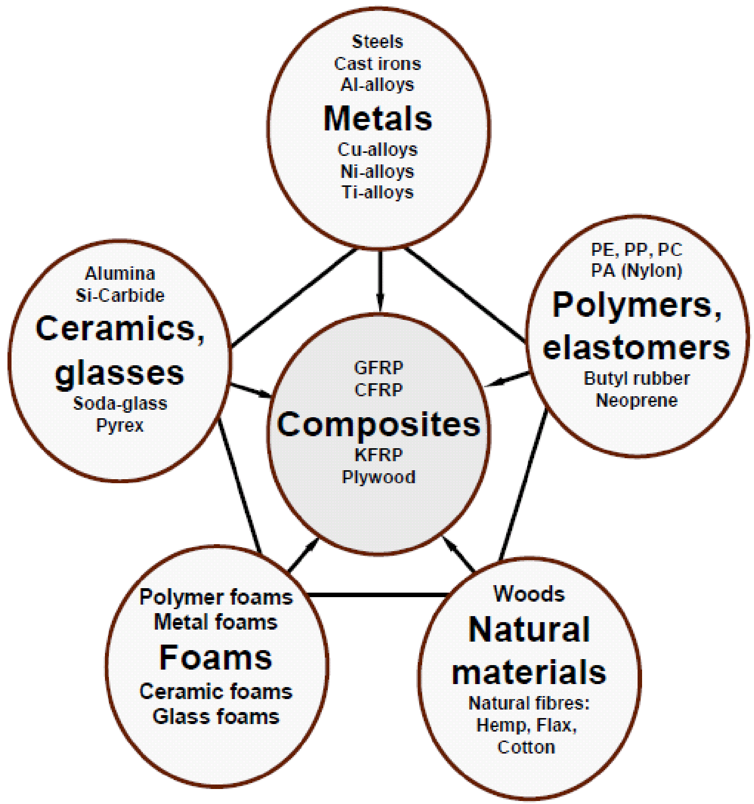
COMPOSITES

Composite Materials: Structure, General Properties, and Applications

COMPOSITES


Steels
Cast irons
Al-alloys
Metals
Cu-alloys
Ni-alloys
Ti-alloys
PE, PP, PC
PA (Nylon)
Polymers, elastomers
Butyl rubber
Neoprene
Alumina
Si-Carbide
Ceramics, glasses
Soda-glass
Pyrex
GFRP
CFRP
Composites
KFRP
Plywood
Polymer foams
Metal foams
Foams
Ceramic foams
Glass foams
Woods
Natural materials
Natural fibres:
Hemp, Flax,
Cotton

Composite Materials

- Metal Matrix Composites (MMC)

  Mixture of ceramics and metals reinforced by strong, high-stiffness fibers

- Ceramic Matrix Composites (CMC)

  Ceramics such as aluminum oxide and silicon carbide embedded with fibers for improved properties, especially high temperature applications.

- Polymer Matrix Composites (PMC)

  Thermosets or thermoplastics mixed with fiber reinforcement or powder.

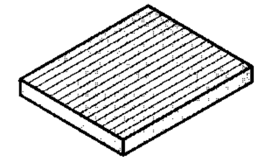
Composite Materials

Primary Phase, Matrix

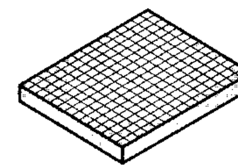
Secondary Phase, Reinforcement

	Metal	Ceramic	Polymer
Metal	Infiltrated powder metallurgy parts	Cermets	Some molding compounds Brake linings
Ceramic	Cermets Cemented carbides Fiber-reinforced metals	SiC whisker-reinforced Al_2O_3	Plastic molding compounds Fiberglass-reinforced plastic
Polymer	NA	NA	Kevlar-reinforced epoxy
Elements (e.g., C, B)	Fiber-reinforced metals	NA	Rubber with carbon black B- or C-reinforced plastics

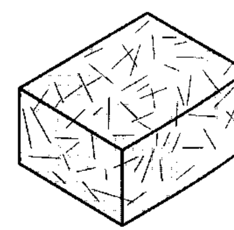
NA = not applicable currently.



1D fibre



Woven fabric



Random fibre

Composite Materials

Fiber	Diameter mils[a]	(mm)	Tensile strength lb/in.^{2}	(MPa)	Elastic modulus lb/in.^{2}	(GPa)
Glass						
E-glass	0.4	(0.01)	500,000	(3450)	10×10^6	(73)
S-glass	0.4	(0.01)	650,000	(4480)	12×10^6	(86)
Carbon	0.4	(0.01)	400,000	(2750)	35×10^6	(240)
Boron	5.5	(0.14)	450,000	(3100)	57×10^6	(393)
Kevlar 49	0.5	(0.013)	500,000	(3450)	19×10^6	(130)
Ceramic						
Al_2O_3	0.8	(0.02)	275,000	(1900)	55×10^6	(380)
SiC	5.0	(0.13)	475,000	(3275)	58×10^6	(400)
Metal						
Steel	5.0	(0.13)	150,000	(1000)	30×10^6	(206)
Tungsten	0.5	(0.013)	580,000	(4000)	59×10^6	(407)

Fibers/Particles Reinforcement

- Glass
- Kevlar
- Carbon
- Thermoplastics
- Alumina
- Boron
- SiC
- Steel
- Si3 N4

- Silica
- Glass beads
- Talc
- Rocks
- Carbon black
- Calcium carbonate

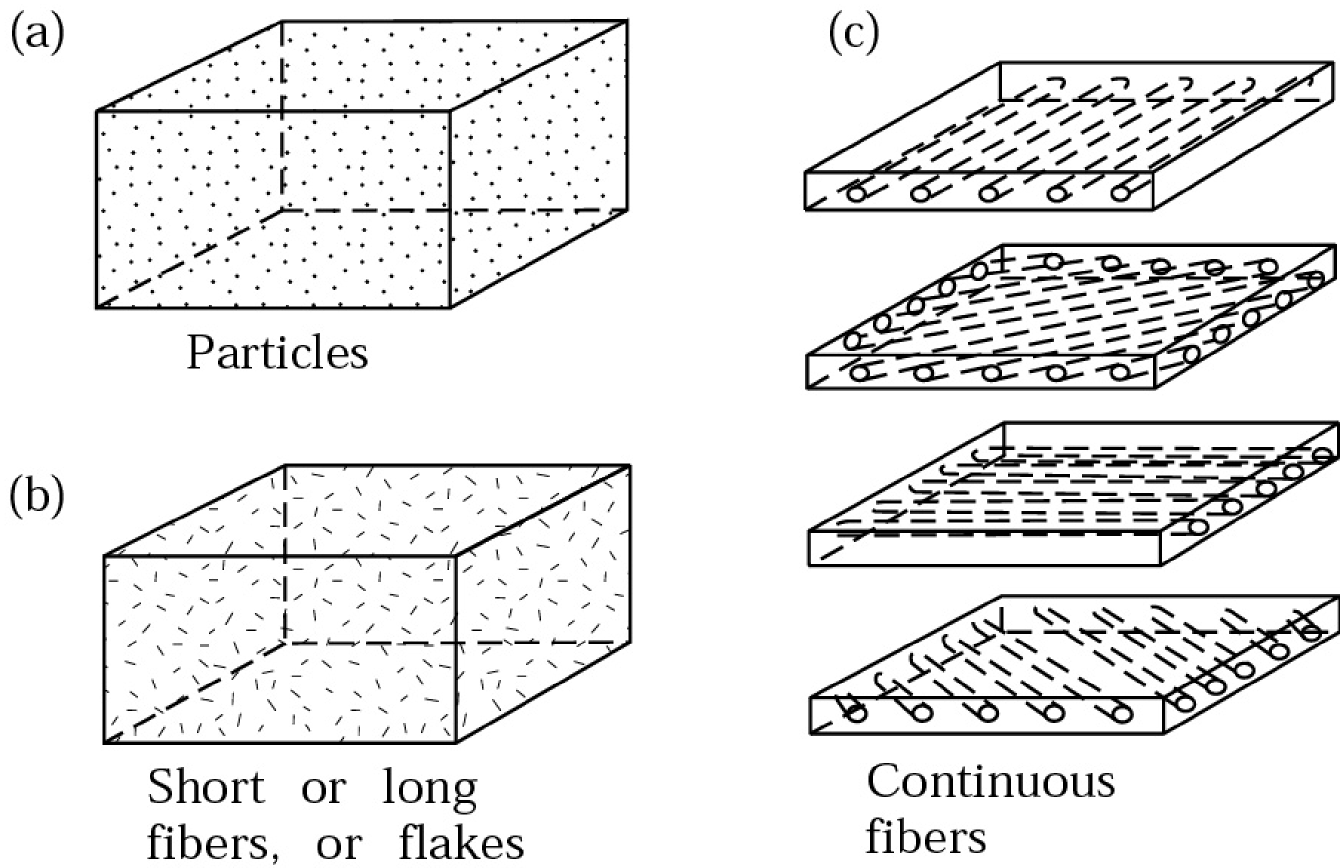
Types and General Characteristics of Composite Materials

TABLE 9.1

Material	Characteristics
Fibers	
Glass	High strength, low stiffness, high density; lowest cost; E (calcium aluminoborosilicate) and S (magnesia-aluminosilicate) types commonly used.
Graphite	Available as high-modulus or high-strength; low cost; less dense than glass.
Boron	High strength and stiffness; highest density; highest cost; has tungsten filament at its center.
Aramids (Kevlar)	Highest strength-to-weight ratio of all fibers; high cost.
Other fibers	Nylon, silicon carbide, silicon nitride, aluminum oxide, boron carbide, boron nitride, tantalum carbide, steel, tungsten, molybdenum.
Matrix materials	
Thermosets	Epoxy and polyester, with the former most commonly used; others are phenolics, fluorocarbons, polyethersulfone, silicon, and polyimides.
Thermoplastics	Polyetheretherketone; tougher than thermosets but lower resistance to temperature.
Metals	Aluminum, aluminum-lithium, magnesium, and titanium; fibers are graphite, aluminum oxide, silicon carbide, and boron.
Ceramics	Silicon carbide, silicon nitride, aluminum oxide, and mullite; fibers are various ceramics.

Methods of Reinforcing Plastics

Figure 9.2 Schematic illustration of methods of reinforcing plastics (matrix) with (a) particles, and (b) short or long fibers or flakes. The four layers of continuous fibers in illustration (c) are assembled into a laminate structure.



Typical Properties of Reinforcing Fibers

TABLE 9.2

Type	**Tensile strength (MPa)**	**Elastic modulus (GPa)**	**Density (kg/m^3)**	**Relative cost**
Boron	3500	380	2600	Highest
Carbon				
High strength	3000	275	1900	Low
High modulus	2000	415	1900	Low
Glass				
E type	3500	73	2480	Lowest
S type	4600	85	2540	Lowest
Kevlar				
29	2800	62	1440	High
49	2800	117	1440	High

Note: These properties vary significantly depending on the material and method of preparation.

Effect of Fiber Type on Fiber-Reinforced Nylon

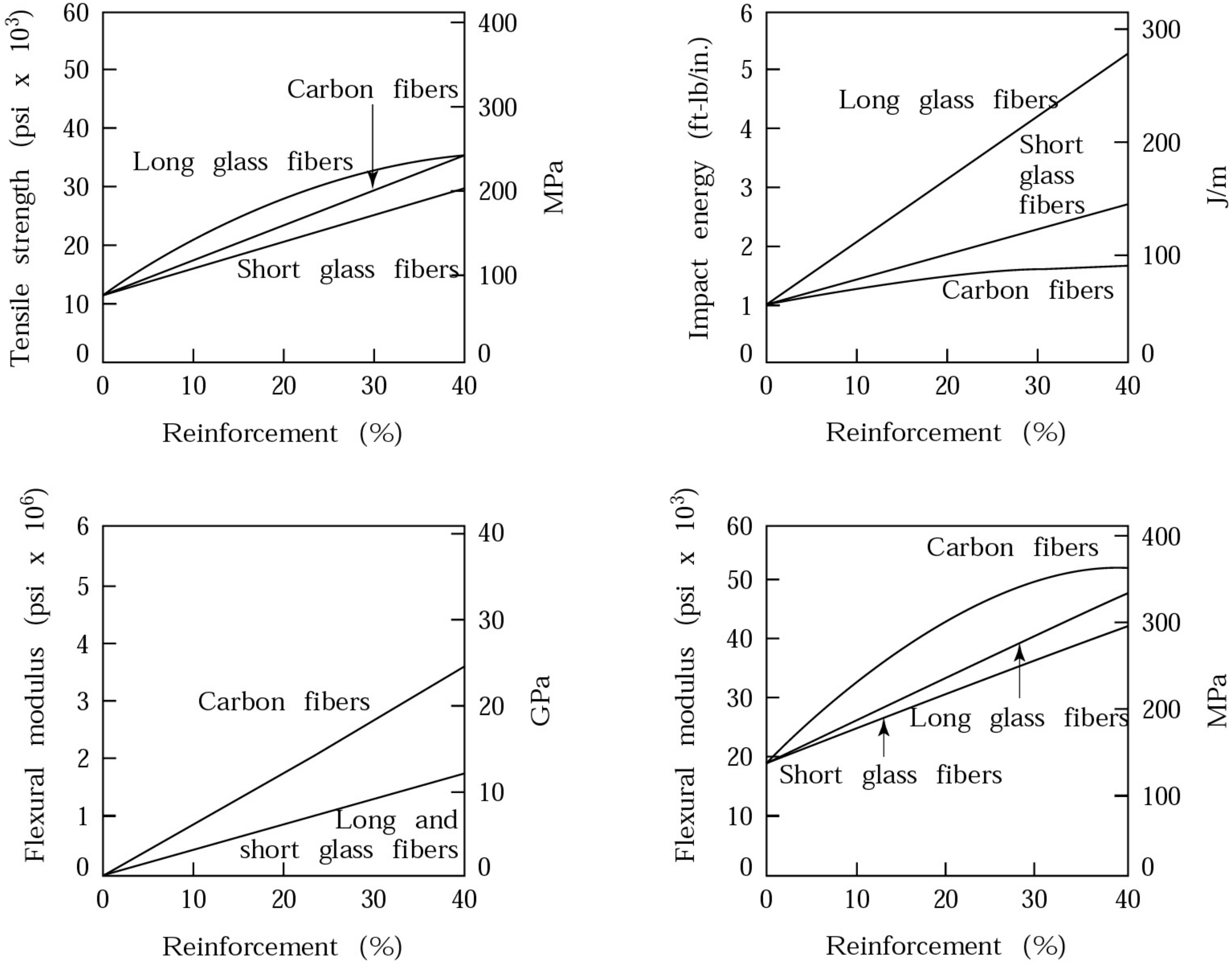
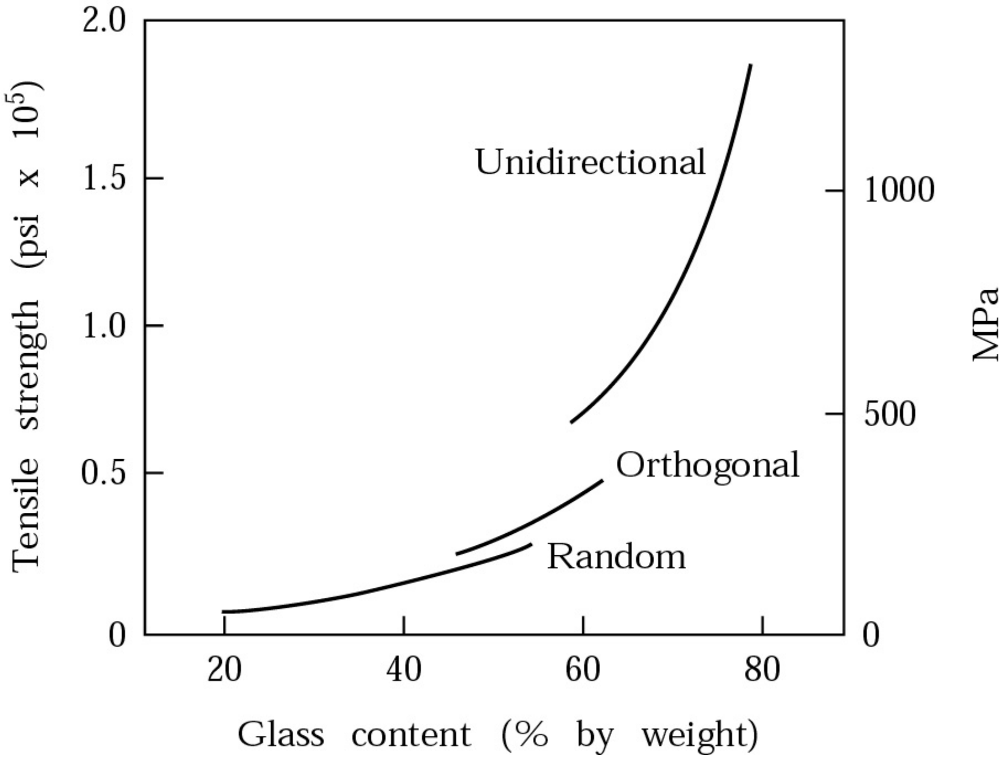


Figure 9.5 The effect of type of fiber on various properties of fiber-reinforced nylon (6,6). *Source*: NASA.

Tensile Strength of Glass-Reinforced Polyester

Figure 9.7 The tensile strength of glass-reinforced polyester as a function of fiber content and fiber direction in the matrix. *Source*: R. M. Ogorkiewicz, *The Engineering Properties of Plastics*. Oxford: Oxford University Press, 1977.



Example of Advanced Materials Construction

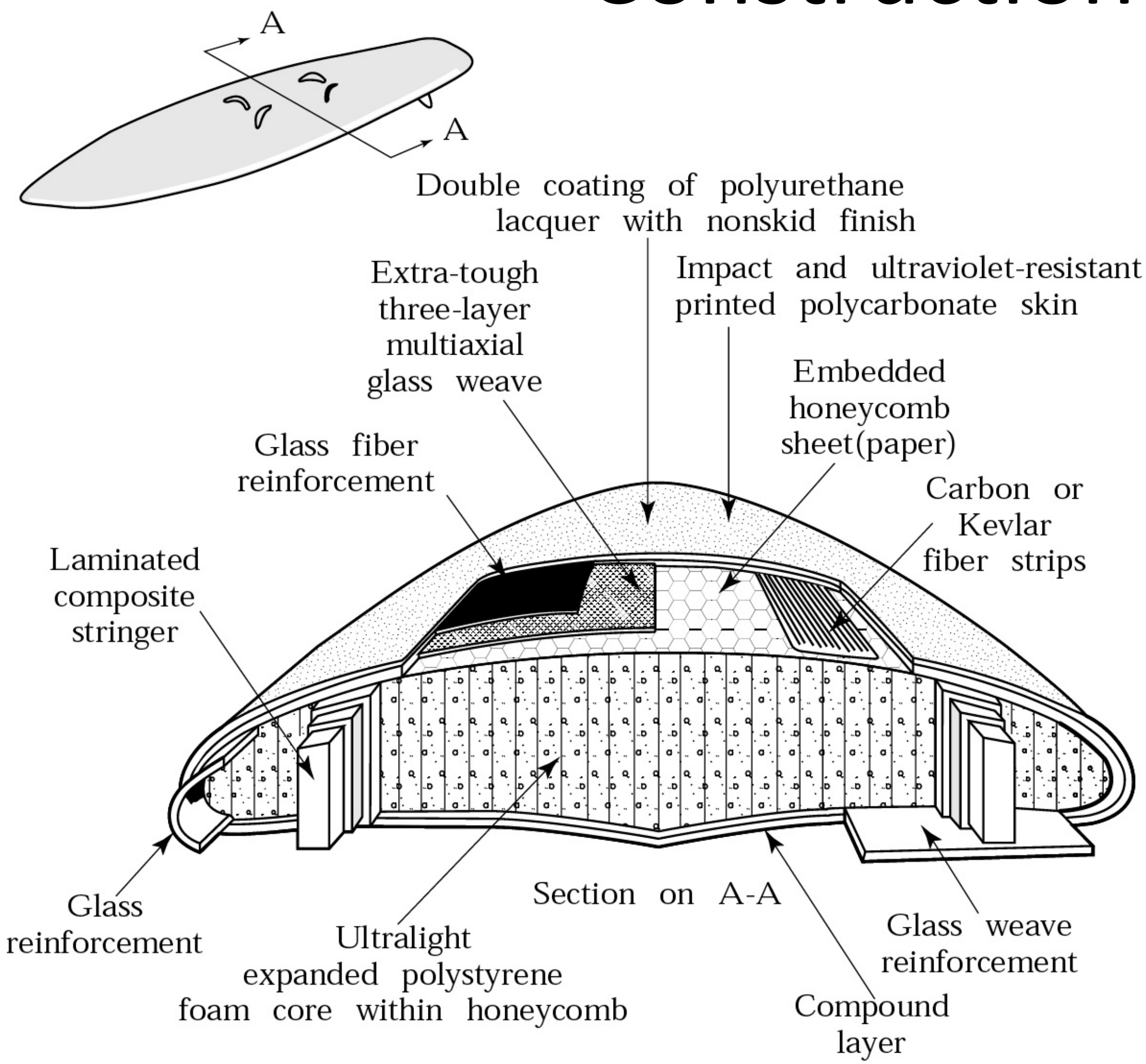


Figure 9.8 Cross-section of a composite sailboard, an example of advanced materials construction. *Source*: K. Easterling, *Tomorrow's Materials* (2d ed.), p. 133. Institute of Metals, 1990.

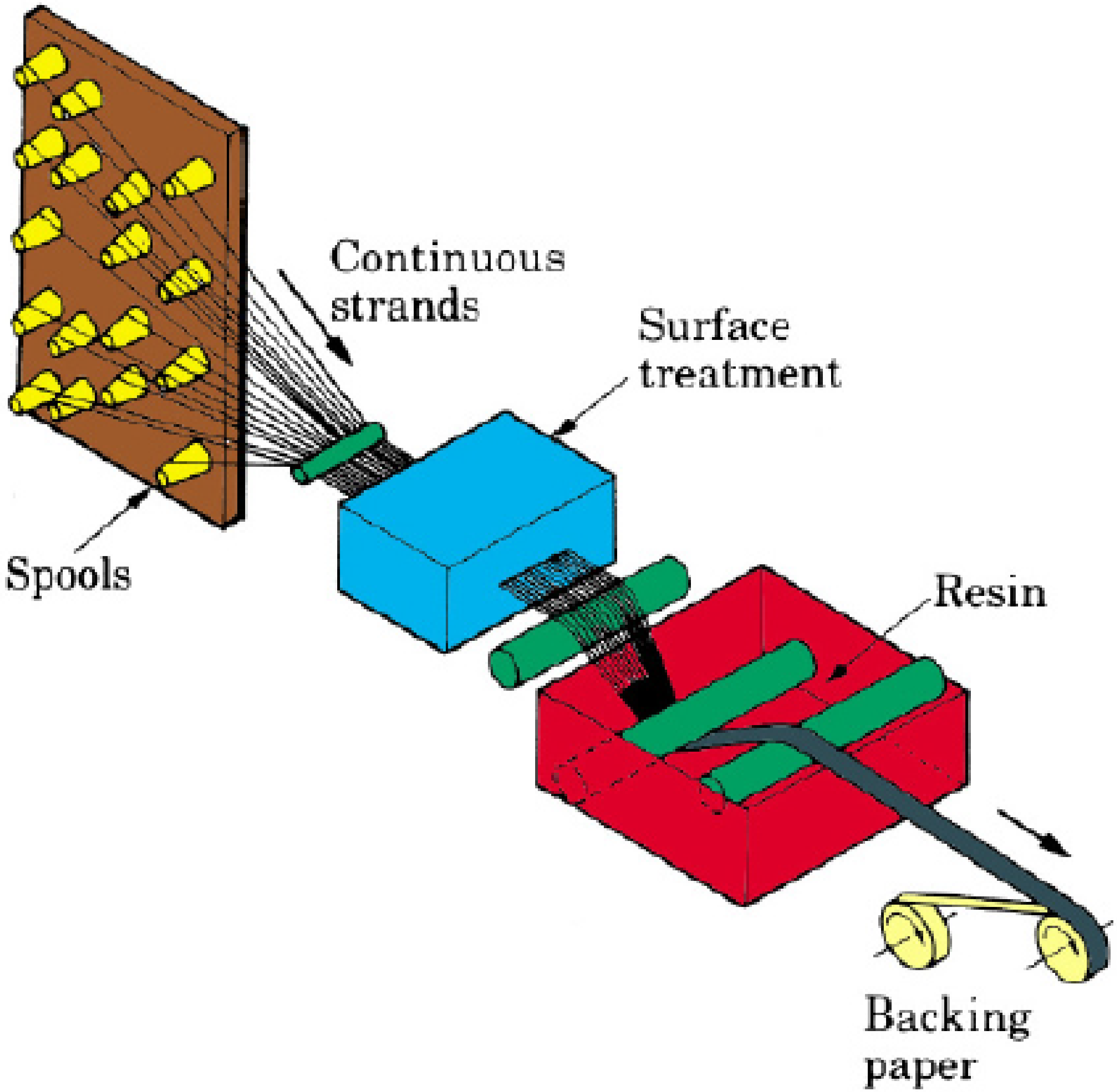
Metal-Matrix Composite Materials and Applications

TABLE 9.3

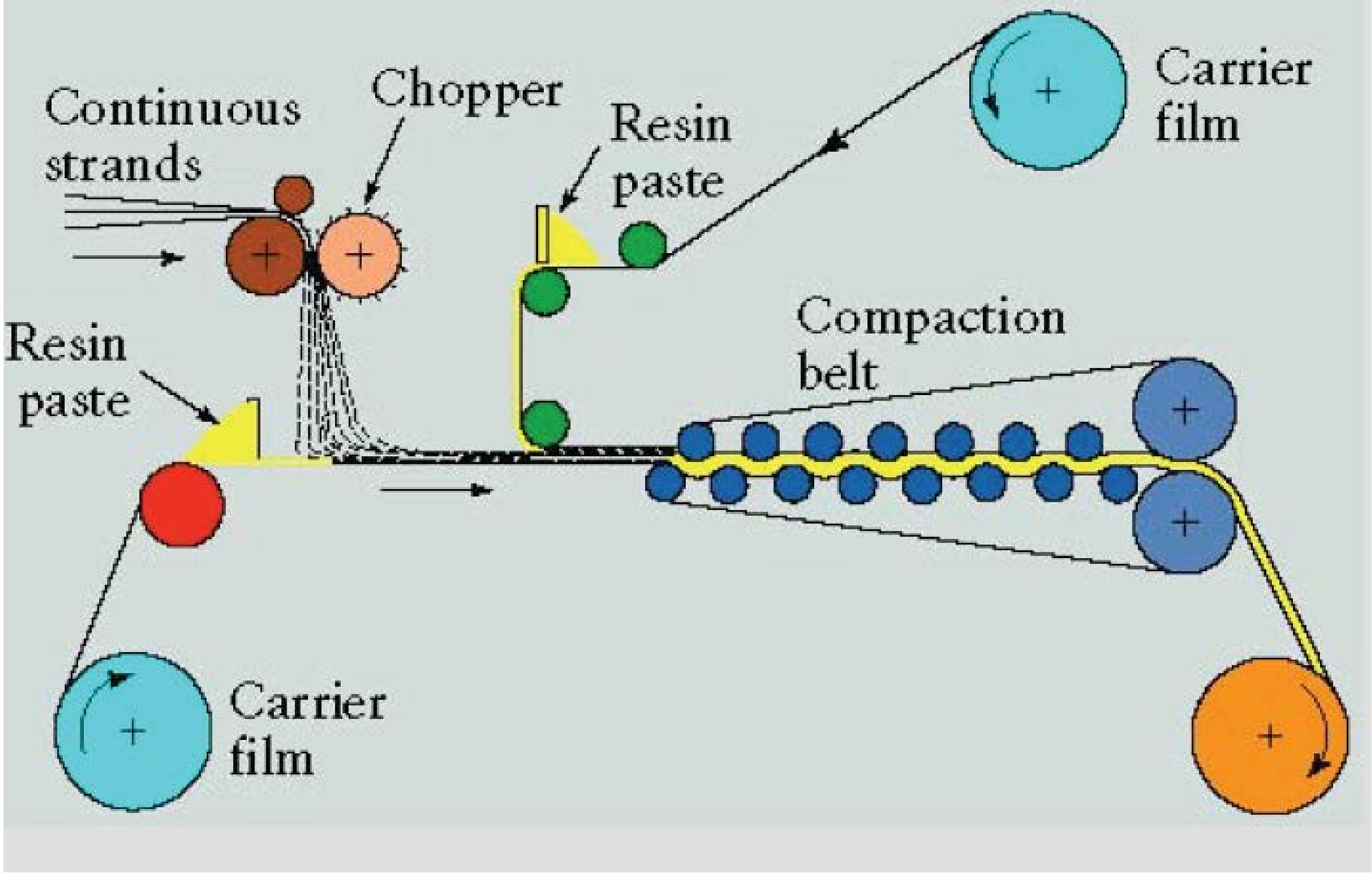
Fiber	Matrix	Applications
Graphite	Aluminum	Satellite, missile, and helicopter structures
	Magnesium	Space and satellite structures
	Lead	Storage-battery plates
	Copper	Electrical contacts and bearings
Boron	Aluminum	Compressor blades and structural supports
	Magnesium	Antenna structures
	Titanium	Jet-engine fan blades
Alumina	Aluminum	Superconductor restraints in fission power reactors
	Lead	Storage-battery plates
	Magnesium	Helicopter transmission structures
Silicon carbide	Aluminum, titanium	High-temperature structures
	Superalloy (cobalt-base)	High-temperature engine components
Molybdenum, tungsten	Superalloy	High-temperature engine components

Processes

- Hand layup
- Vacuum bagging/autoclave
- Compression molding
  - SMC/BMC
- Liquid resin molding
- Resin transfer molding
- Pultrusion
- Filament winding
- Injection molding
- Thermoplastics processing
- Automated tape laying


Continuous
strands
Surface
treatment
Spools
Resin
Backing
paper

Sheet Prepreg



Bag Forming

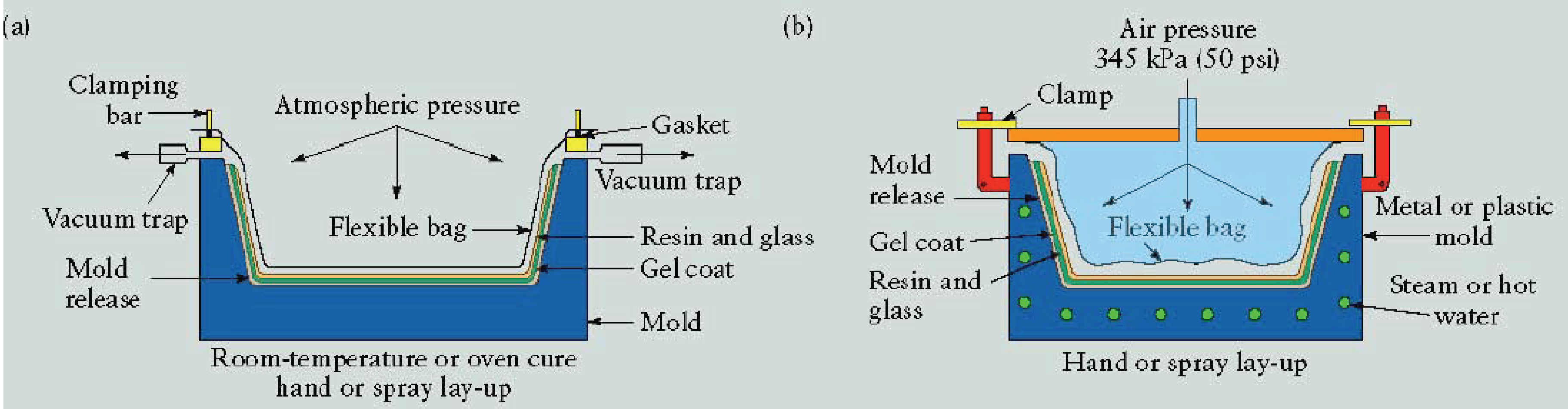


FIGURE 10.36 (a) Vacuum-bag forming. (b) Pressure-bag forming. *Source*: T.H. Meister.

Hand Lay-up and Spray-up

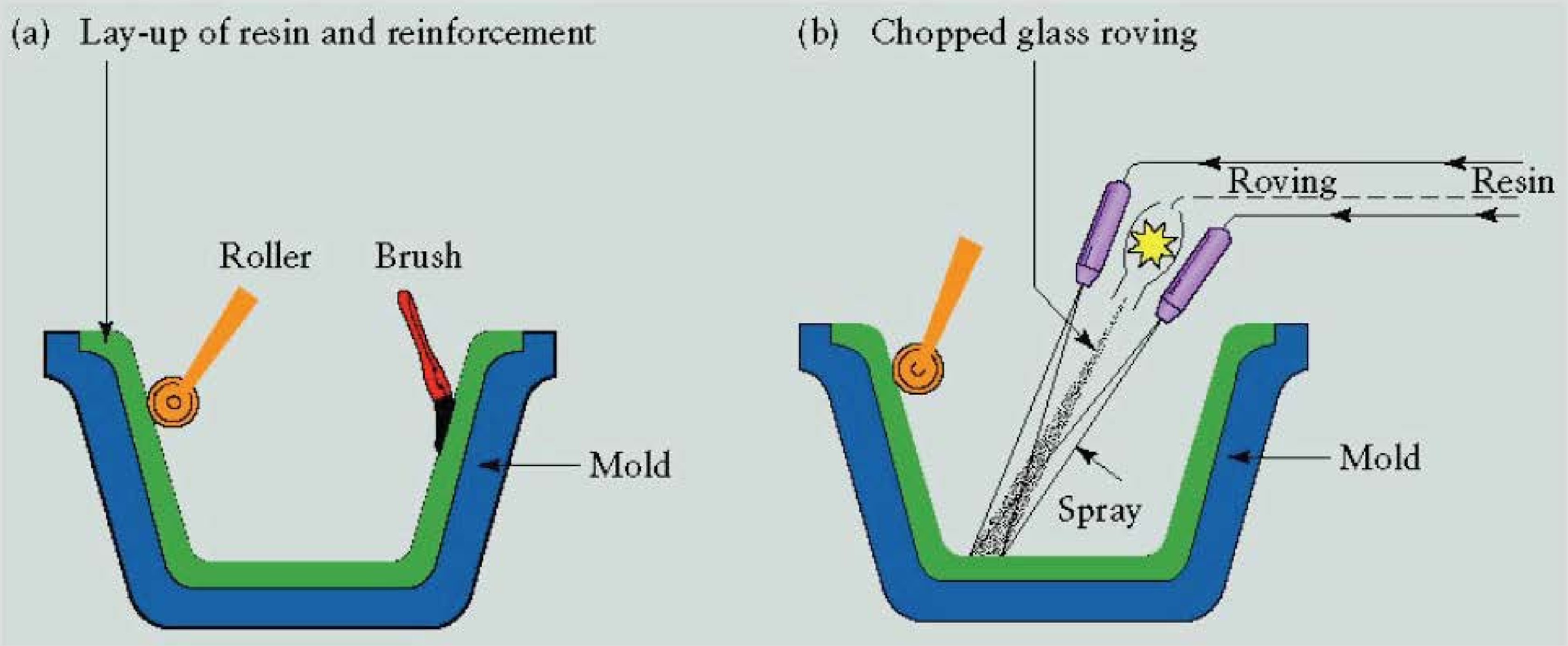
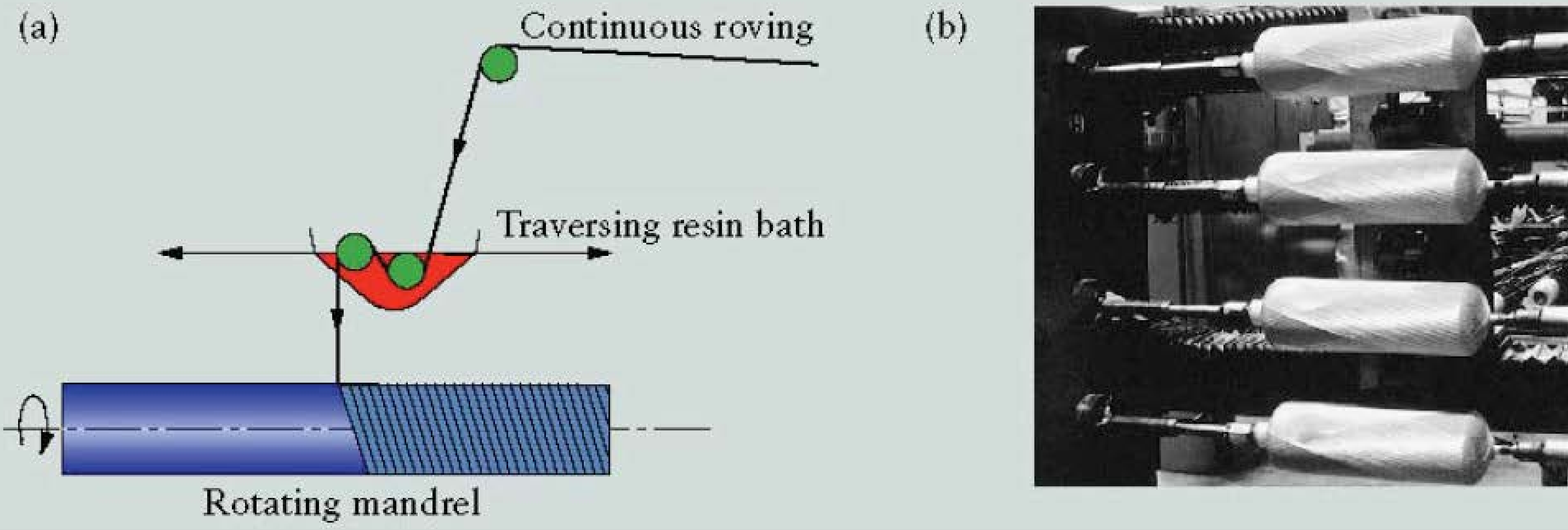
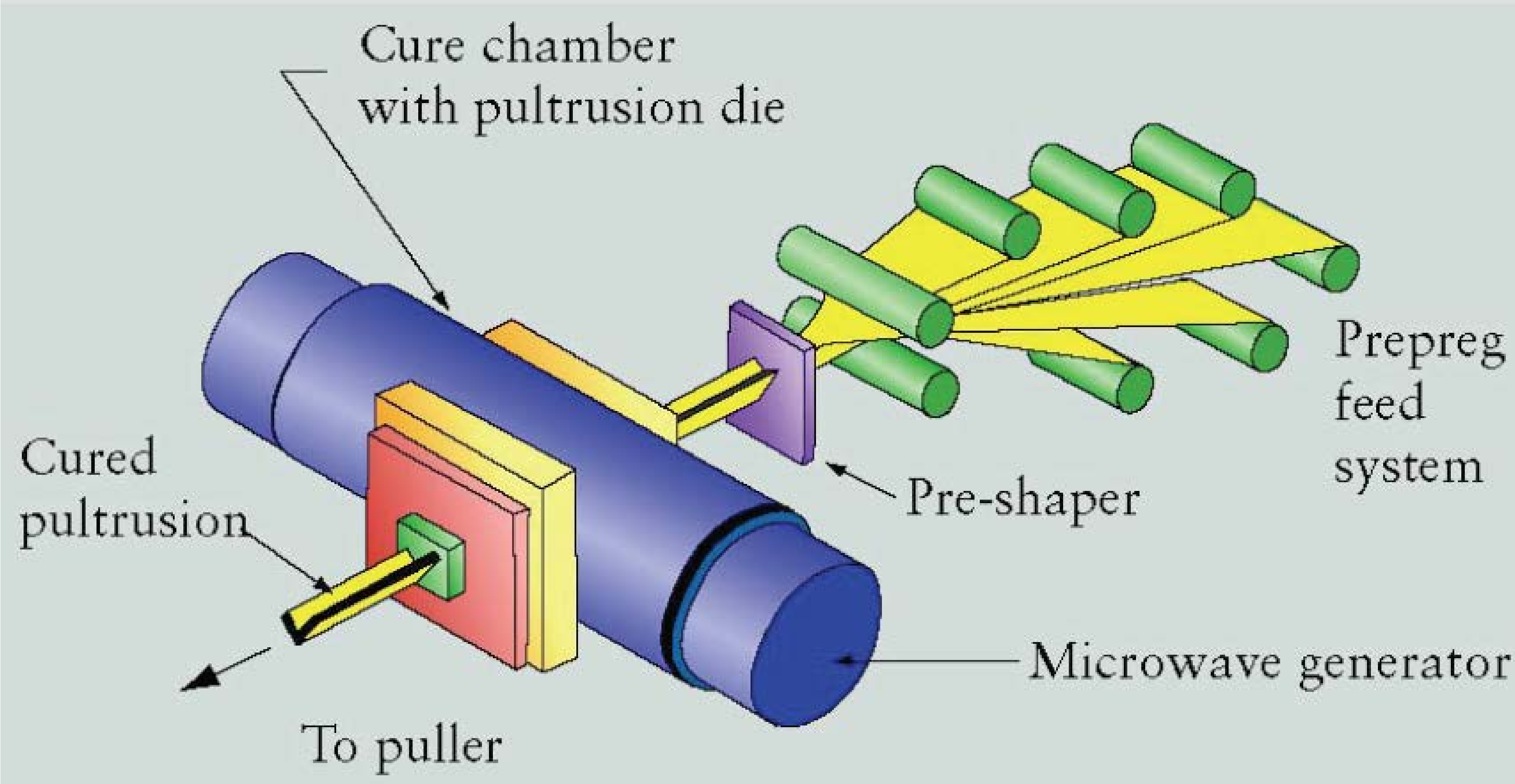


FIGURE 10.37 Manual methods of processing reinforced plastics: (a) hand lay-up and (b) spray-up. These methods are also called *open-mold processing*.


(a)
Continuous roving
Traversing resin bath
Rotating mandrel
(b)

Pultrusion


Cure chamber
with pultrusion die
Prepreg
feed
system
Cured
pultrusion
Pre-shaper
Microwave generator
To puller