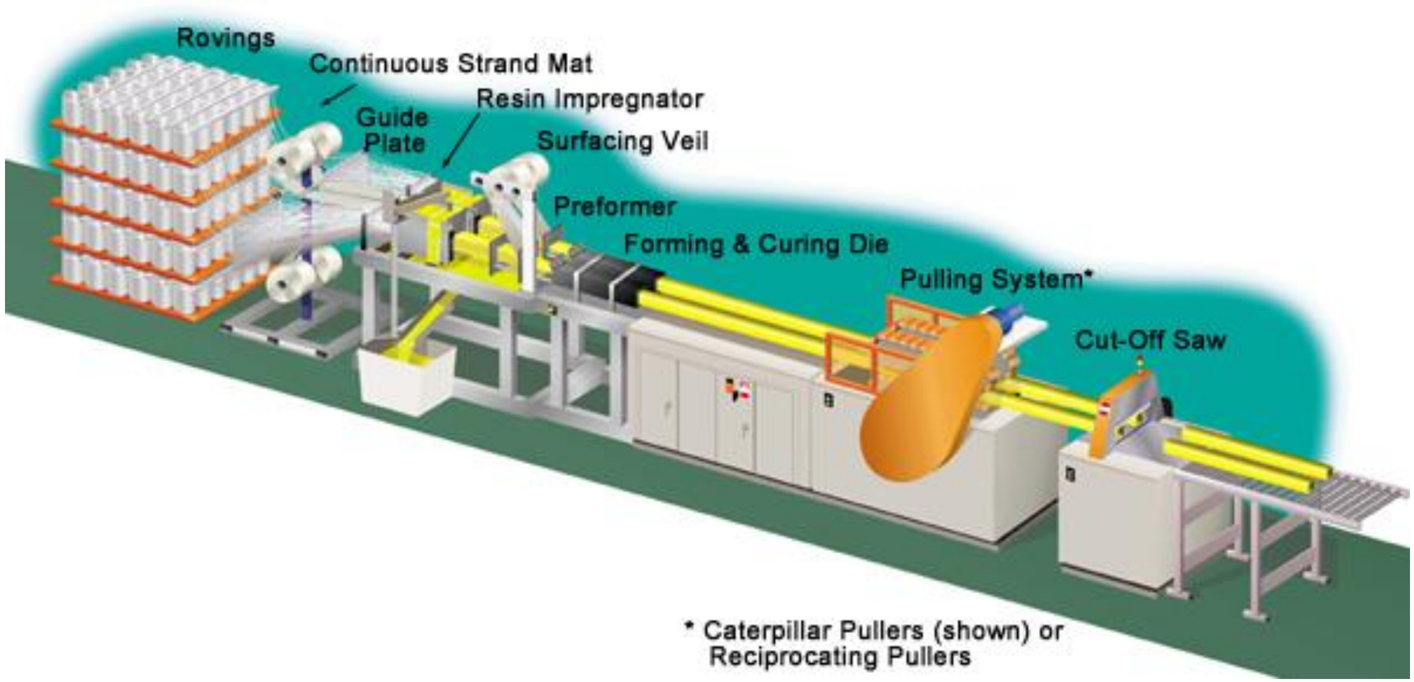
Stampaggio dell'SMC



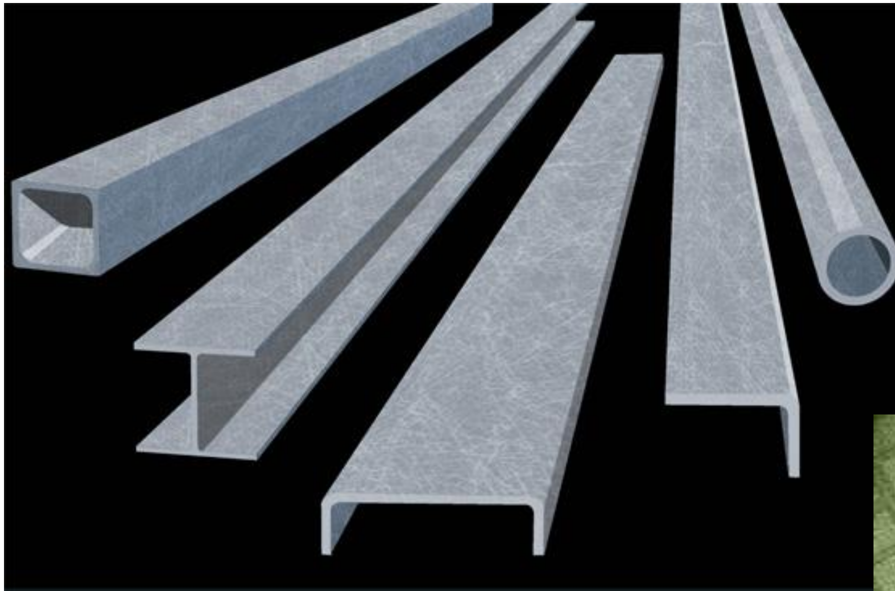
Continuous Moulding

Pultrusione

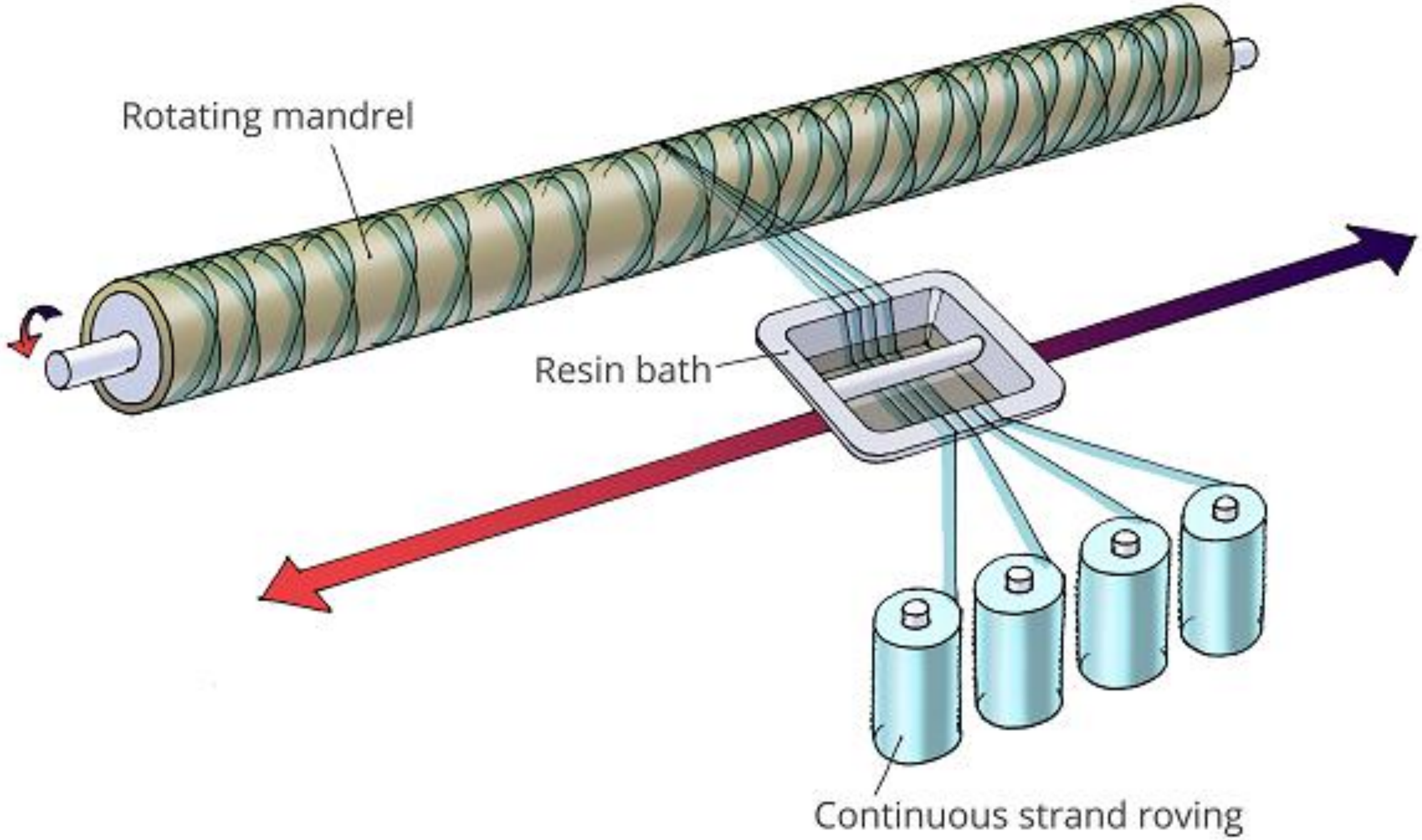




Pultrusione

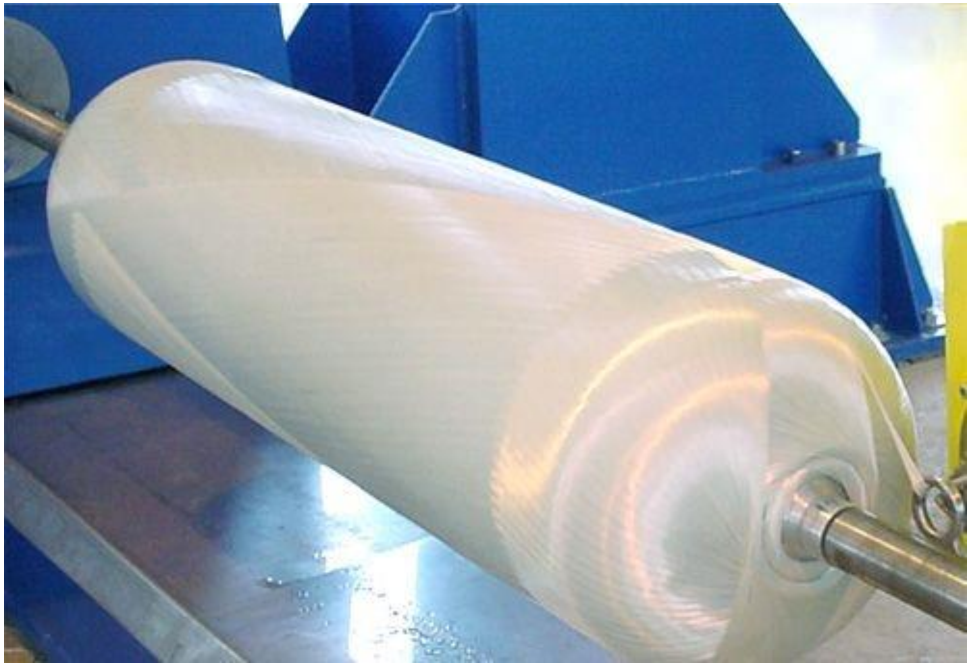


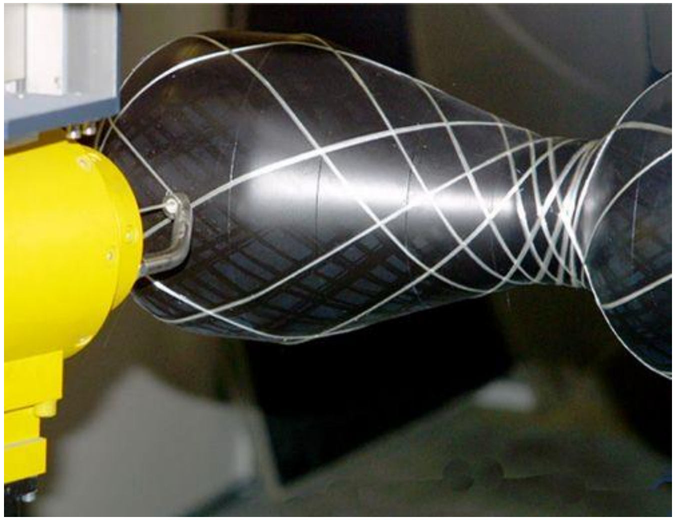
Filament winding

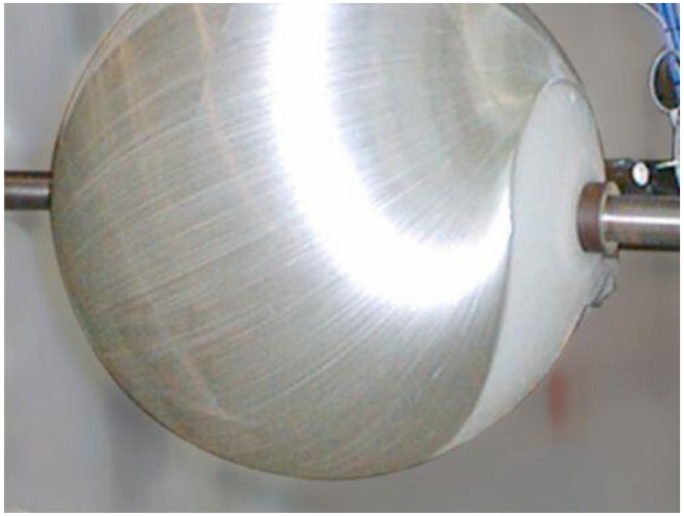


Filament winding

Filament winding





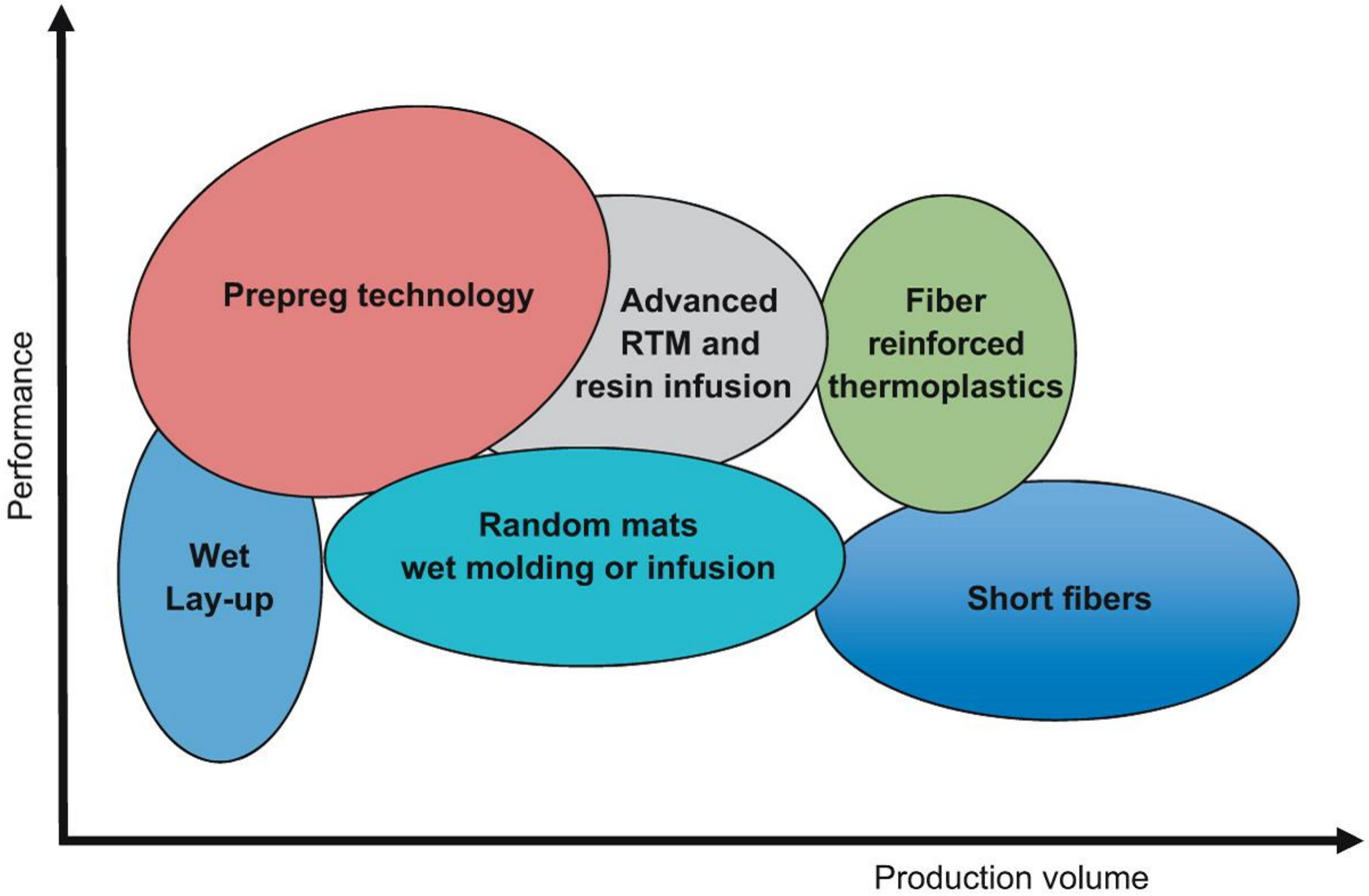


Confronto tra tecnologie di produzione

Method	Personnel cost	Capital investment cost	Level of automation	Production rate	Component quality/ Mechanical properties	Miscellaneous	Application example
Hand lay-up	3	0	0	0	0	Open process (health hazards)	▪ Prototypes and exclusive items ▪ Swimming pools
Vacuum infusion	3	0	0	0	1	Suitable for large parts	▪ Rotor blades for wind turbines ▪ Boats
Pultrusion	0	3	3	3	3	Only suitable for profiles	▪ Pipes, tubes and profiles
Filament winding	0	3	3	1	3	Not suitable for complex geometries	▪ Pressure tanks
RTM	1	2	2–3	2	2	Suitable for mass production	▪ Automotive parts ▪ Small aircraft parts
Prepreg/ Autoclave	2	2	1–2	1	3	Limited prepreg shelf-life	▪ Racing car parts ▪ Aerospace components ▪ Repair patches

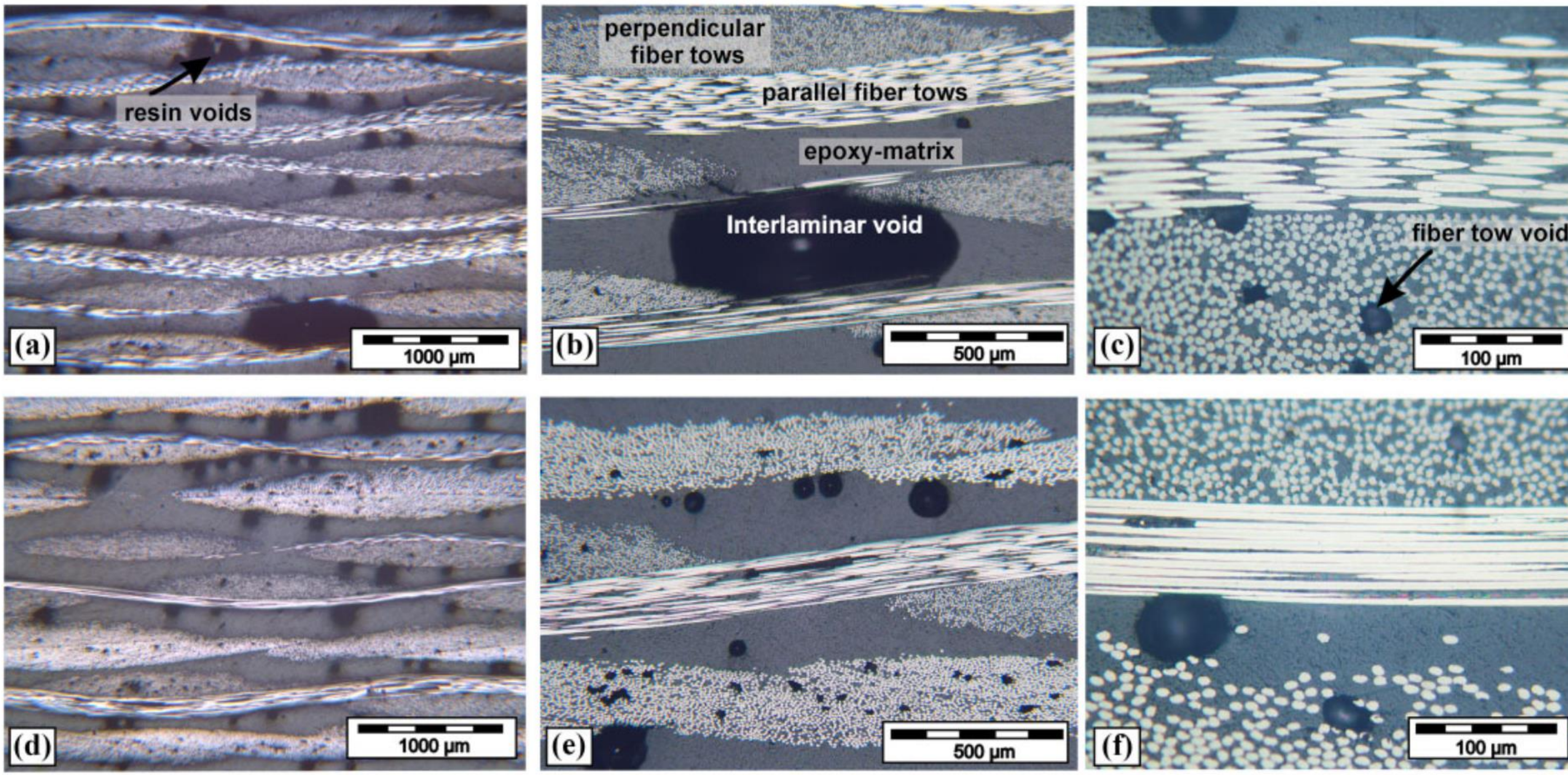
0: Low 1: middle 2: high 3: very high

Proprietà vs. Volumi di produzione

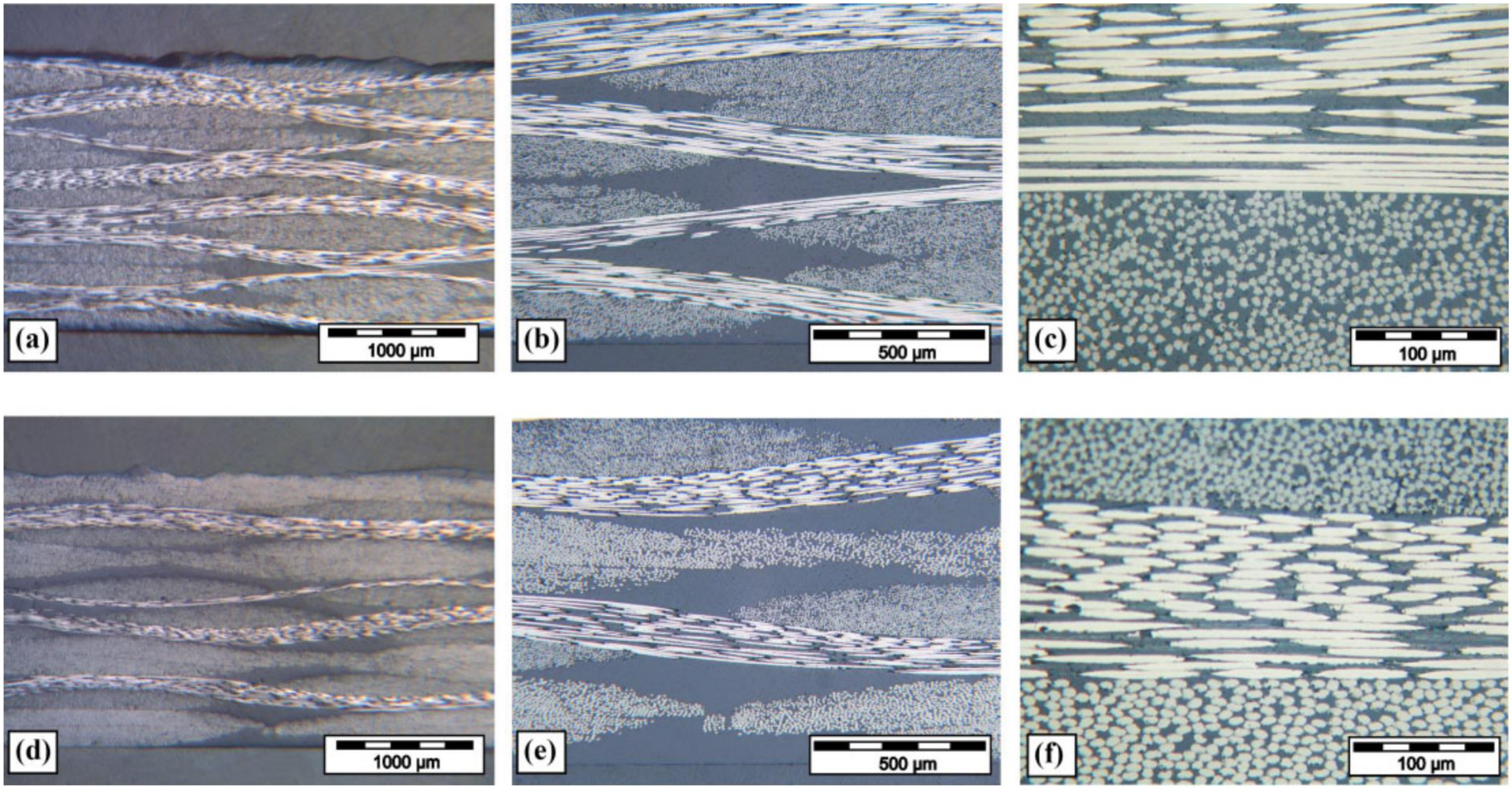


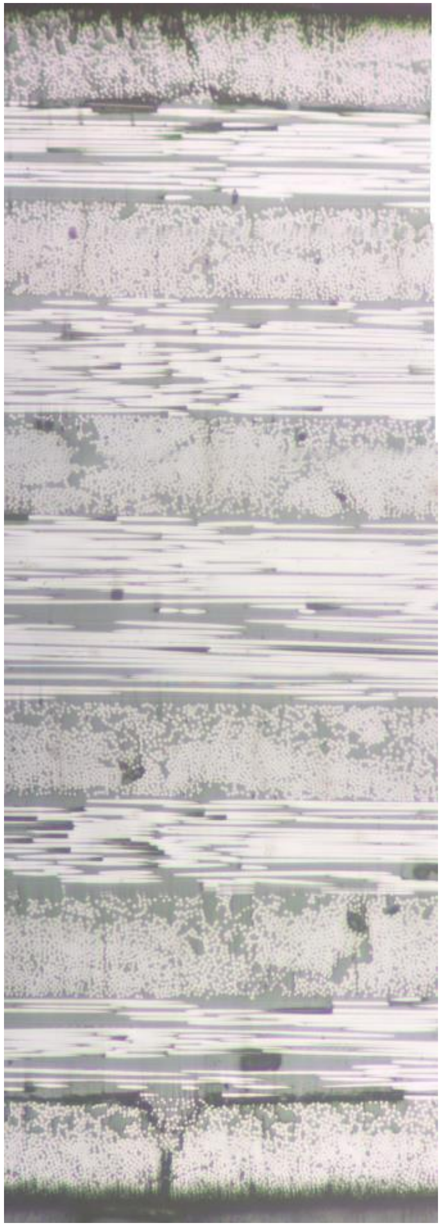
MICROSTRUTTURA
DI MATERIALI COMPOSITI

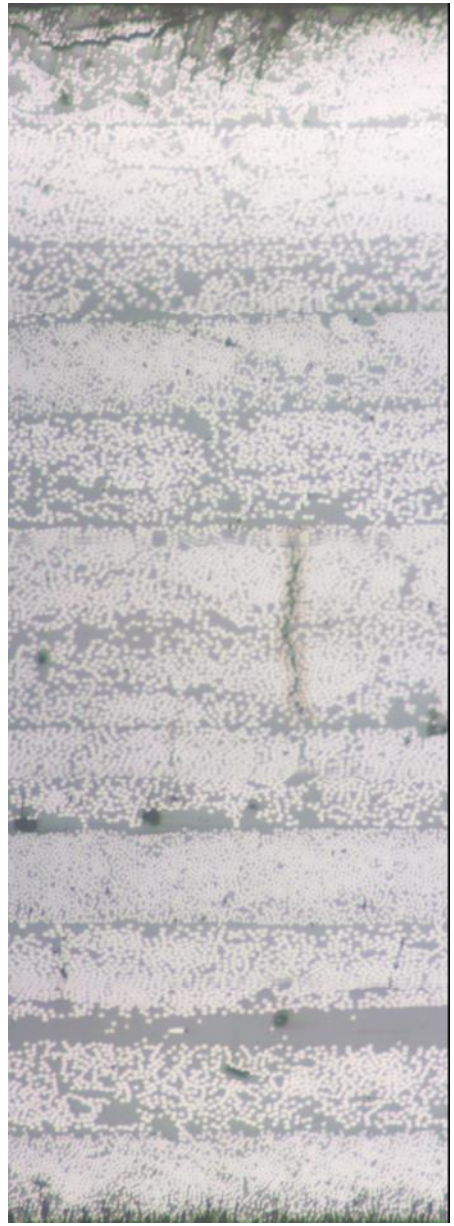
Wet Layup + Vacuum Bag
carbon/epoxy (tessuto plain weave)



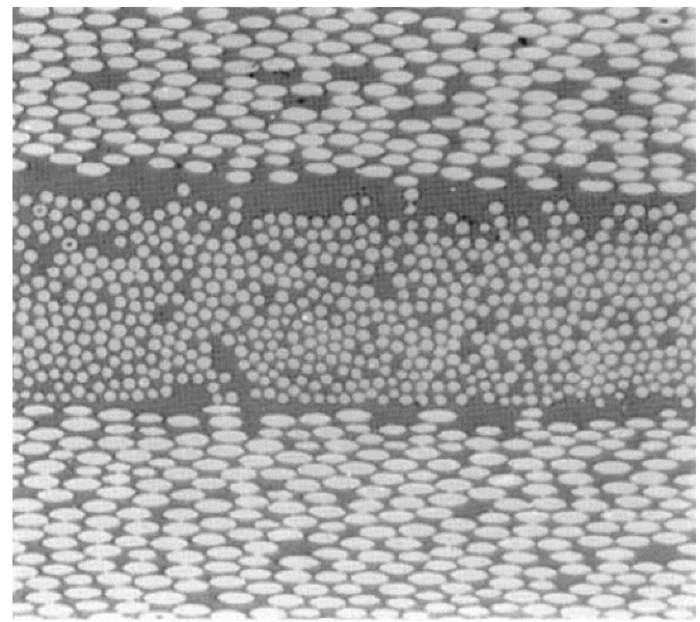
Prepreg - Autoclave (4 bar) + Vacuum bag carbon/epoxy (tessuto plain weave)



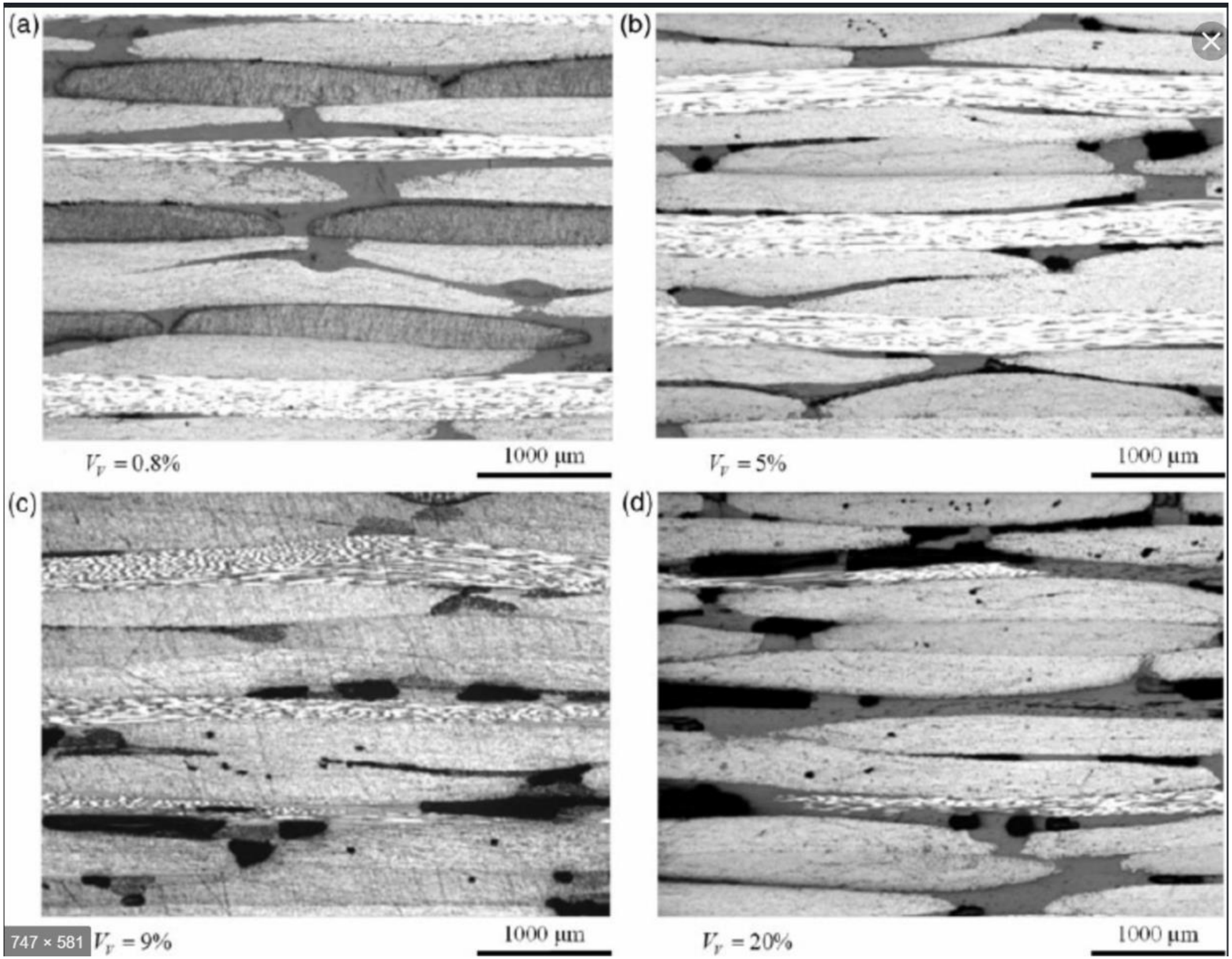




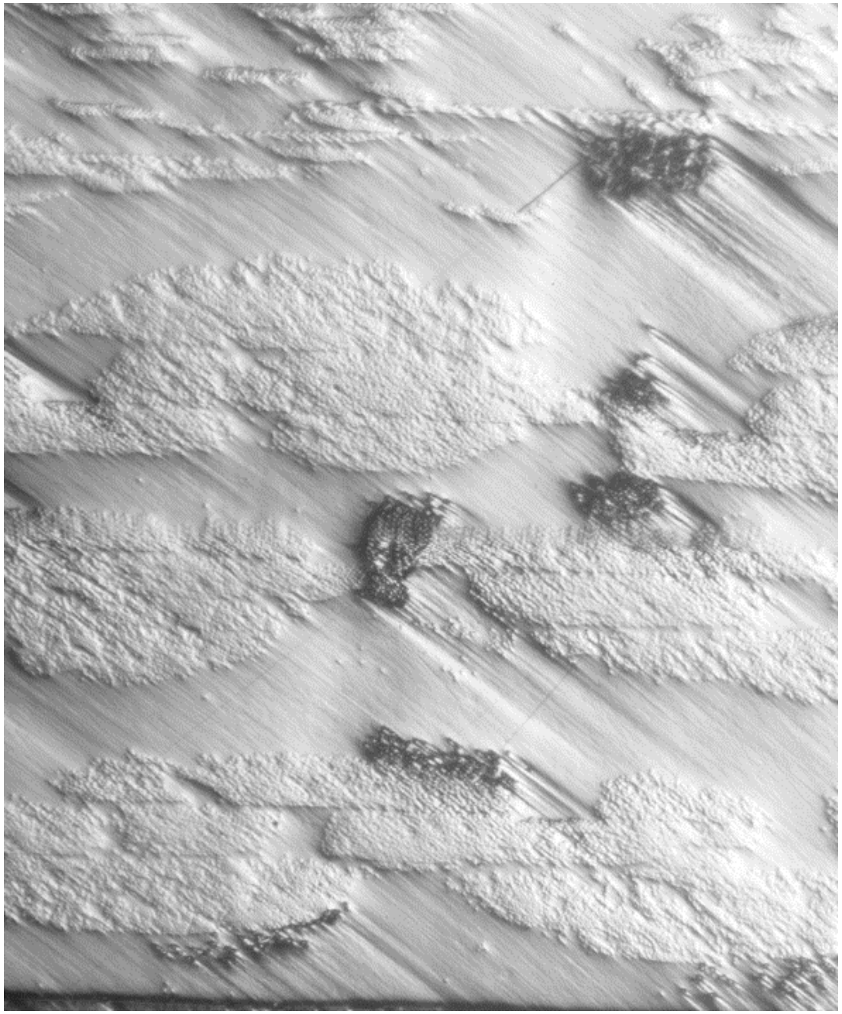
PREPREG in AUTOCLAVE
Carbon/epoxy
lamine unidirezionali



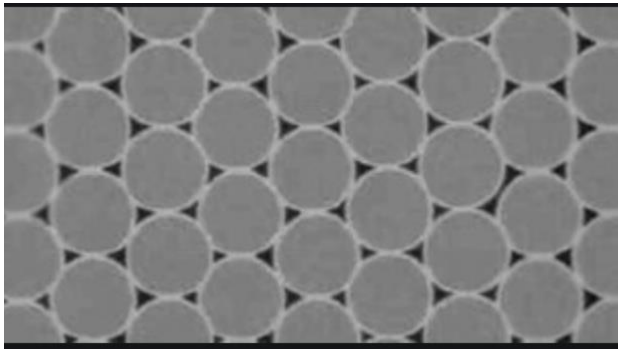
DIFFERENTI POROSITA'

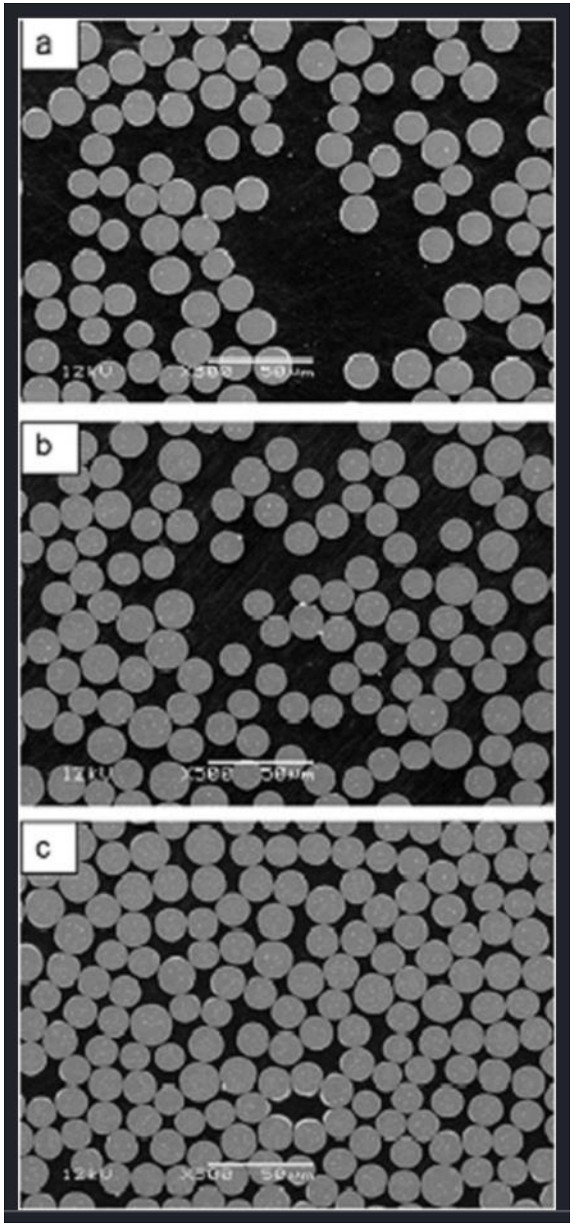


INFUSIONE
(Pala di turbina eolica
Fibre di vetro/resina poliestere)

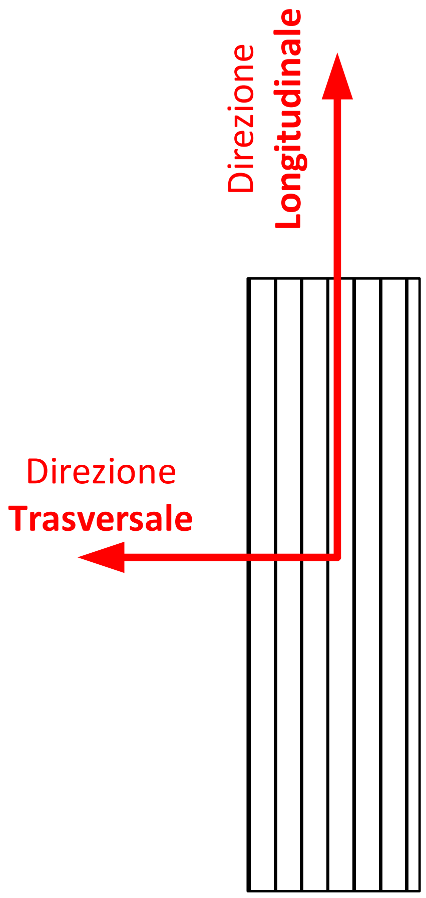


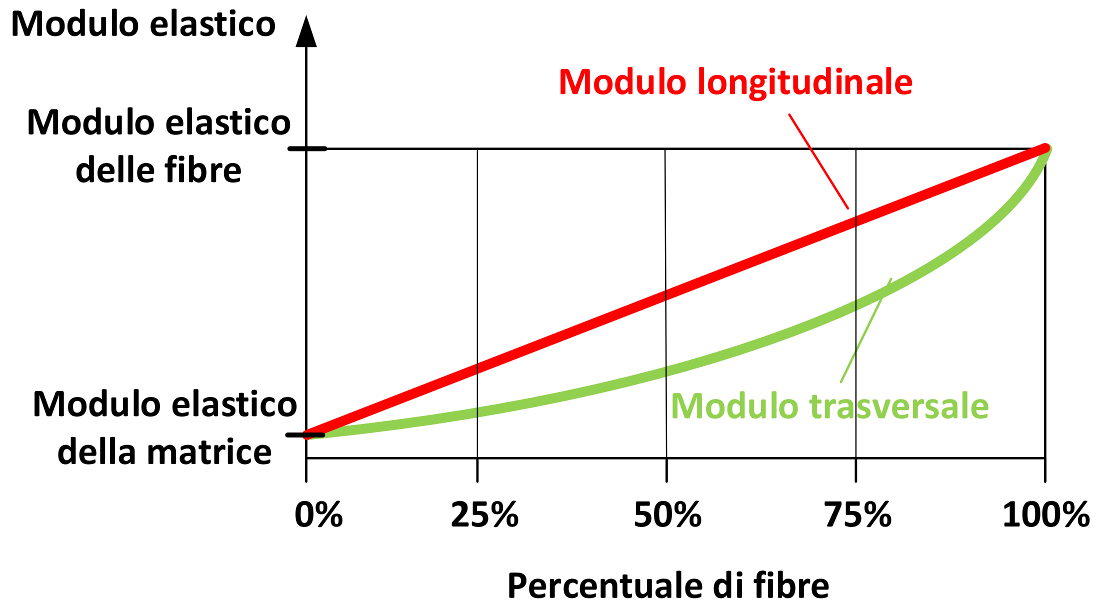
DIFFERENTI FRAZIONI DI FIBRA

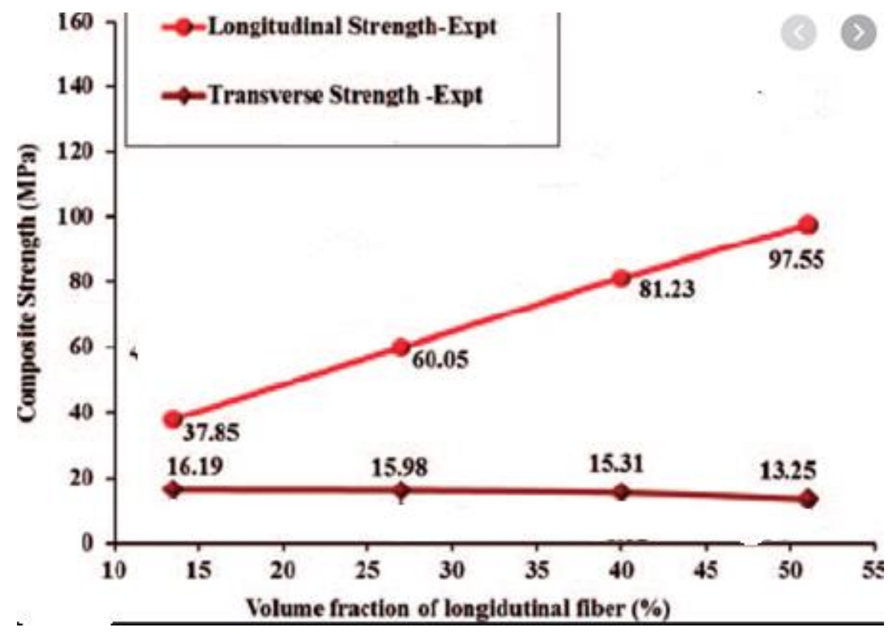




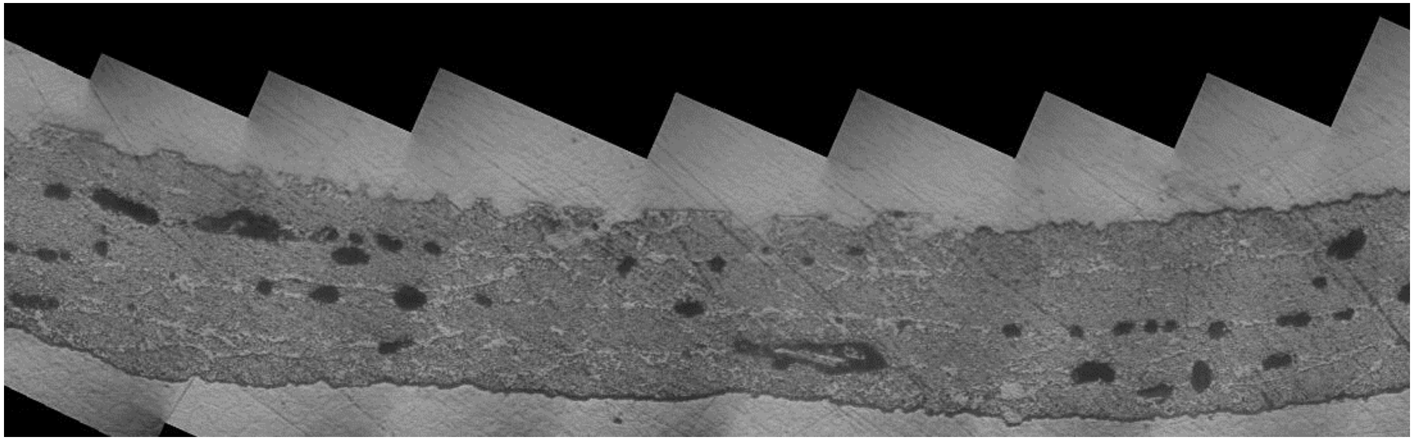
PROPRIETA' MATERIALE



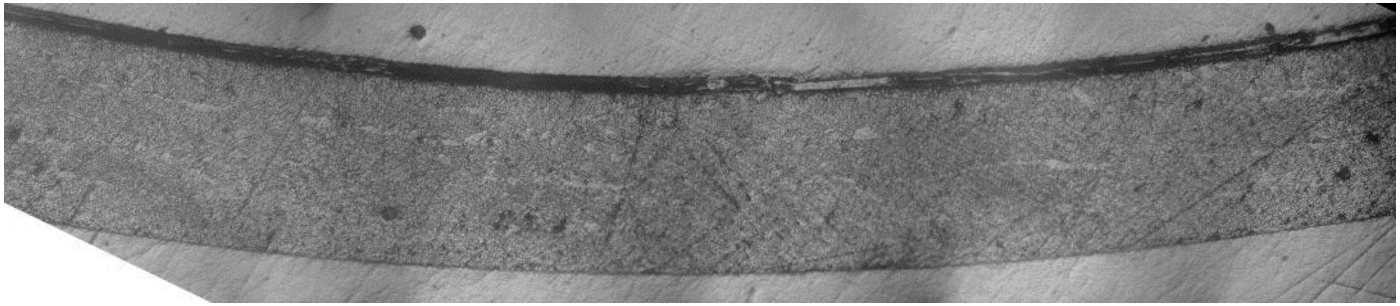




TUBE ROLLING
prepreg - nastro termorestingente + forno

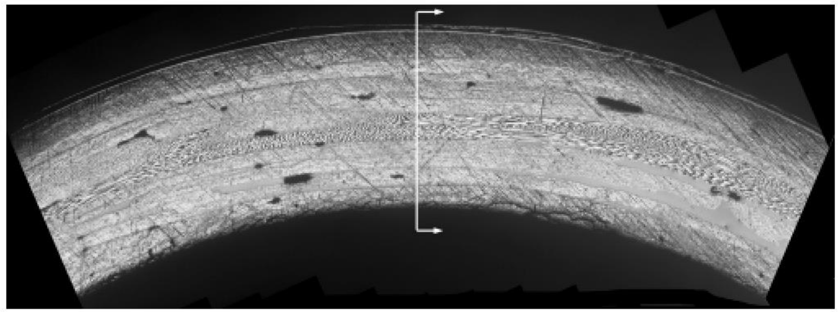


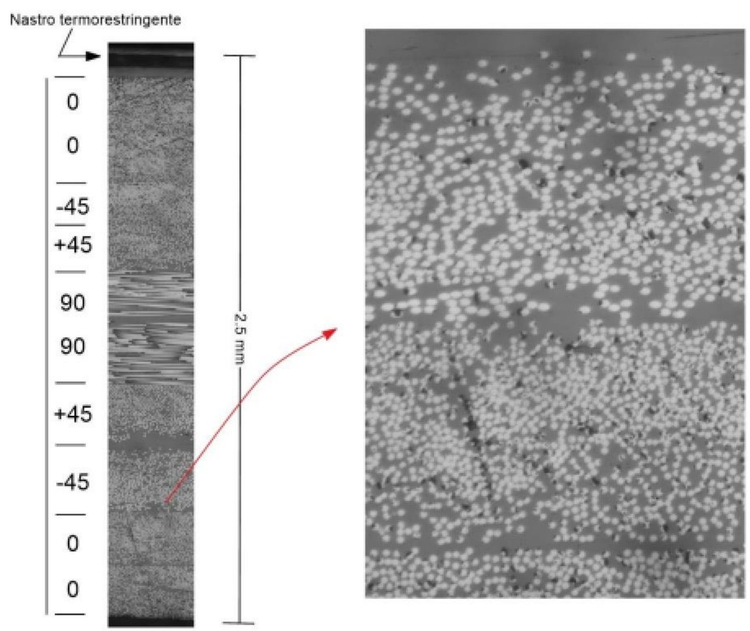
p = 0 bar



p = 2 bar

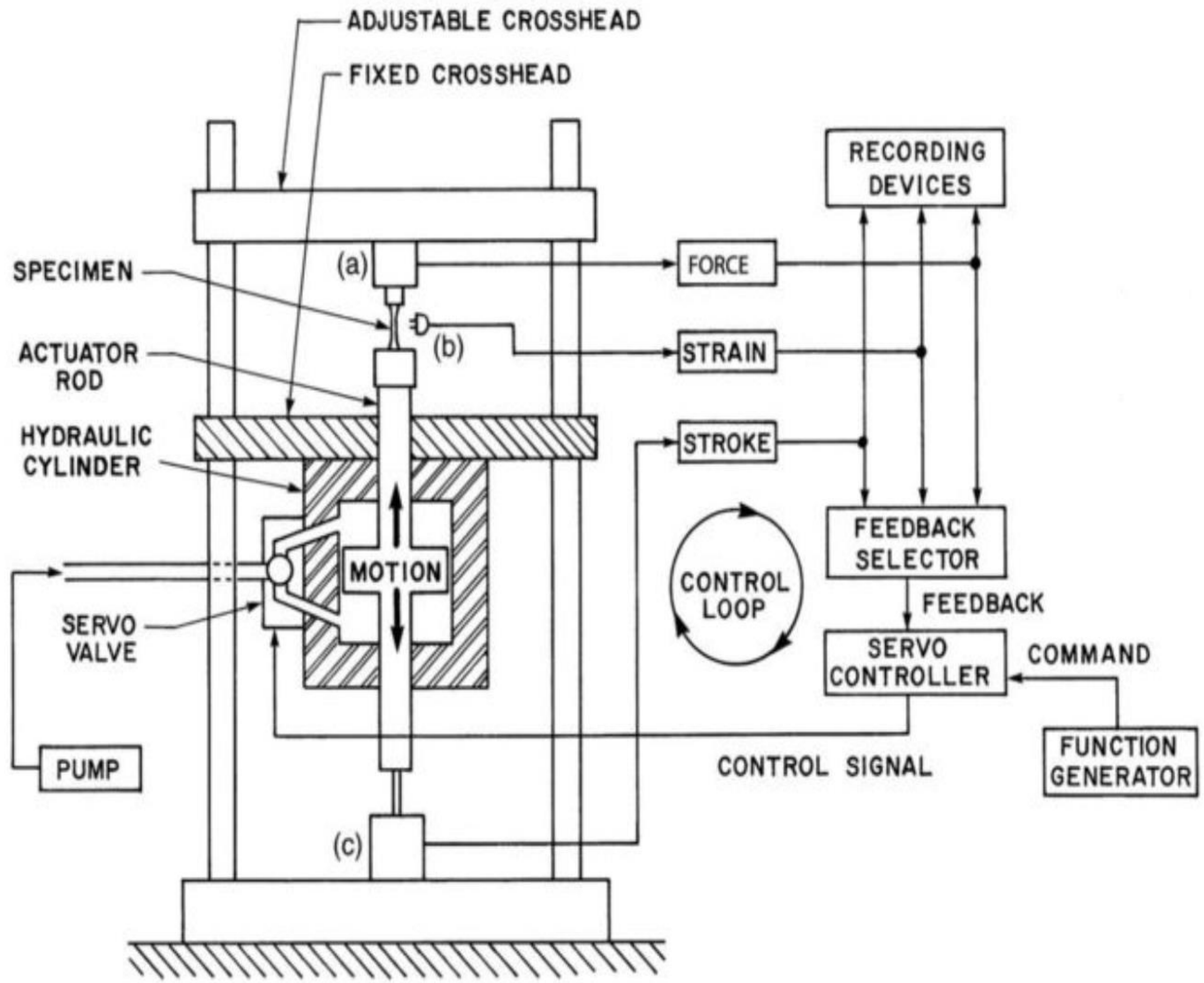
TUBE ROLLING



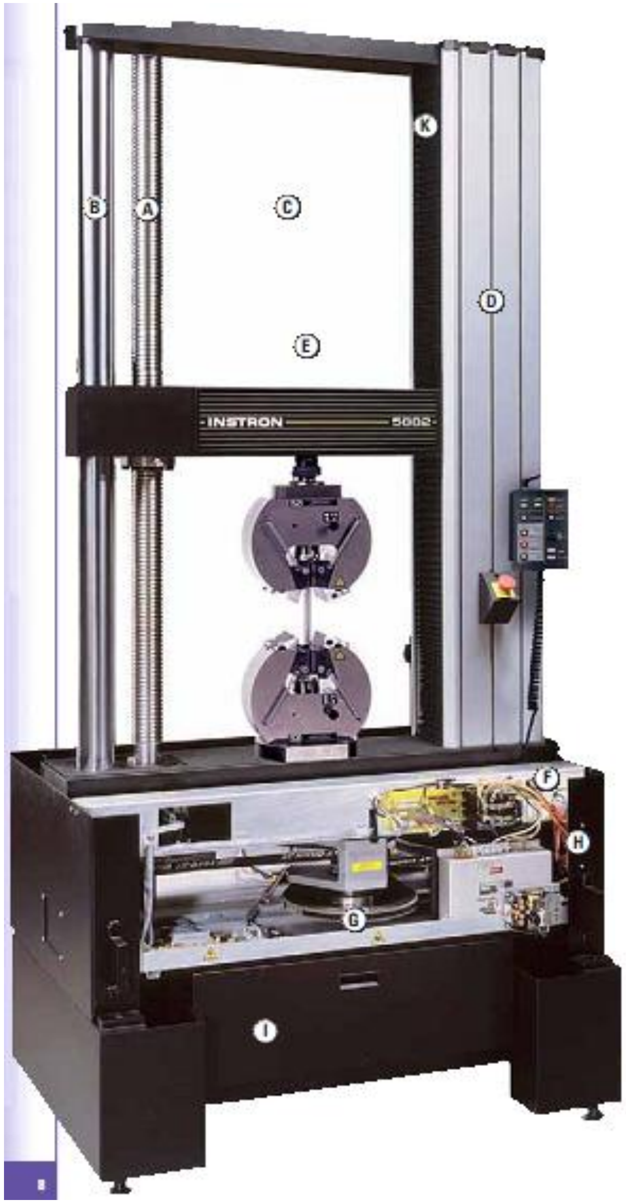


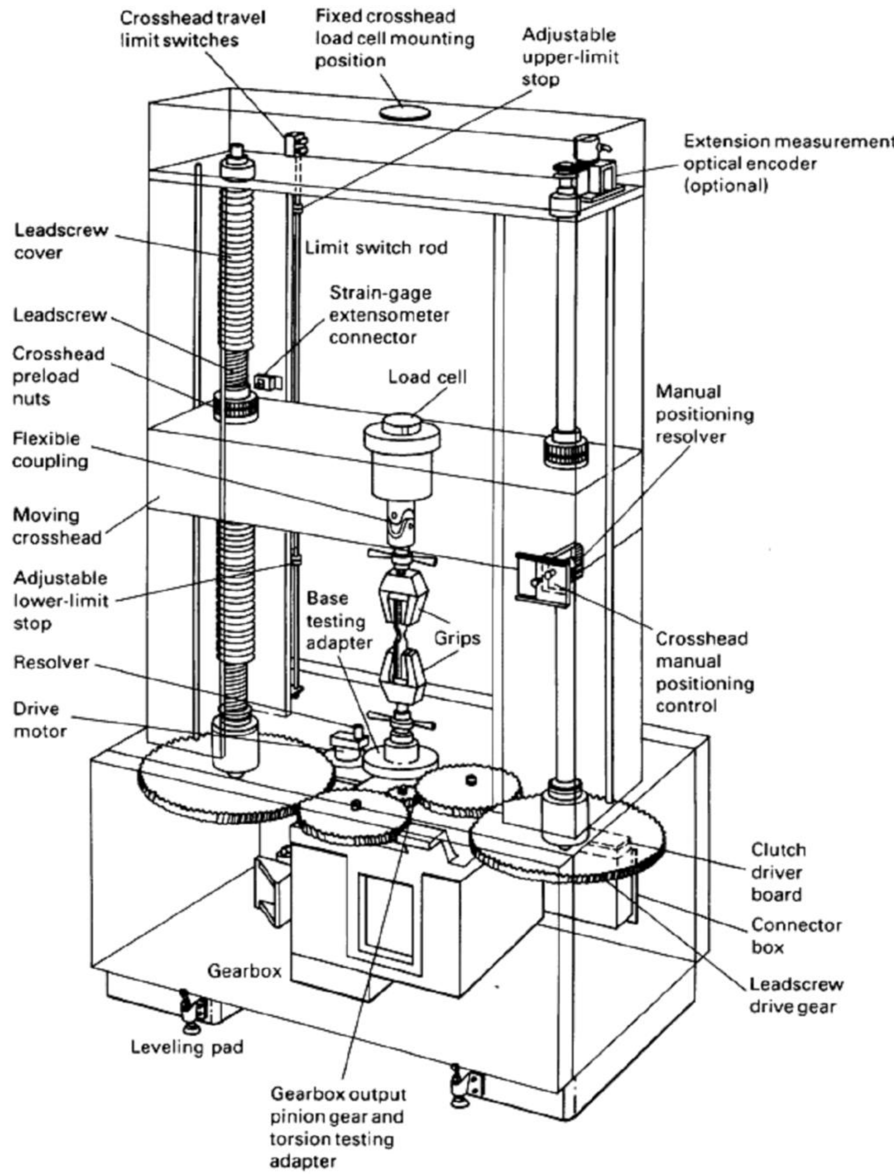
MACCHINE DI PROVA E TRASDUTTORI

Macchina di prova servoidraulica (< 30 Hz)

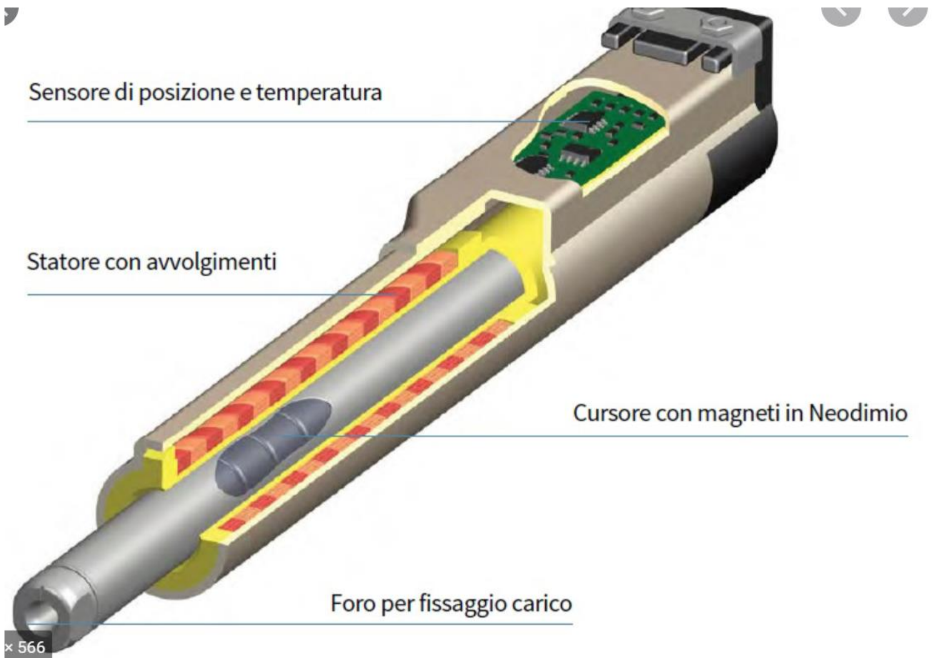


Macchina di prova servoelettrica (< 1 Hz)



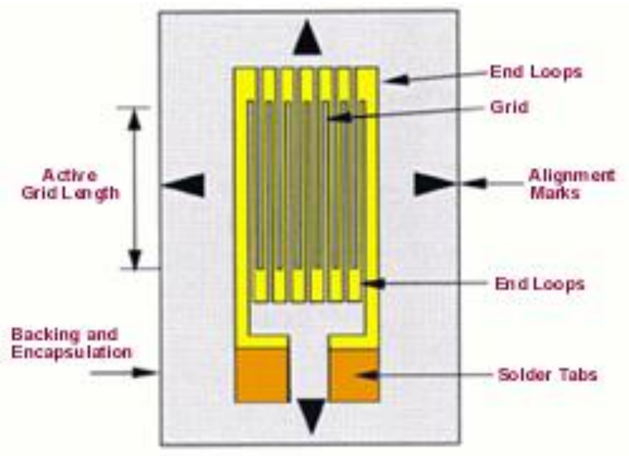


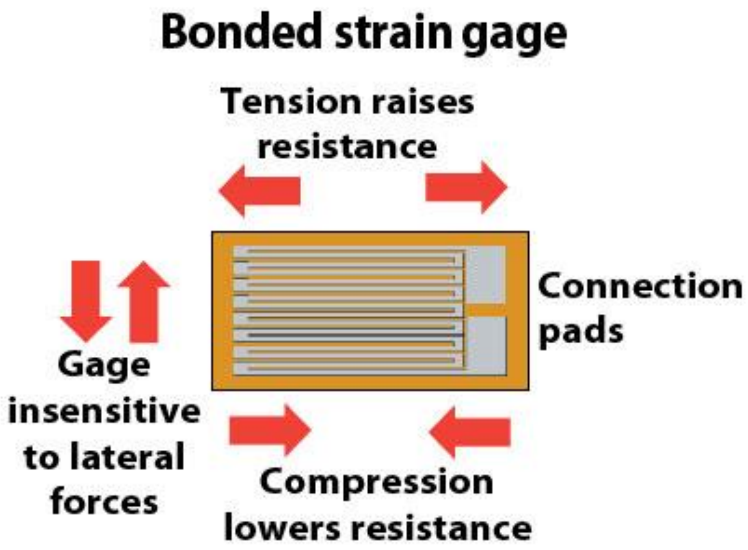
Macchine di prova elettrodinamica (<100 Hz)

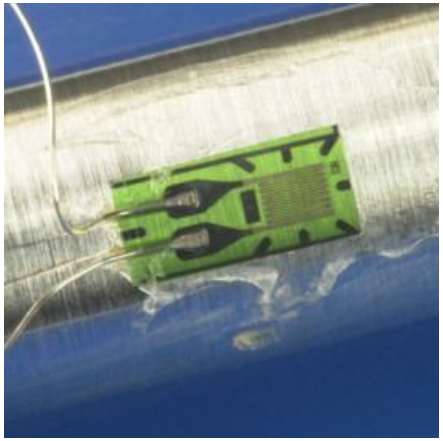


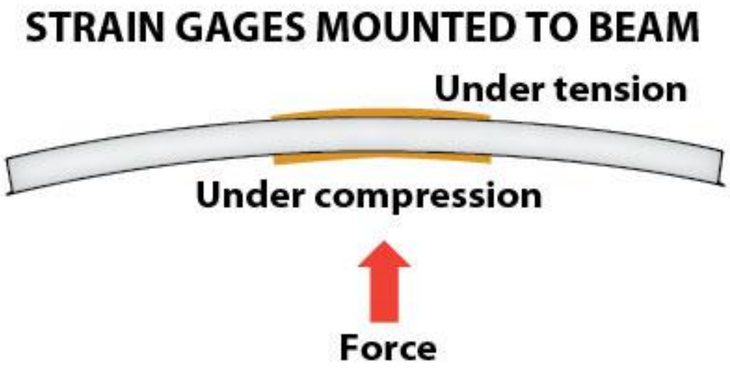
Motore elettrico lineare

Misura di deformazioni
Estensimetri (Strain Gauges)

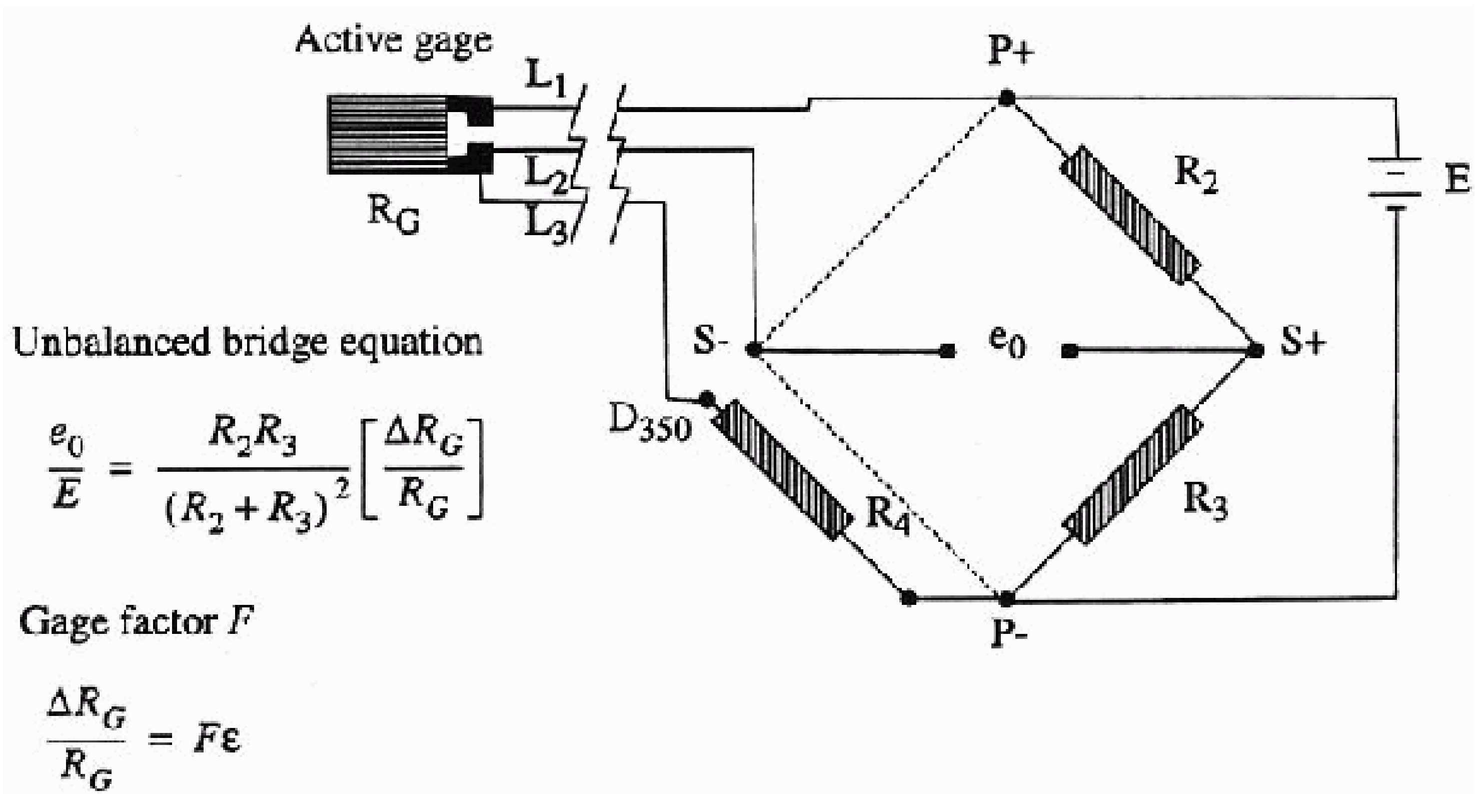




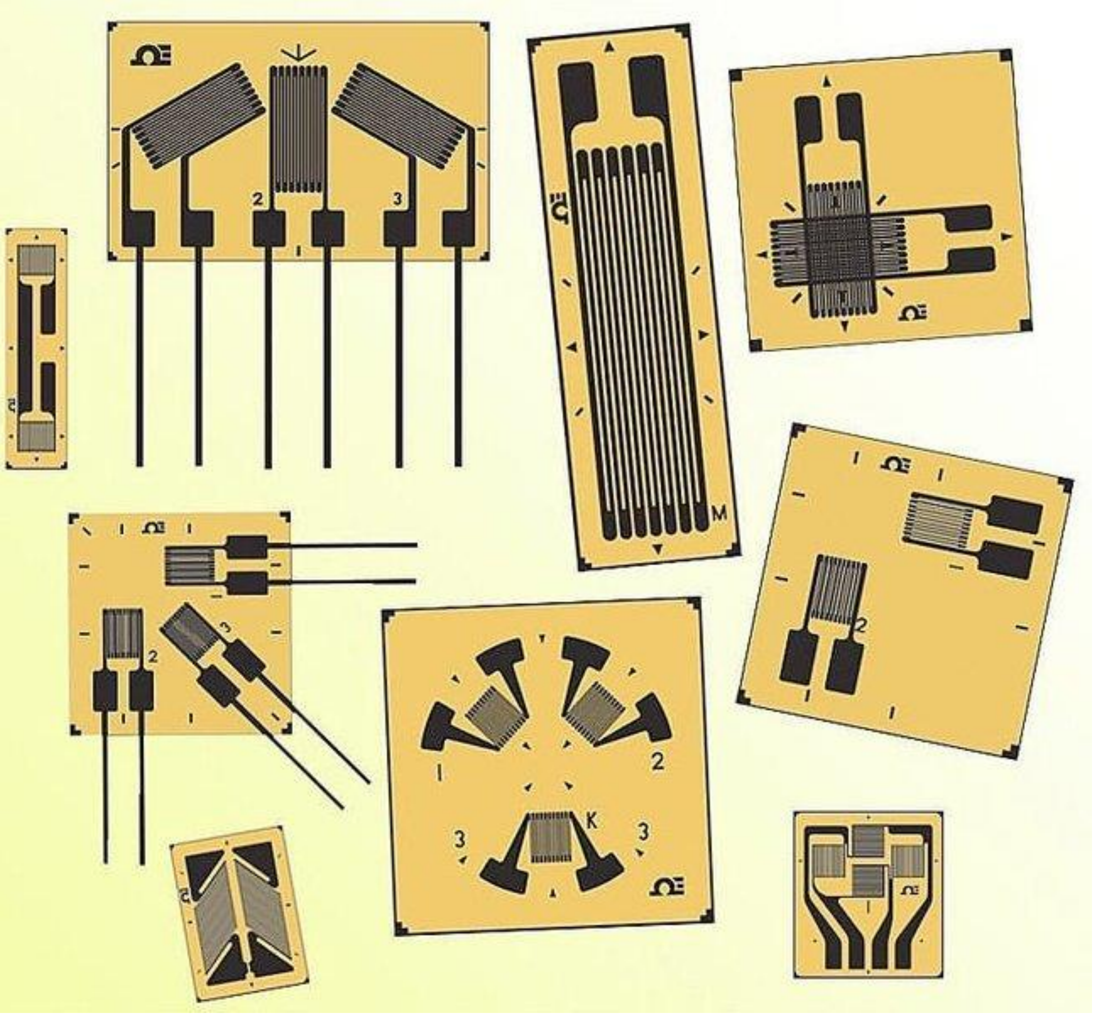




Misura di deformazioni
Estensimetri (Strain Gauges)

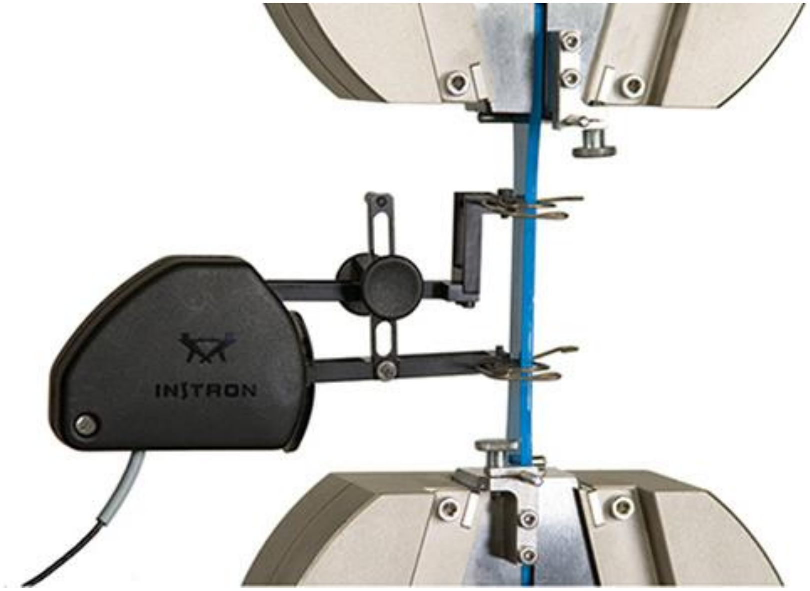


Misura di deformazioni
Estensimetri (Strain Gauges)

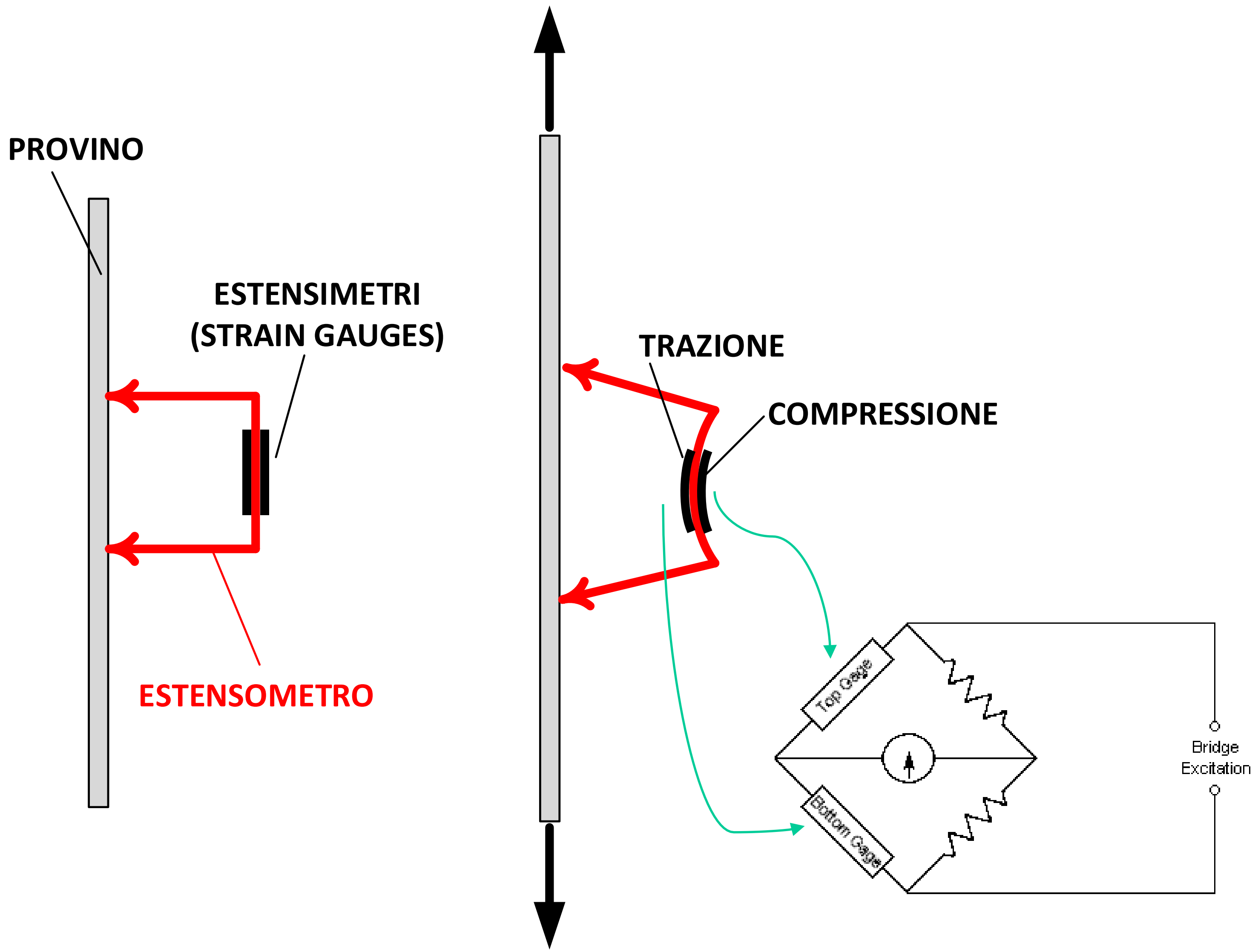


Misura di deformazioni
Estensometro (Clip Gauge)

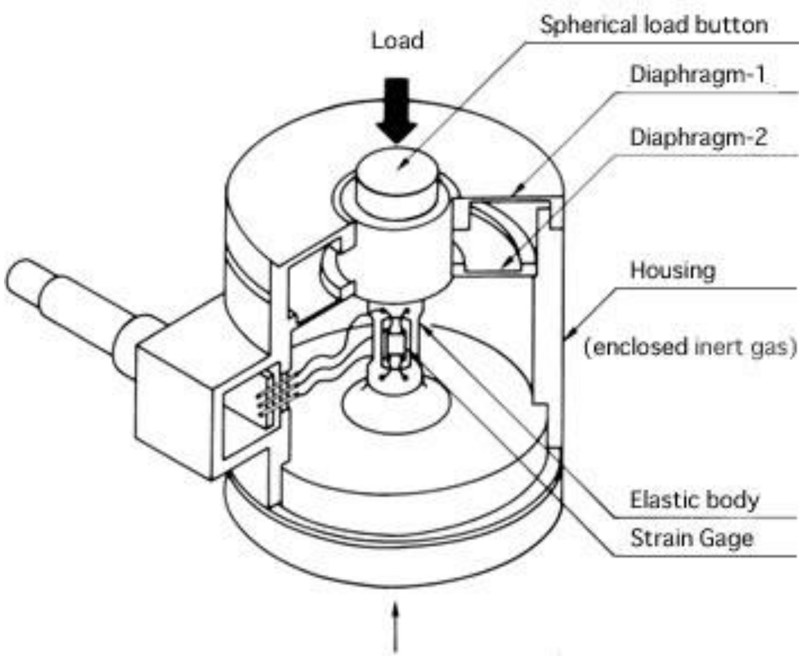
ESTENSOMETRI LONGITUDINALI **ESTENSOMETRO TRASVERSALE**

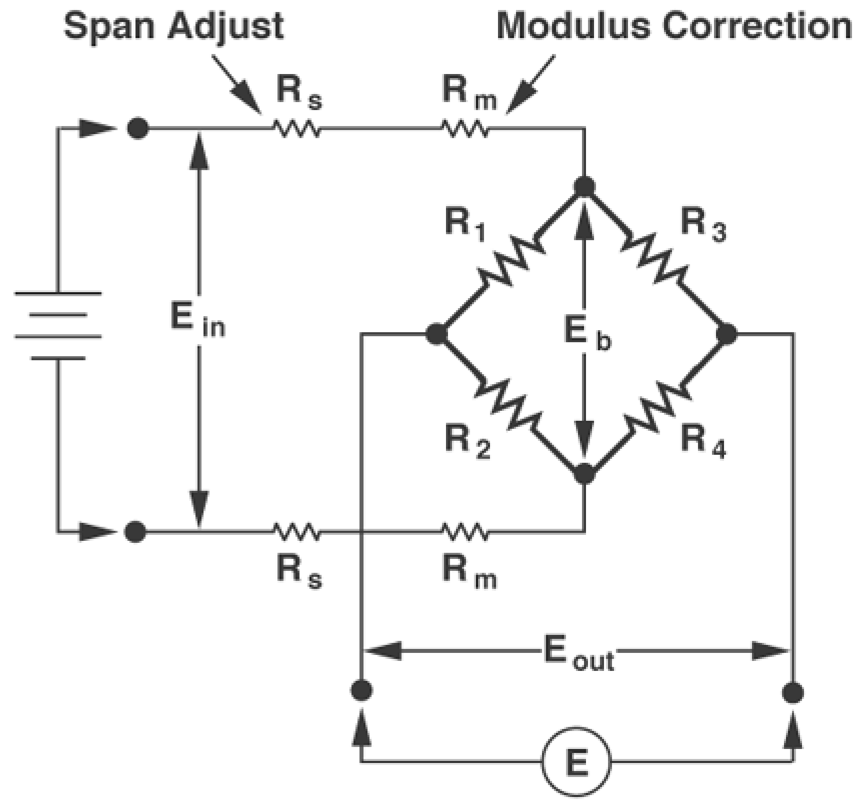


Misura di deformazioni
Estensometri (Clip Gauges)



Misura della forza
Celle di carico (Load cells)





Misura della forza
Celle di carico (Load cells)