

Compósitos

Prof. Vera Lúcia Arantes

FIGHTER AIRCRAFT MATERIALS

Utilization Of High Cost Airframe Materials Has Been Increasing To Improve Aircraft Performance

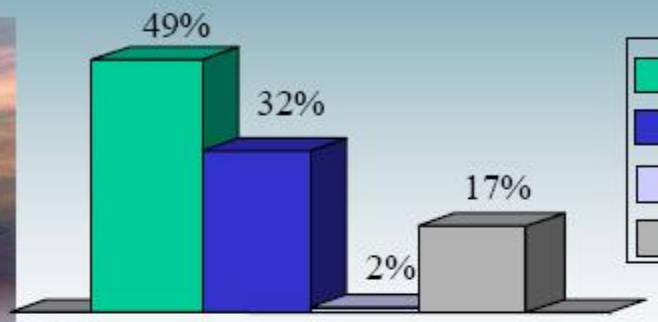
1987

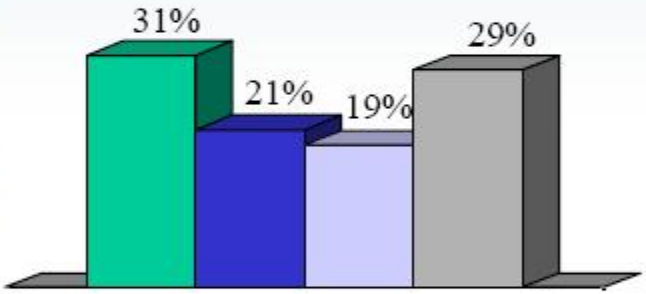
present

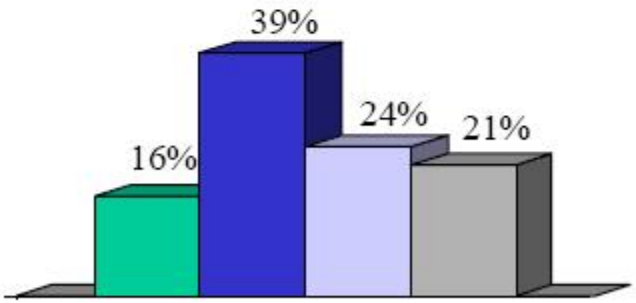






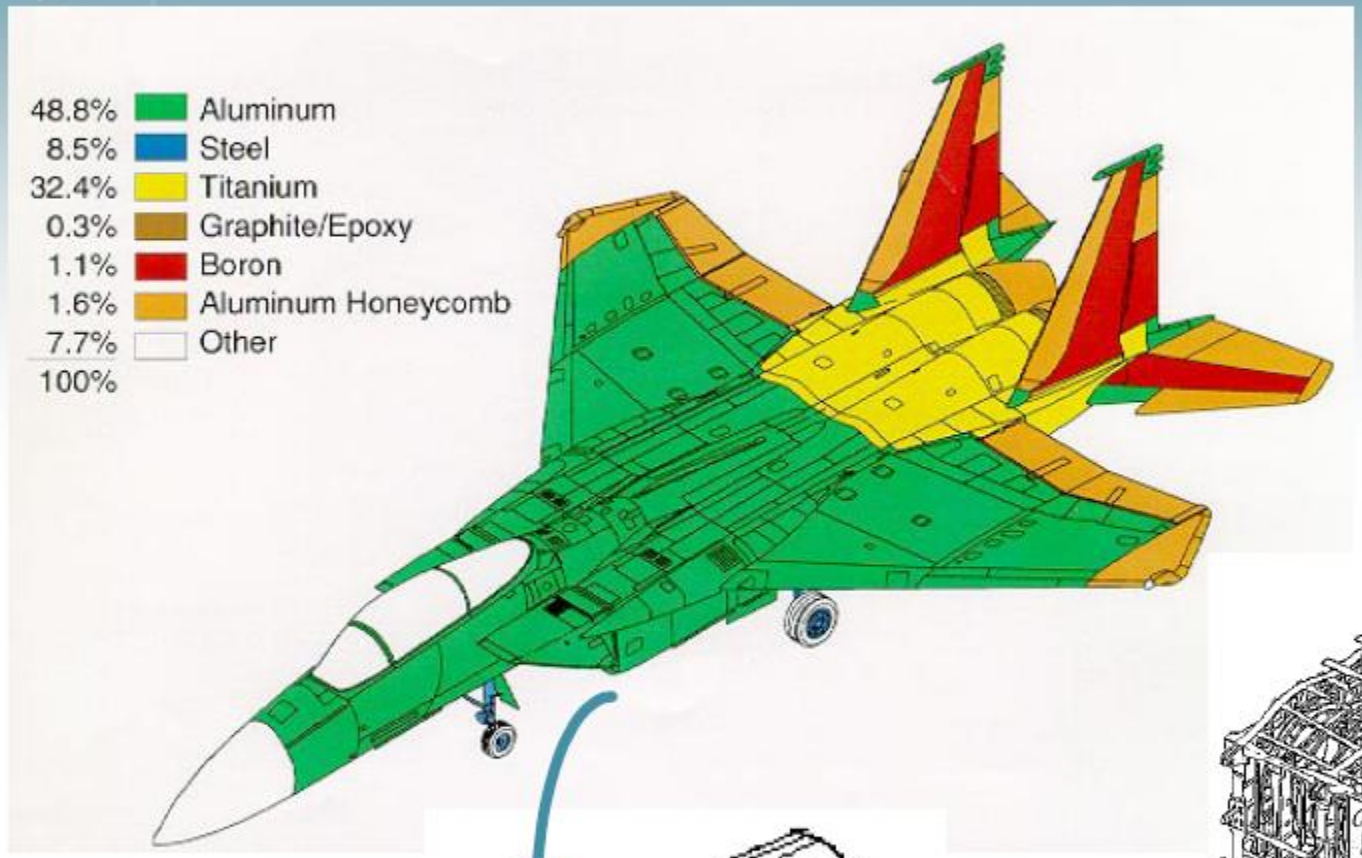




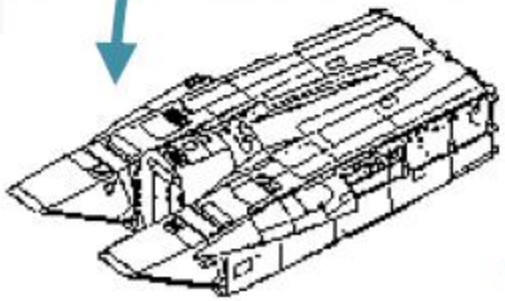


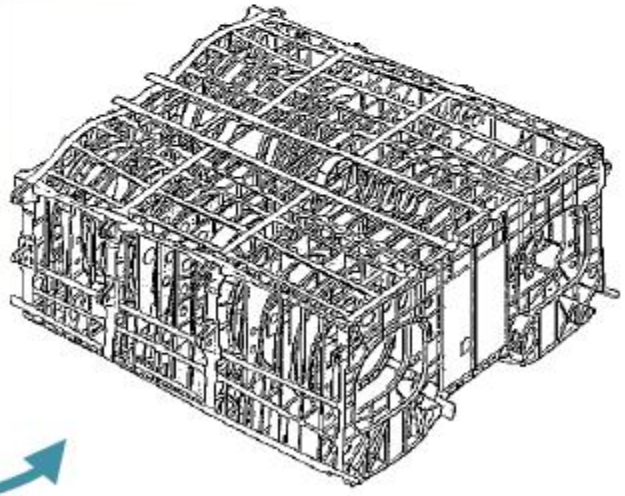
Affordability Is Now Being Emphasized When Selecting Airframe Materials

F-15 SKIN/STRINGER CONSTRUCTION



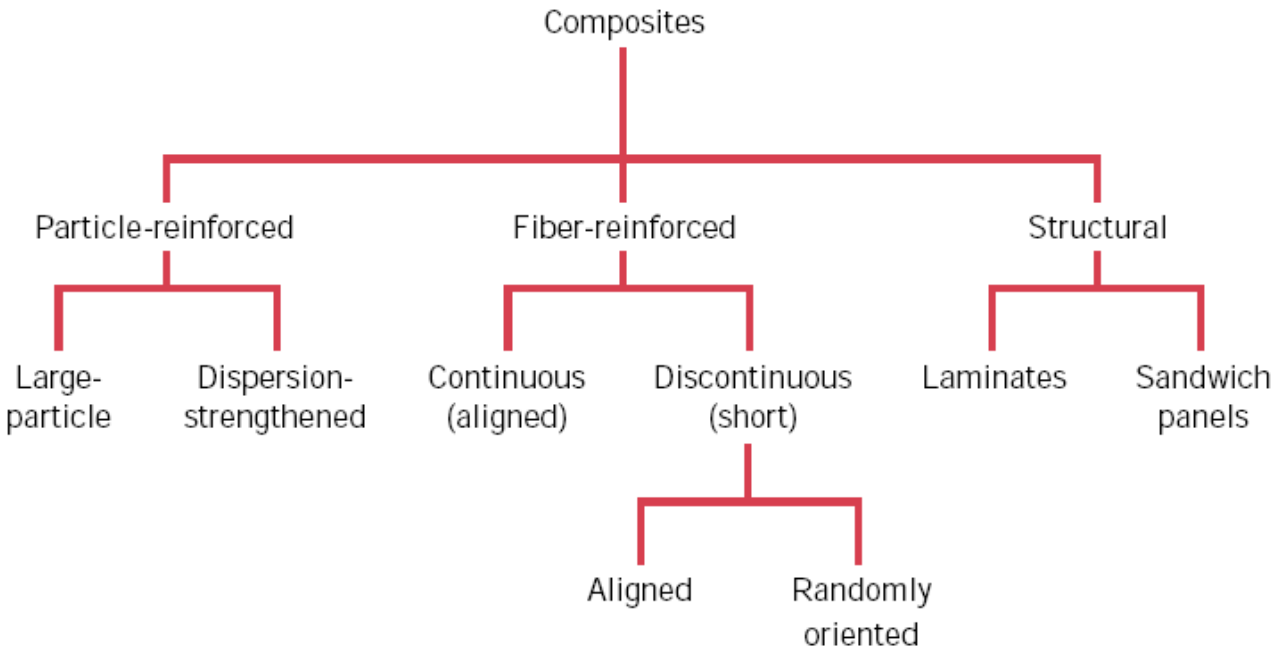
Advanced Metallic Materials With Greater Structural Efficiency, And Processes That Produce Complex Unitized Components *Improve Affordability*





MCMS Collaboration that works.

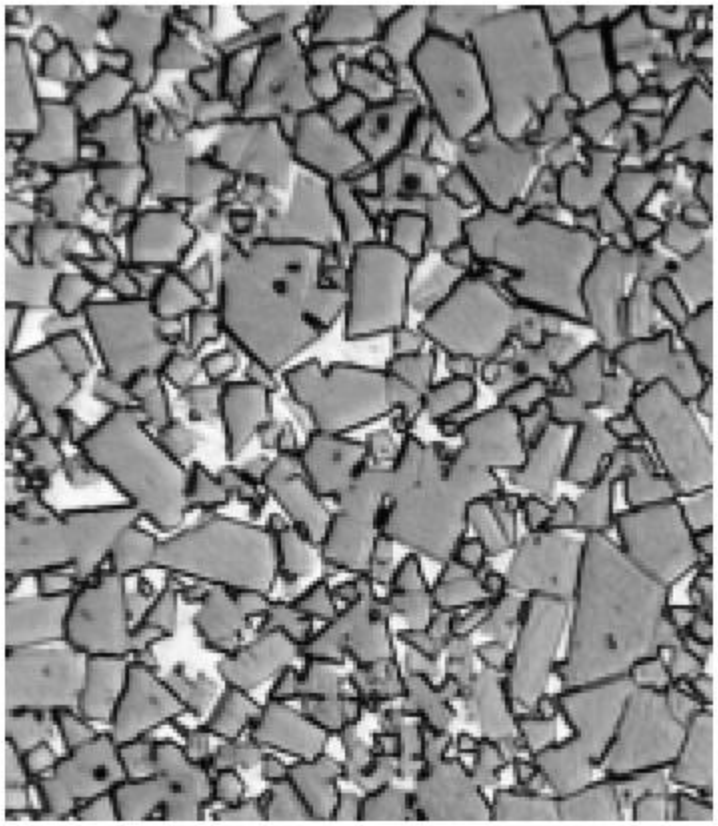
Classificação



Compósitos com Partículas Grandes

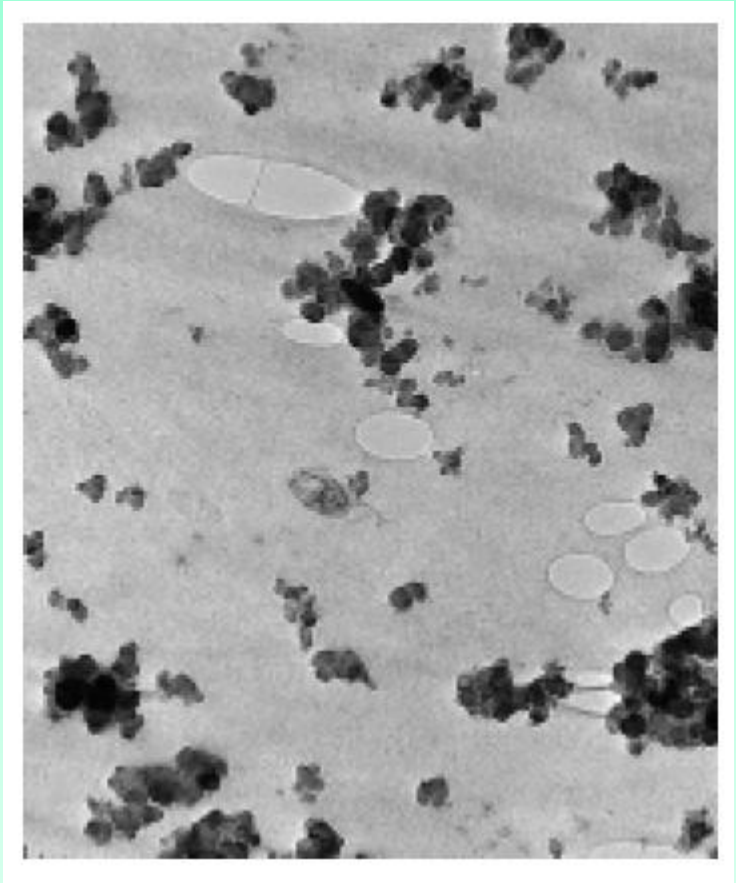
- O termo “grande” é usado para indicar que as interações partícula-matriz não podem ser tratadas em nível atômico ou molecular e sim pela mecânica do contínuo.
- Essencialmente, a matriz transfere parte da tensão aplicada às partículas, as quais suportam uma fração da carga.
- O grau de reforço depende de uma ligação forte na interface matriz-partícula.

Exemplos



Carbeto cimentado WC-Co

Exemplos



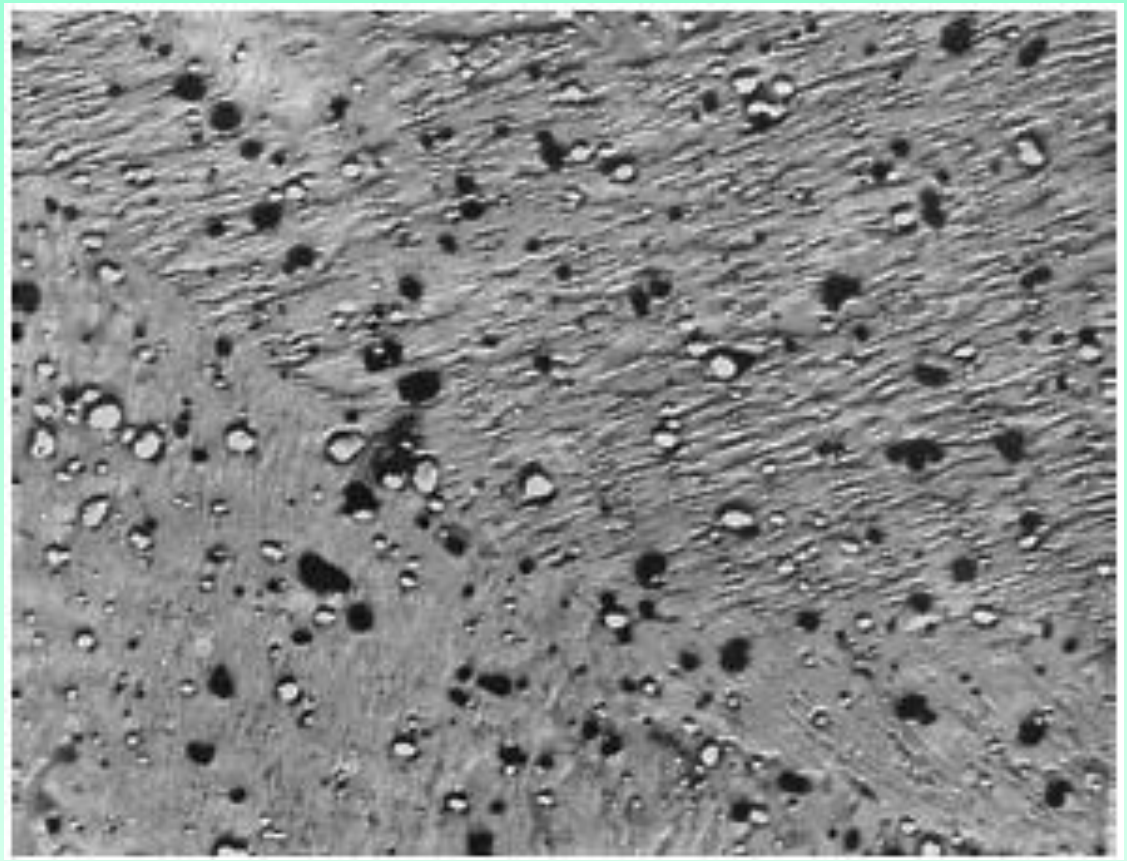
Borracha com Negro de fumo

Compósitos Reforçados por Dispersão

- Grupo especial de nanocompósitos reforçados por dispersão de partículas de 10 a 250nm de diâmetro é classificado como **compósitos reforçados por partículas**.

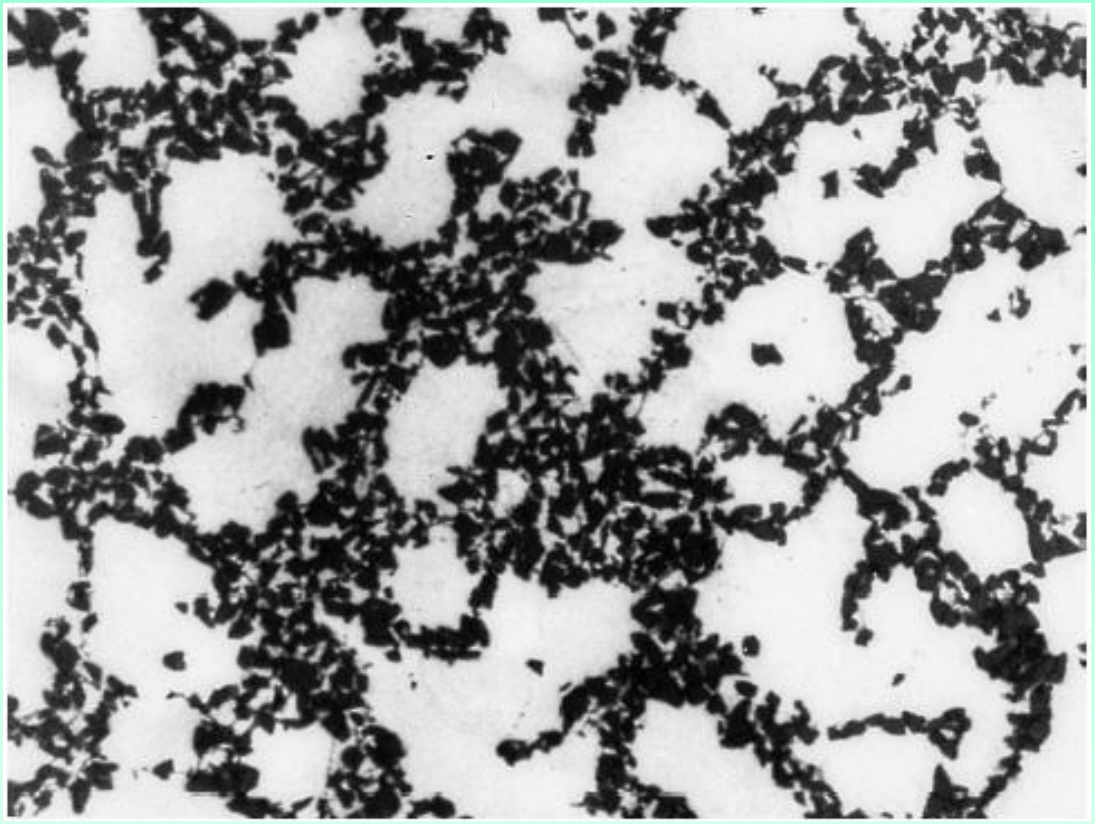
- **Fase dispersa:** partículas finas de óxidos ou cerâmicas covalentes formadas em uma matrix metálica. Elas interferem com o movimento de discordâncias aumentando a resitência mecânica, até a elavadas temperaturas.

Exemplos



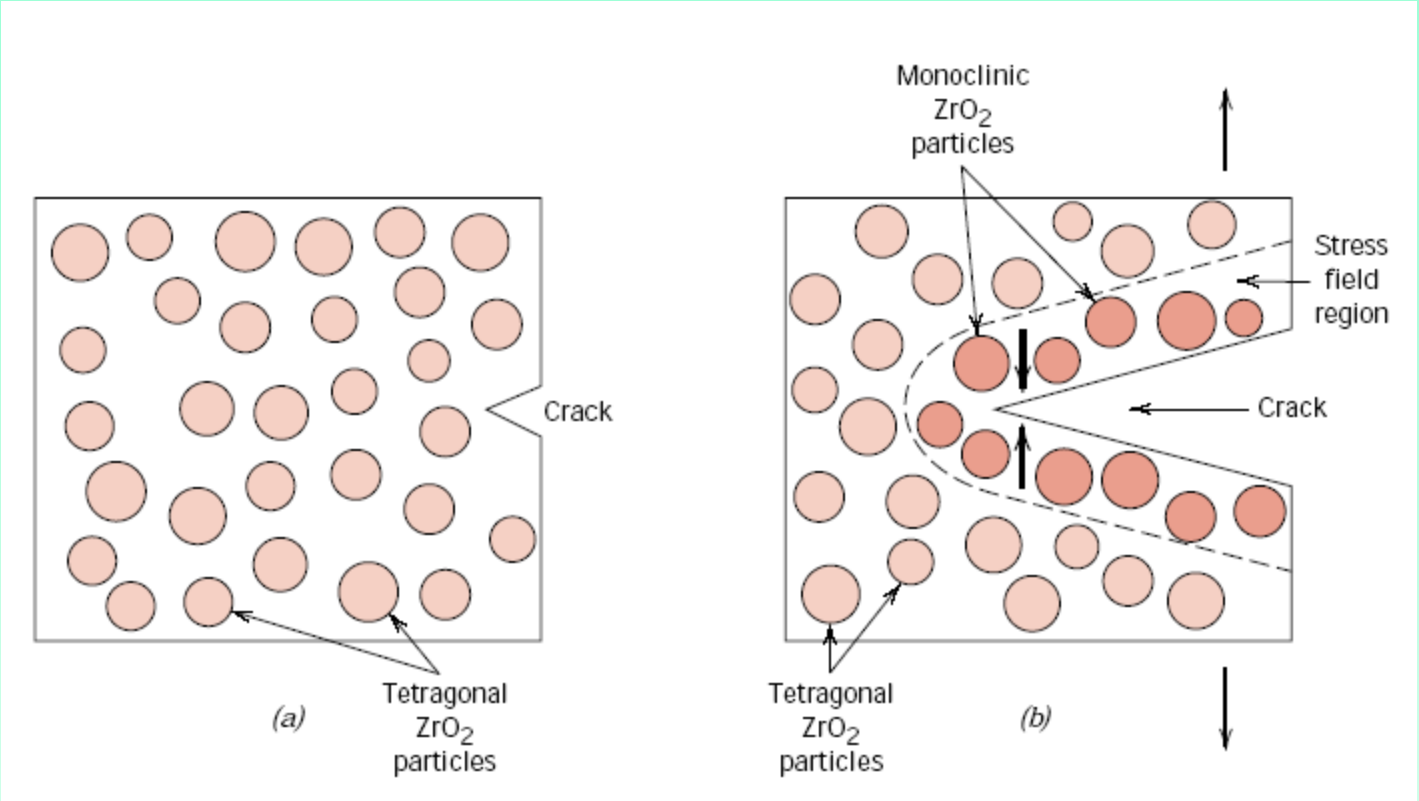
Ni-ThO

Exemplos

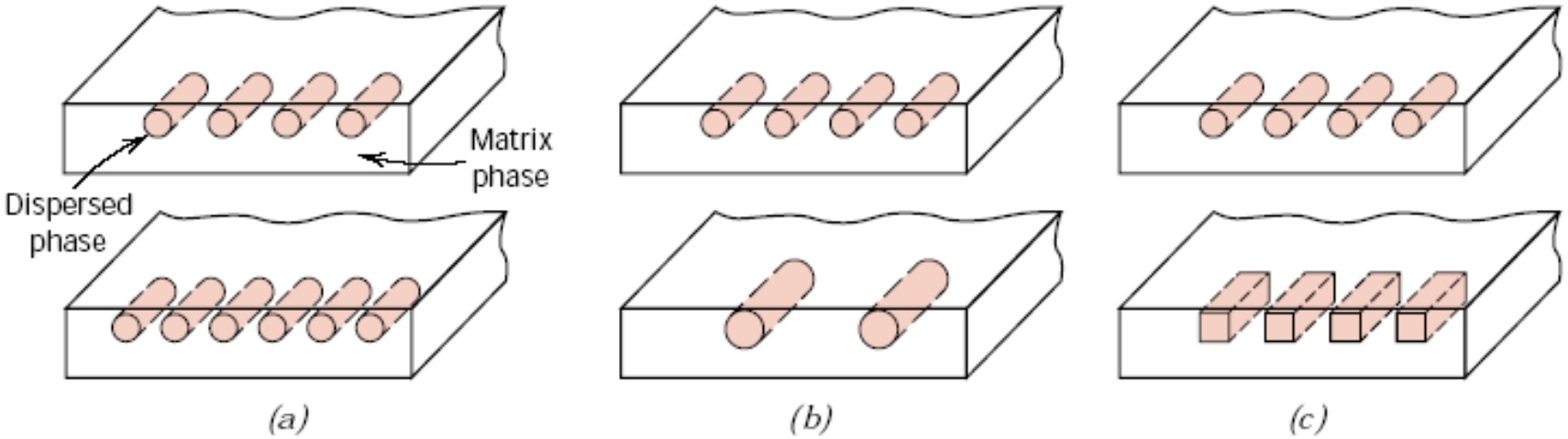


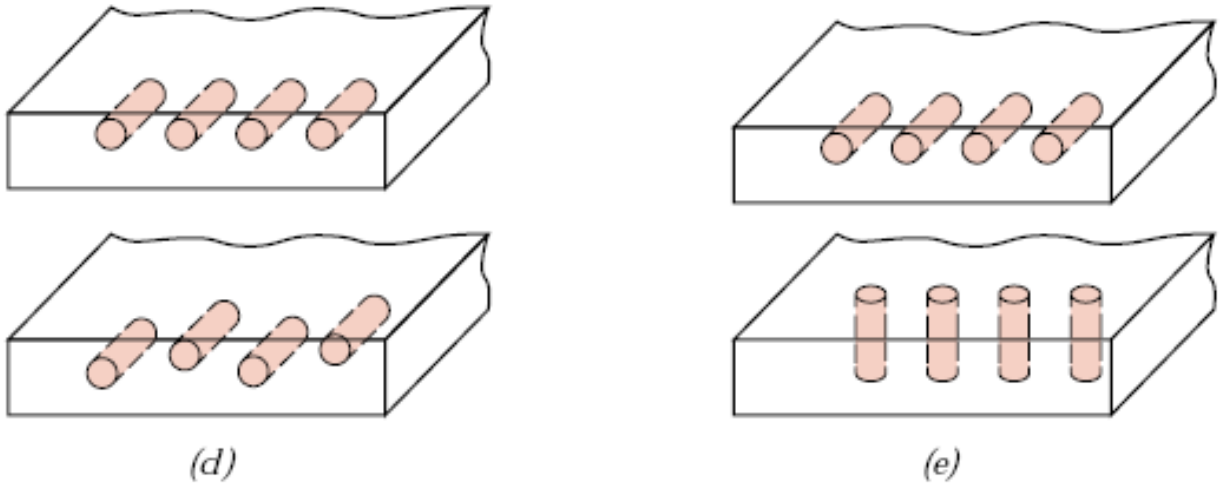
Al-SiC

Tenacificação com Partículas de Zircônia



Geometria, Orientação e Distribuição





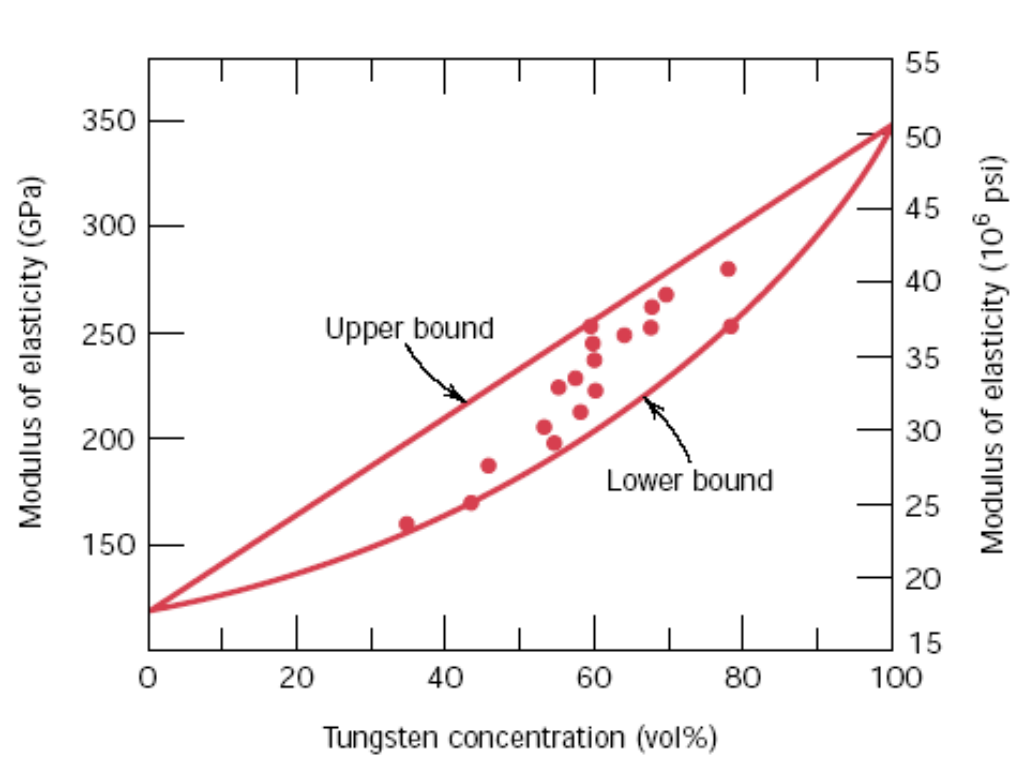
Reforço com Partículas

Regra das misturas

$$E_C(s) = E_m V_m + E_p V_p$$

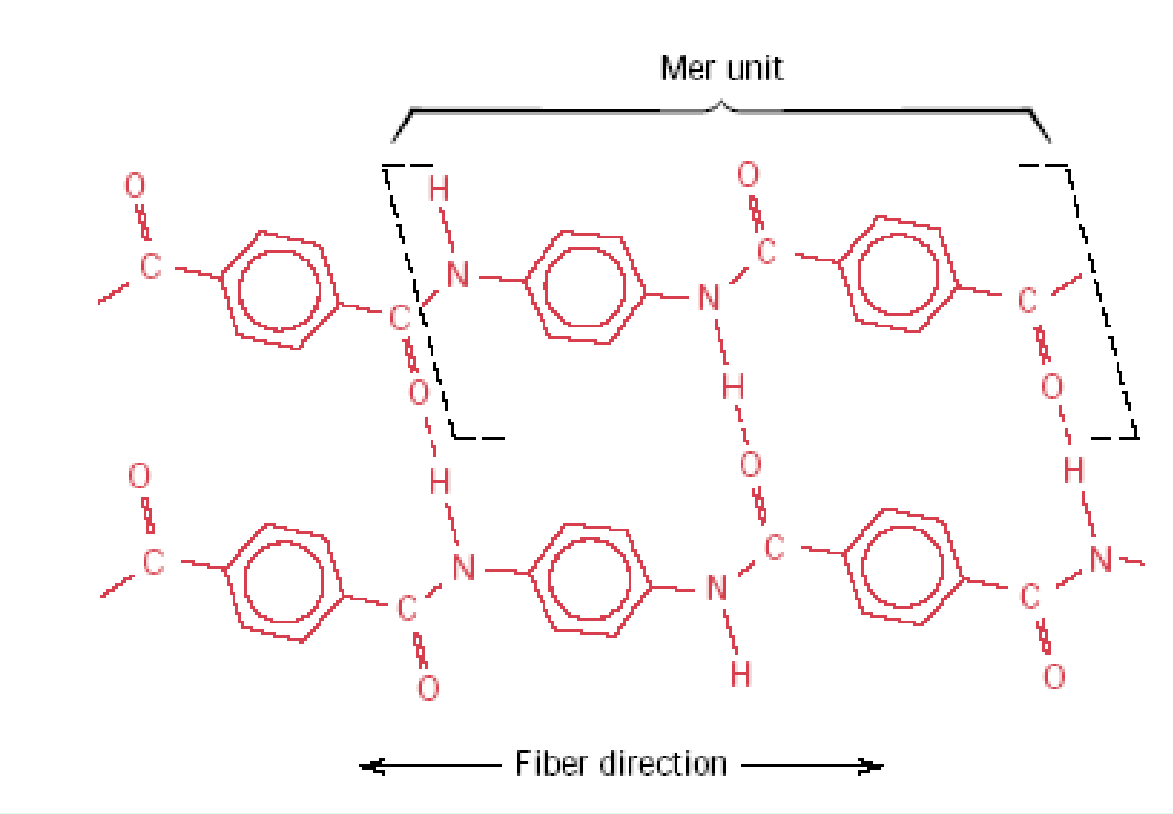
$$E_C(i) = \frac{E_m E_p}{V_m E_p + V_p E_m}$$

Módulo de Elasticidade



Compósitos Reforçados com Fibras

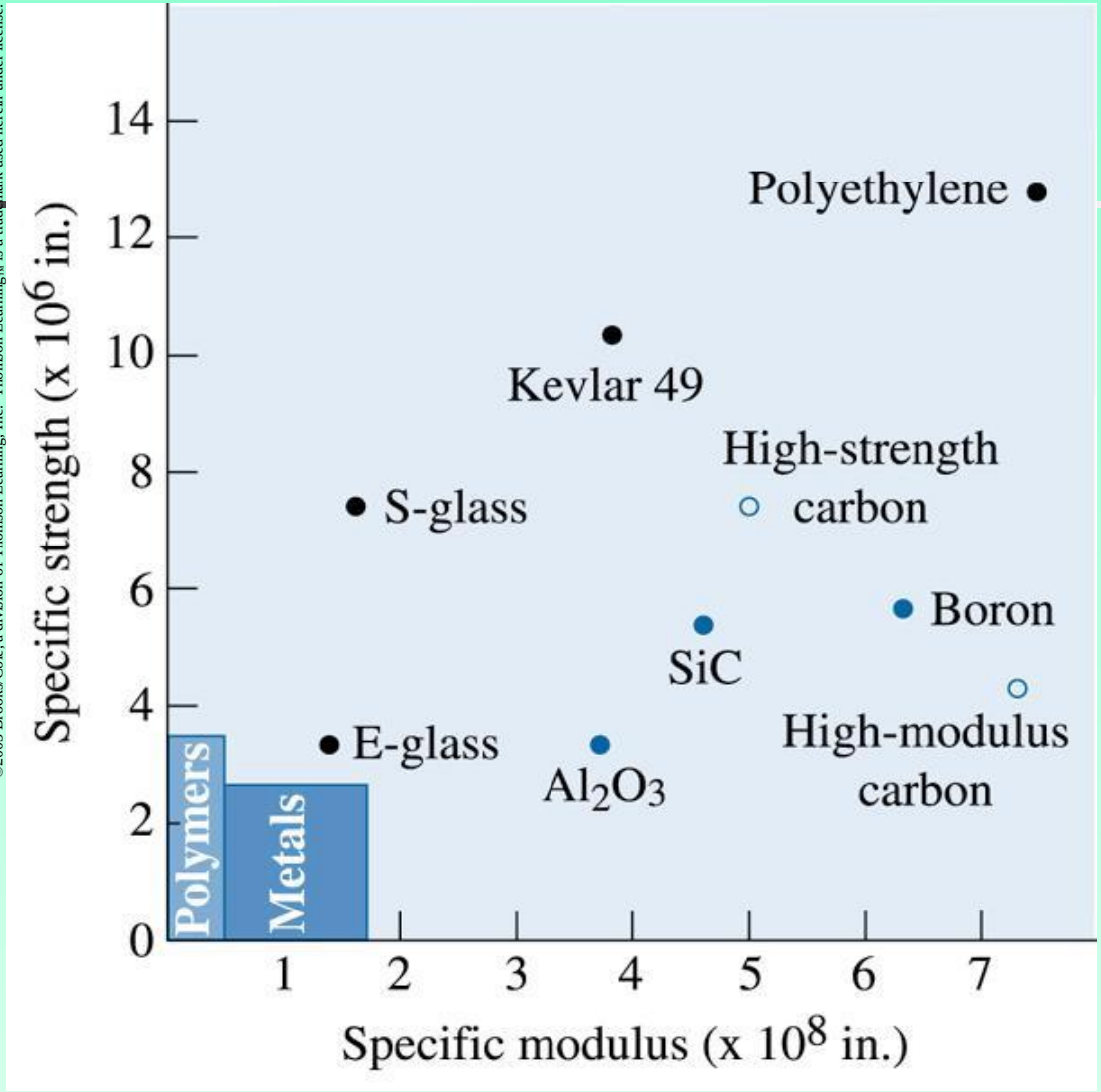
Por que usar fibras?



Aramida (Kevlar)

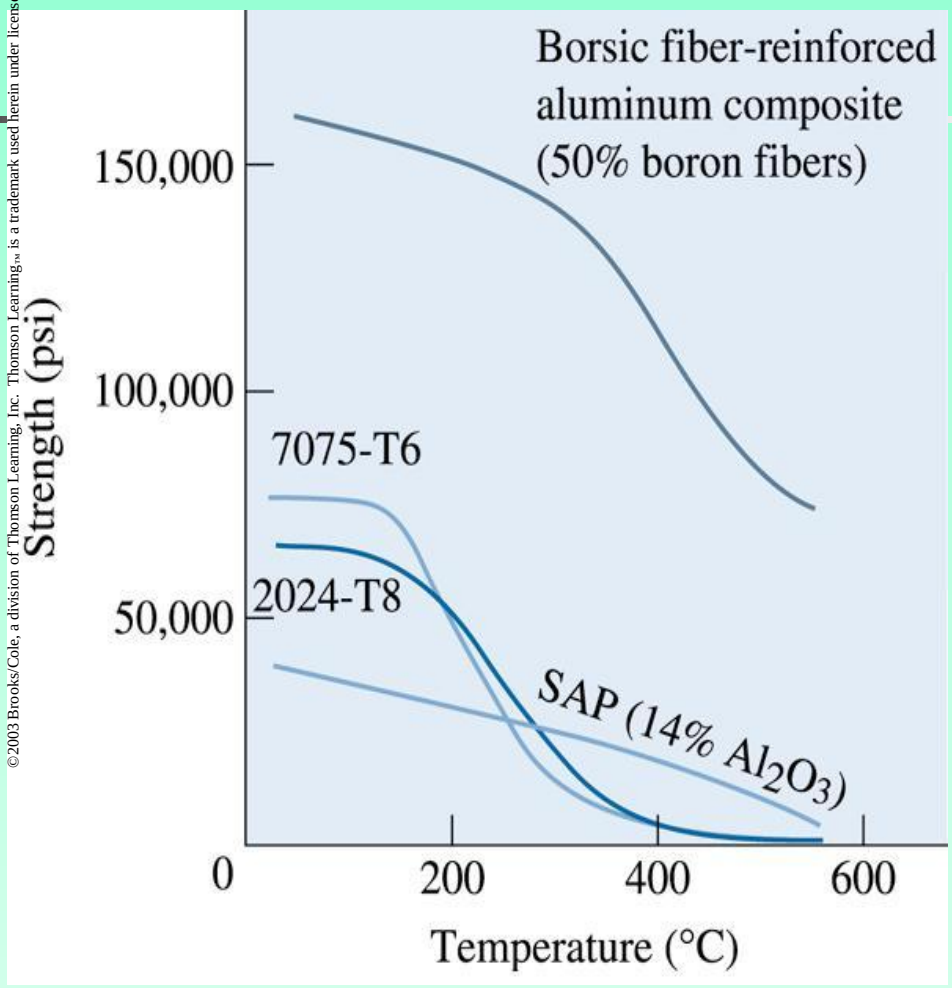
Propriedades Mecânicas das Fibras

©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.



Valores de resistência específica e módulo elástico para vários materiais

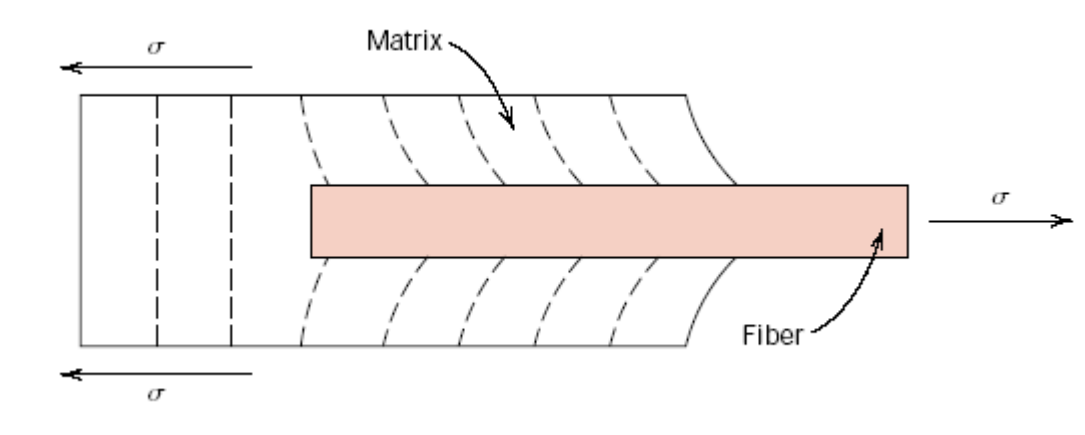
Fibras X Partículas



©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

Tensão de escoamento X Temperatura para ligas de alumínio, compósitos reforçados com partículas e reforçados com fibras

Compósitos Reforçados com Fibras

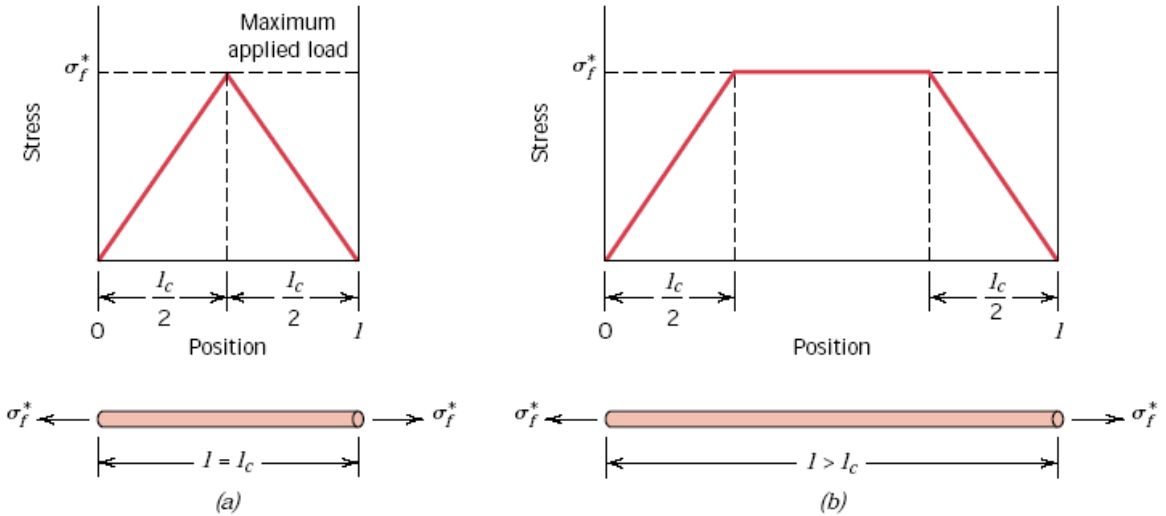


$$l_c = \frac{\sigma_f d}{2\tau_c}$$

Comprimento crítico da fibra

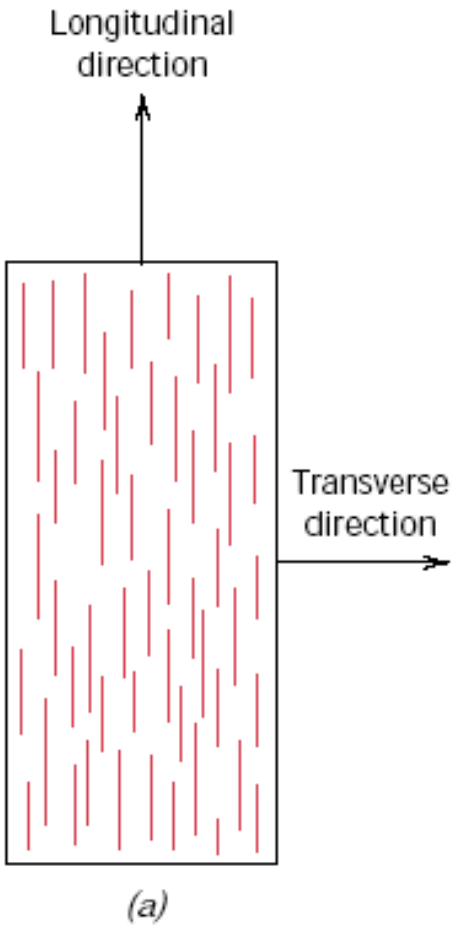
$l >> l_c$, fibras contínuas (normalmente $l > 15 l_c$)

Influência do Comprimento

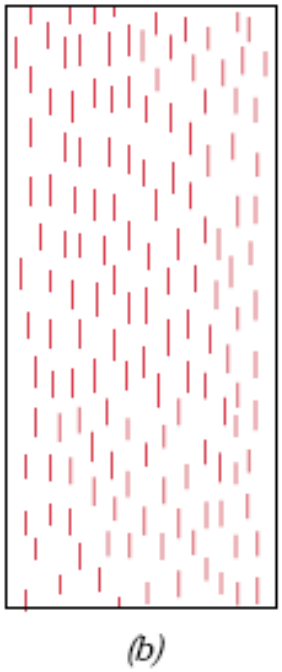


Perfis de tensão em função da posição axial na fibra

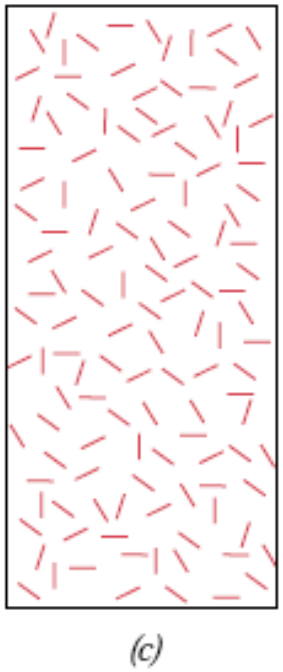
Orientação



Contínuas e alinhadas

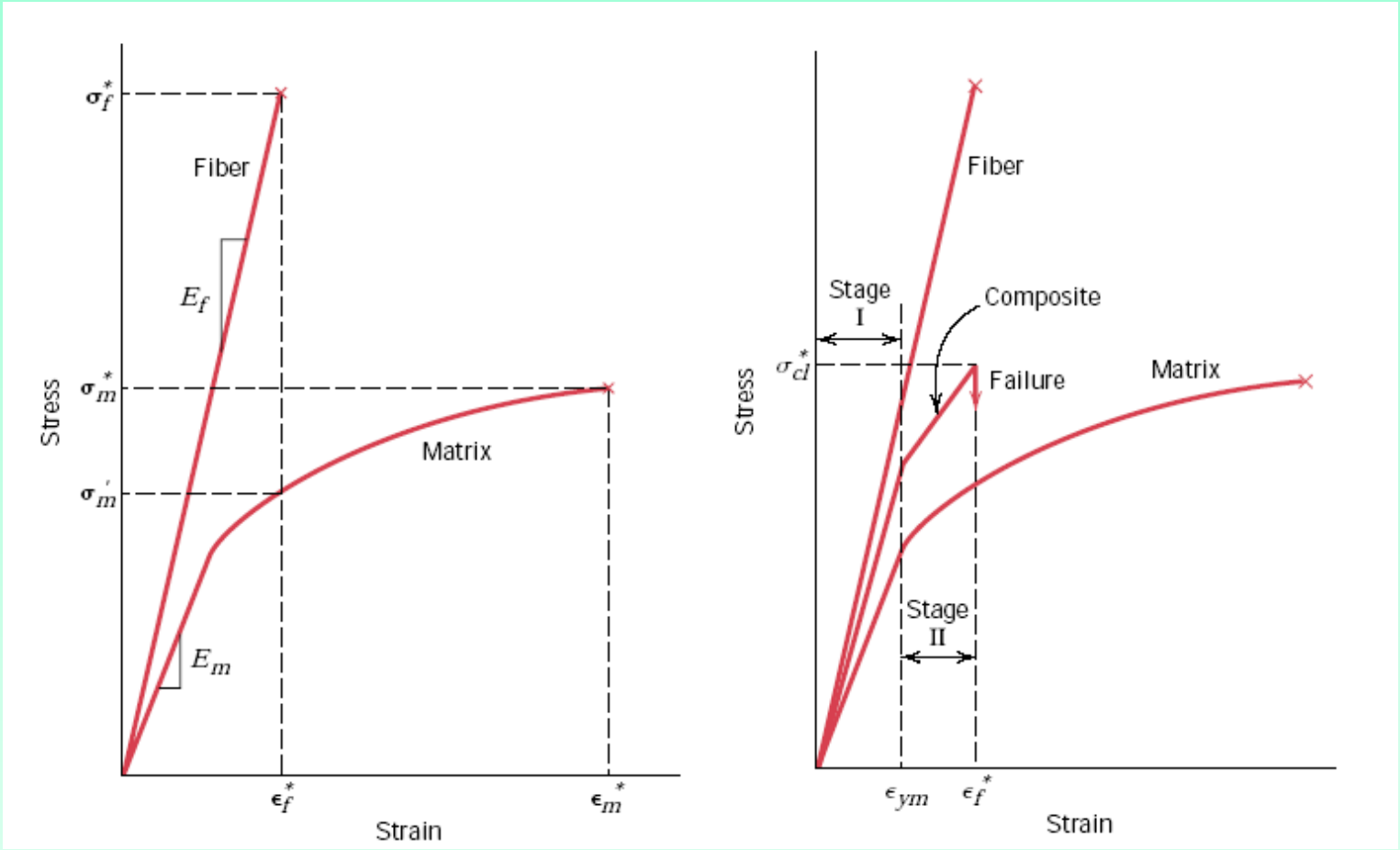


Descontínuas e alinhadas



Descontínuas e aleatórias

Fibras alinhadas



Fibras contínuas e orientadas

Na direção longitudinal:

- Assume-se deformação igual para fibra e matriz:

$$\varepsilon_c = \varepsilon_m = \varepsilon_f$$

Na direção transversal:

- Assume-se tensão igual para fibra e matriz:

$$\sigma_c = \sigma_m = \sigma_f$$

Fibras contínuas orientadas

Direção Longitudinal

$$\sigma_c = \upsilon_f \sigma_f + \upsilon_m \sigma_m$$

$$E_c = E_m \upsilon_m + E_f \upsilon_f$$

$$\frac{F_f}{F_m} = \frac{E_f \upsilon_f}{E_m \upsilon_m}$$

Razão entre as cargas suportadas pela fibra e pela matriz

Direção Transversal

$$\frac{1}{E_c} = \frac{\upsilon_f}{E_f} + \frac{\upsilon_m}{E_m}$$

Fibras descontínuas e alinhadas

Direção Longitudinal

para $l > l_c$:

$$\sigma_c^* = \sigma_f^{*\tau_c} \upsilon_f \left(1 - \frac{l_c}{2l}\right) + \sigma_m^{'} \upsilon_m$$

para $l < l_c$:

$$\sigma_c^* = \frac{l\tau_c}{d} \upsilon_f + \sigma_m^{'} \upsilon_m$$

τ_c é o menor valor entre a resistência da interface matriz-fibra e limite de escoamento da matriz (cisalhamento)

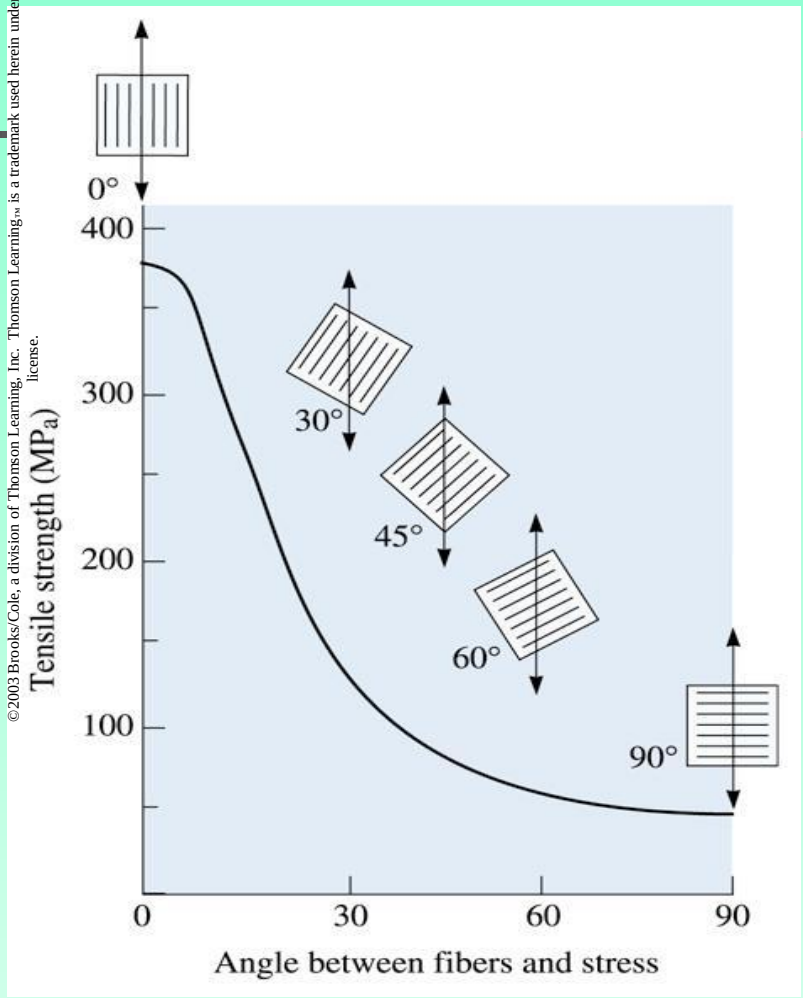
Fibras descontínuas e aleatoriamente distribuídas

$$E_c = E_m \upsilon_m + K.E_f \upsilon_f$$

Normalmente 0,1 < K < 0,6

K = fator de eficiência, depende de V_f e da razão E_f/E_m

Efeito da Orientação



©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

Influência da orientação da fibra sobre o compósito epóxi reforçado com fibra de vidro

Efeito da Orientação (Fator de Eficiência K)

Table 15.3 **Reinforcement Efficiency of Fiber-Reinforced Composites for Several Fiber Orientations and at Various Directions of Stress Application**

Fiber Orientation	*Stress Direction*	*Reinforcement Efficiency*
All fibers parallel	Parallel to fibers	1
	Perpendicular to fibers	0
Fibers randomly and uniformly distributed within a specific plane	Any direction in the plane of the fibers	$\frac{3}{8}$
Fibers randomly and uniformly distributed within three dimensions in space	Any direction	$\frac{1}{5}$

Source: H. Krenchel, *Fibre Reinforcement,* Copenhagen: Akademisk Forlag, 1964 [33].

Anisotropia dos Compósitos com Fibras Unidirecionais

Table 15.1 Typical Longitudinal and Transverse Tensile Strengths for Three Unidirectional Fiber-Reinforced Composites. The Fiber Content for Each is Approximately 50 Vol%

Material	*Longitudinal Tensile Strength (MPa)*	*Transverse Tensile Strength (MPa)*
Glass–Polyester	700	20
Carbon (High Modulus)–Epoxy	1000	35
Kevlar–Epoxy	1200	20

Source: D. Hull and T. W. Clyne, *An Introduction to Composite Materials,* 2nd edition, Cambridge University Press, 1996, p. 179.

Efeito da Fração Volumétrica de Reforço

Table 15.2 Properties of Unreinforced and Reinforced Polycarbonates with Randomly Oriented Glass Fibers

		Fiber Reinforcement (vol%)		
Property	*Unreinforced*	*20*	*30*	*40*
Specific gravity	1.19–1.22	1.35	1.43	1.52
Tensile strength [MPa (ksi)]	59–62 (8.5–9.0)	110 (16)	131 (19)	159 (23)
Modulus of elasticity [GPa (10^6 psi)]	2.24–2.345 (0.325–0.340)	5.93 (0.86)	8.62 (1.25)	11.6 (1.68)
Elongation (%)	90–115	4–6	3–5	3–5
Impact strength, notched Izod (lb_f/in.)	12–16	2.0	2.0	2.5

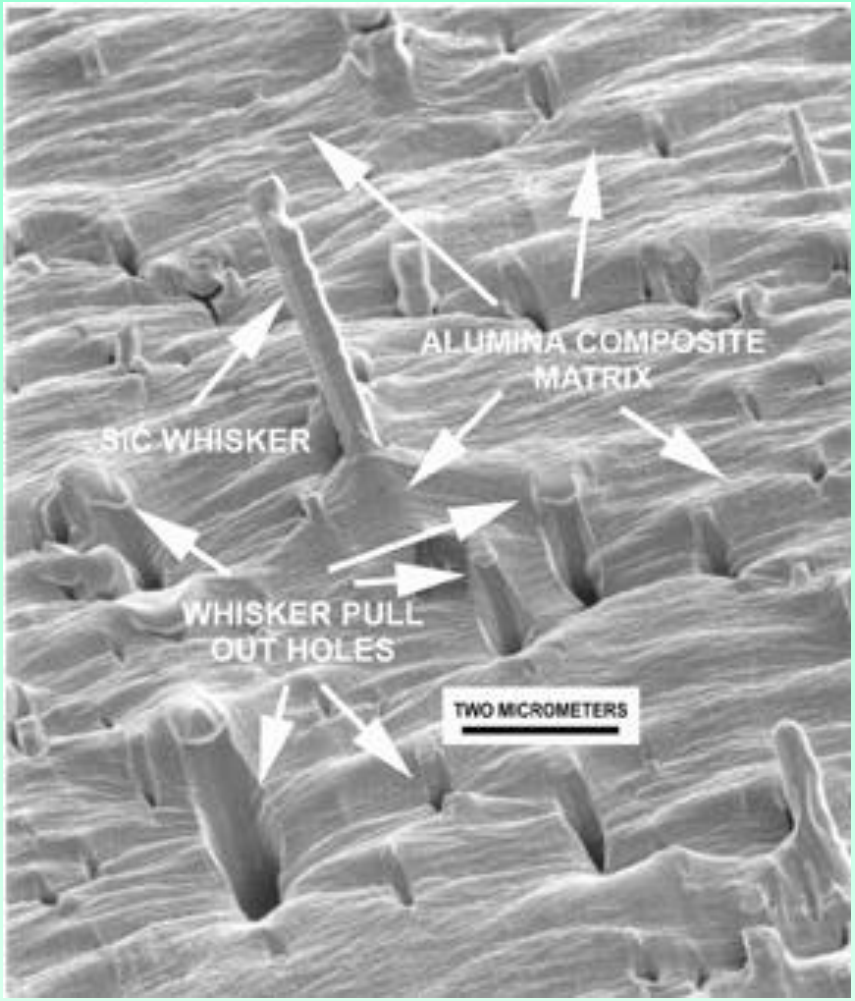
Source: Adapted from Materials Engineering's *Materials Selector*, copyright © Penton/IPC.

Table 15.4 Characteristics of Several Fiber-Reinforcement Materials

Material	*Specific Gravity*	*Tensile Strength* [*GPa* (10^3 *psi*)]	*Specific Strength* (*GPa*)	*Modulus of Elasticity* [*GPa* (10^6 *psi*)]	*Specific Modulus* (*GPa*)
		Whiskers			
Graphite	2.2	20 (3)	9.1	700 (100)	318
Silicon nitride	3.2	5–7 (0.75–1.0)	1.56–2.2	350–380 (50–55)	109–118
Aluminum oxide	4.0	10–20 (1–3)	2.5–5.0	700–1500 (100–220)	175–375
Silicon carbide	3.2	20 (3)	6.25	480 (70)	150
		Fibers			
Aluminum oxide	3.95	1.38 (0.2)	0.35	379 (55)	96
Aramid (Kevlar 49)	1.44	3.6–4.1 (0.525–0.600)	2.5–2.85	131 (19)	91
Carbon[a]	1.78–2.15	1.5–4.8 (0.22–0.70)	0.70–2.70	228–724 (32–100)	106–407
E-Glass	2.58	3.45 (0.5)	1.34	72.5 (10.5)	28.1
Boron	2.57	3.6 (0.52)	1.40	400 (60)	156
Silicon carbide	3.0	3.9 (0.57)	1.30	400 (60)	133
UHMWPE (Spectra 900)	0.97	2.6 (0.38)	2.68	117 (17)	121
		Metallic Wires			
High-strength steel	7.9	2.39 (0.35)	0.30	210 (30)	26.6
Molybdenum	10.2	2.2 (0.32)	0.22	324 (47)	31.8
Tungsten	19.3	2.89 (0.42)	0.15	407 (59)	21.1

[a] The term "carbon" instead of "graphite" is used to denote these fibers, since they are composed of crystalline graphite regions, and also of noncrystalline material and areas of crystal misalignment.

Fratura de cerâmica com adição de Whiskers



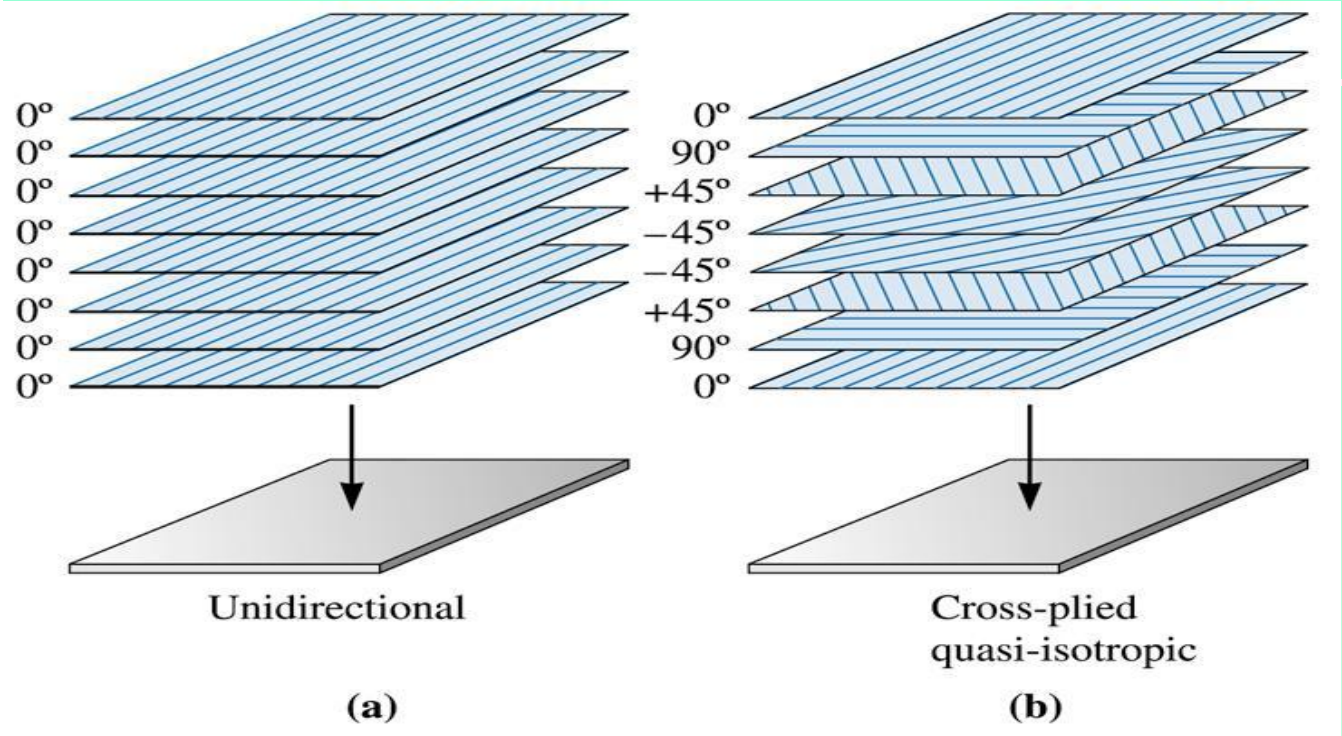
"pull out"

Compósitos Estruturais

São compostos normalmente tanto por materiais homogêneos como por materiais compósitos, cujas propriedades dependem não somente das propriedades dos materiais constituintes, mas também de fatores geométricos dos vários elementos estruturais, definidos no projeto.

Ex.: compósitos laminares e **painéis em sanduíche**

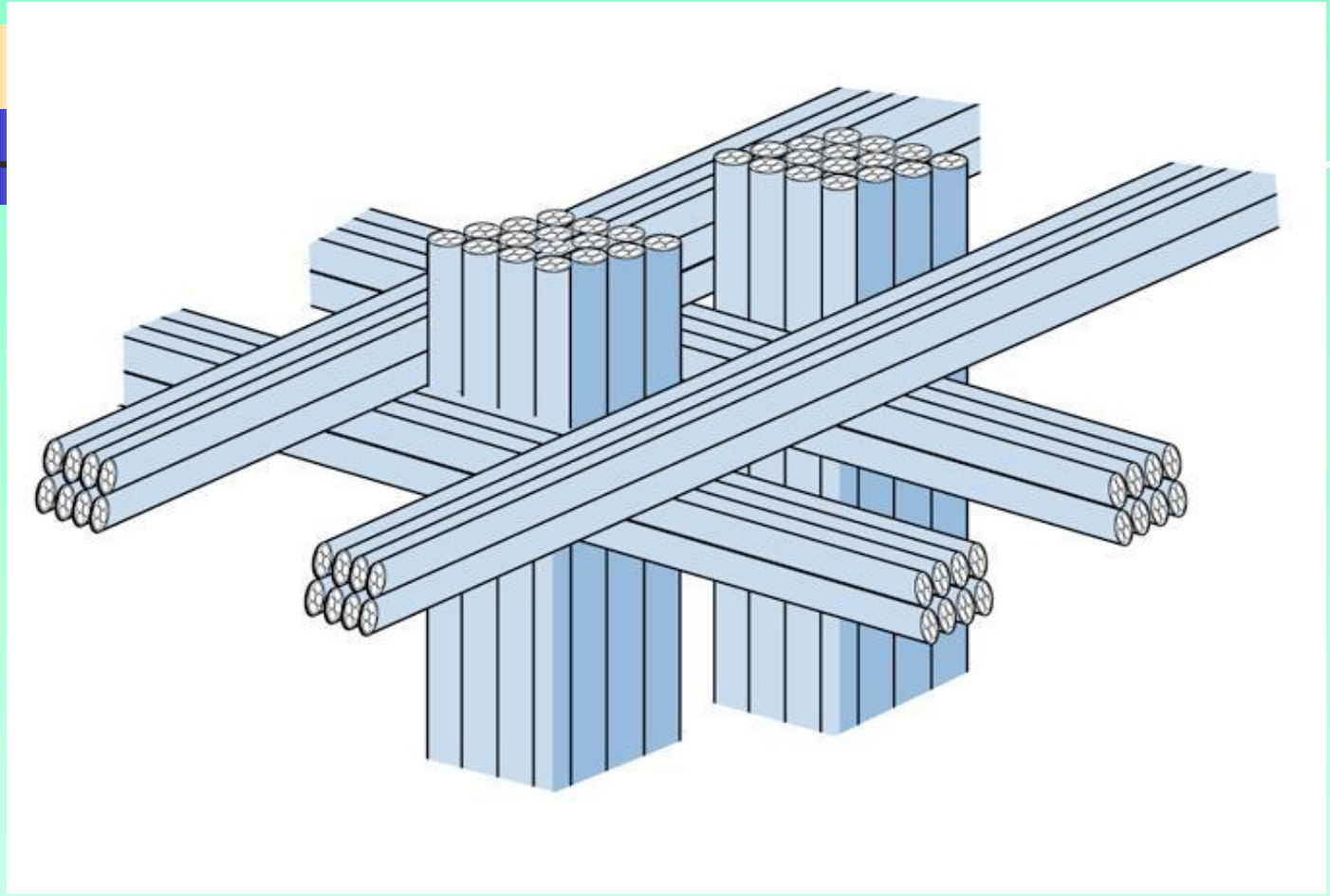
Compósitos Laminares



©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

(a) Fitas contendo fibras alinhadas podem ser unidas de maneira a produzir um (b) compósito multi-camadas com diferentes orientações para produzir um compósito quasi-isotrópico. Nesse caso, um compósito 0°/+45°/90° composite foi construido.

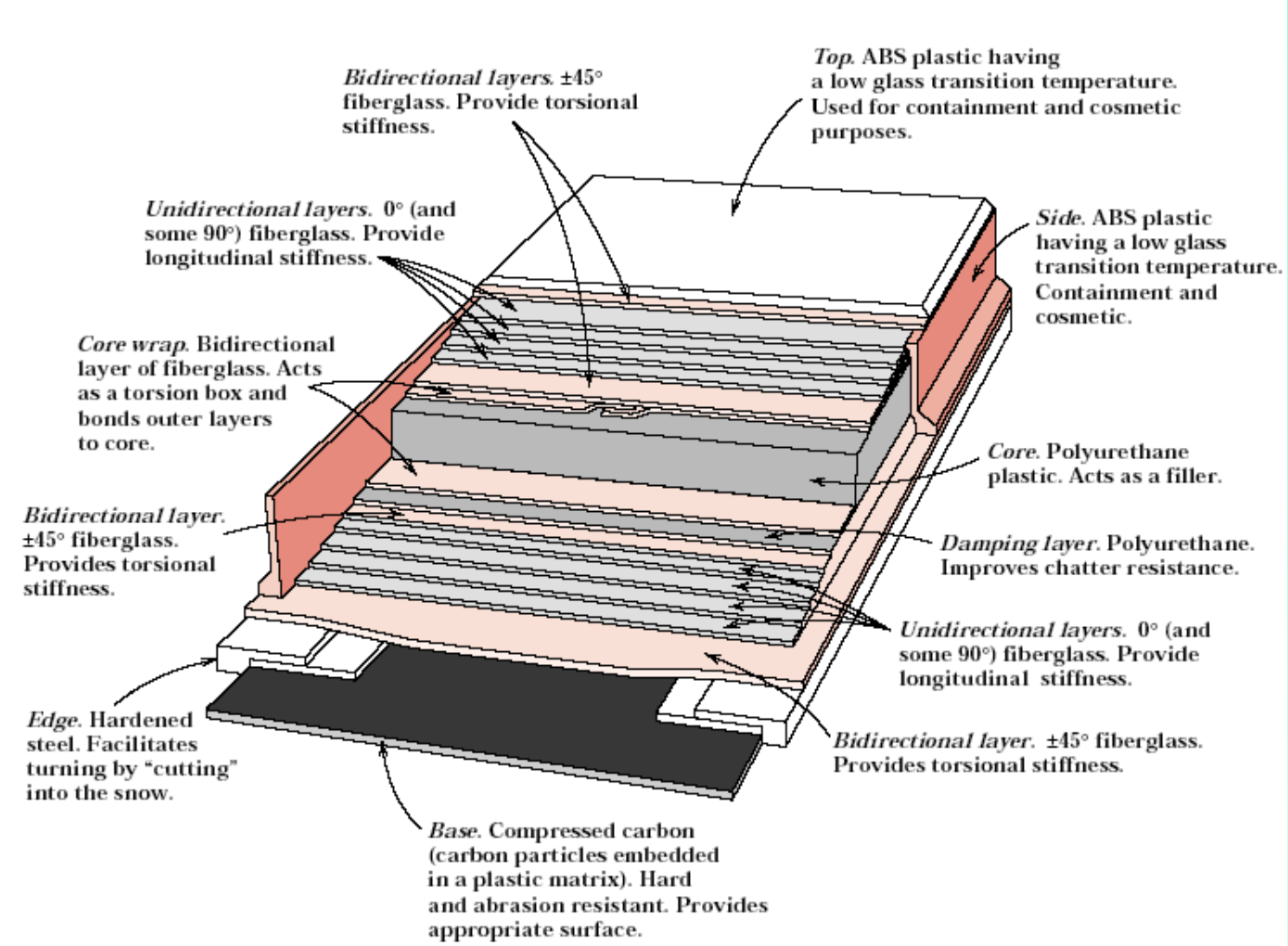
Compósitos Laminares



©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

Visão tridimensional de um tecido construido com arranjo aleatório de fibras

Esqui Moderno



Painéis Sanduíche

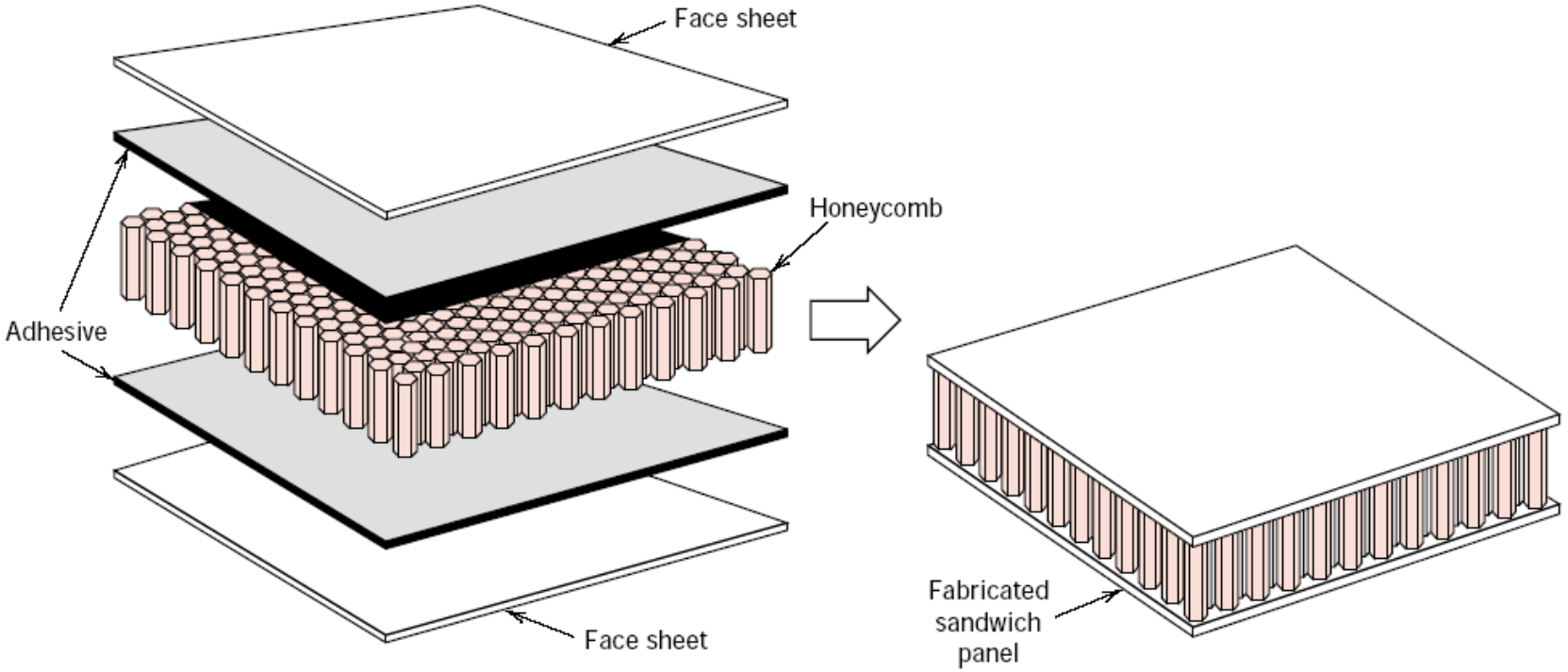
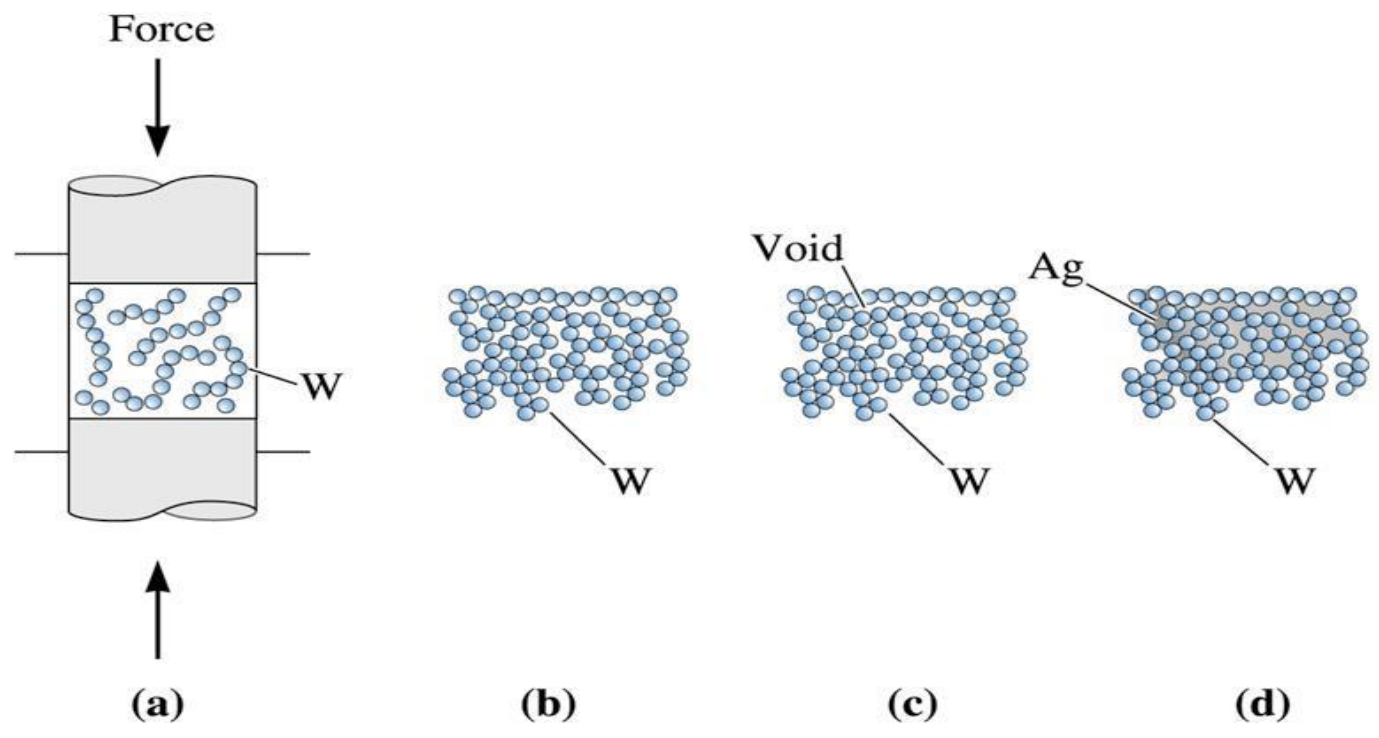


FIGURE 15.17 Schematic diagram showing the construction of a honeycomb core sandwich panel. (Reprinted with permission from *Engineered Materials Handbook,* Vol. 1, *Composites,* ASM International, Metals Park, OH, 1987.)

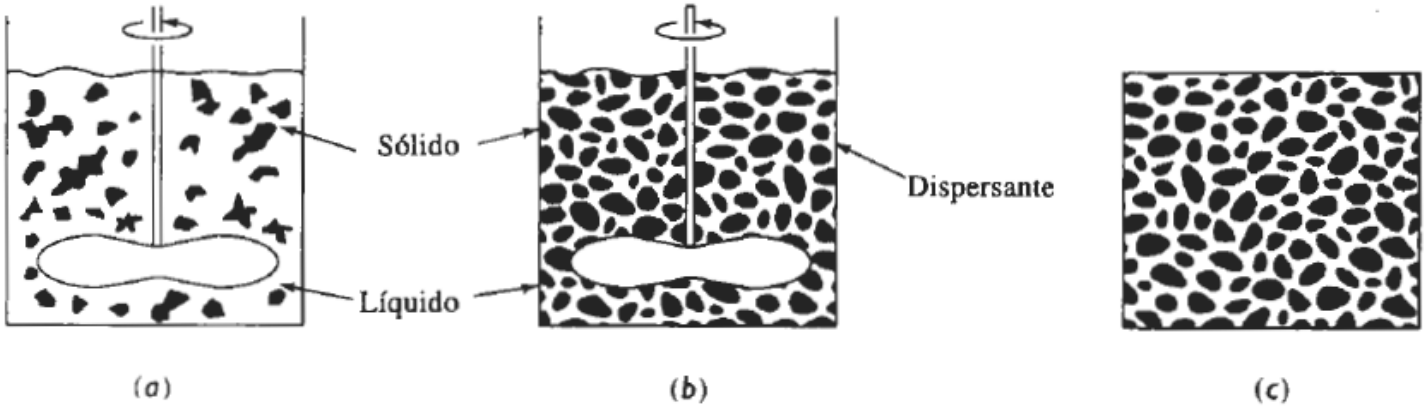
Processamento de Compósitos com Partículas (Sinterização)

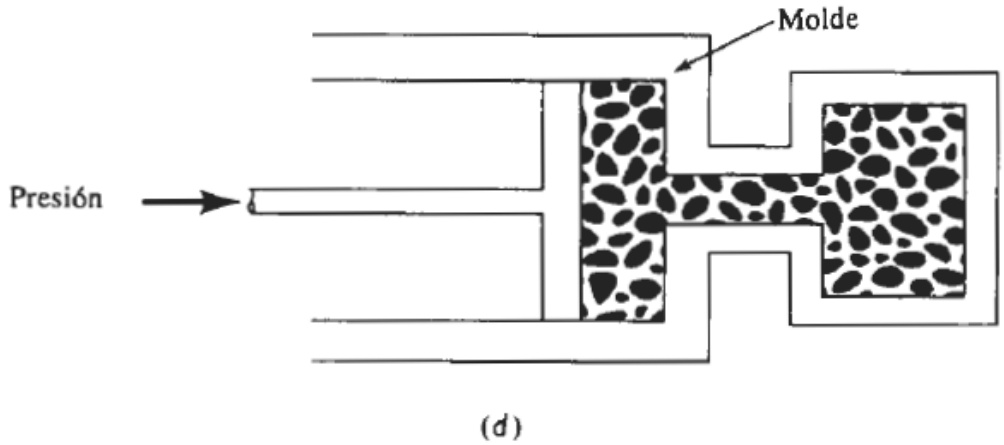


©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

Etapas envolvidas na produção de compósito elétrico prata-tungstênio: (a) o pó de W é prensado; (b) um compacto de baixa densidade é produzido; (c) sinterização da peça de W; (d) infiltração da peça por prata líquida.

Processamento de Compósitos com Partículas (Fundição)

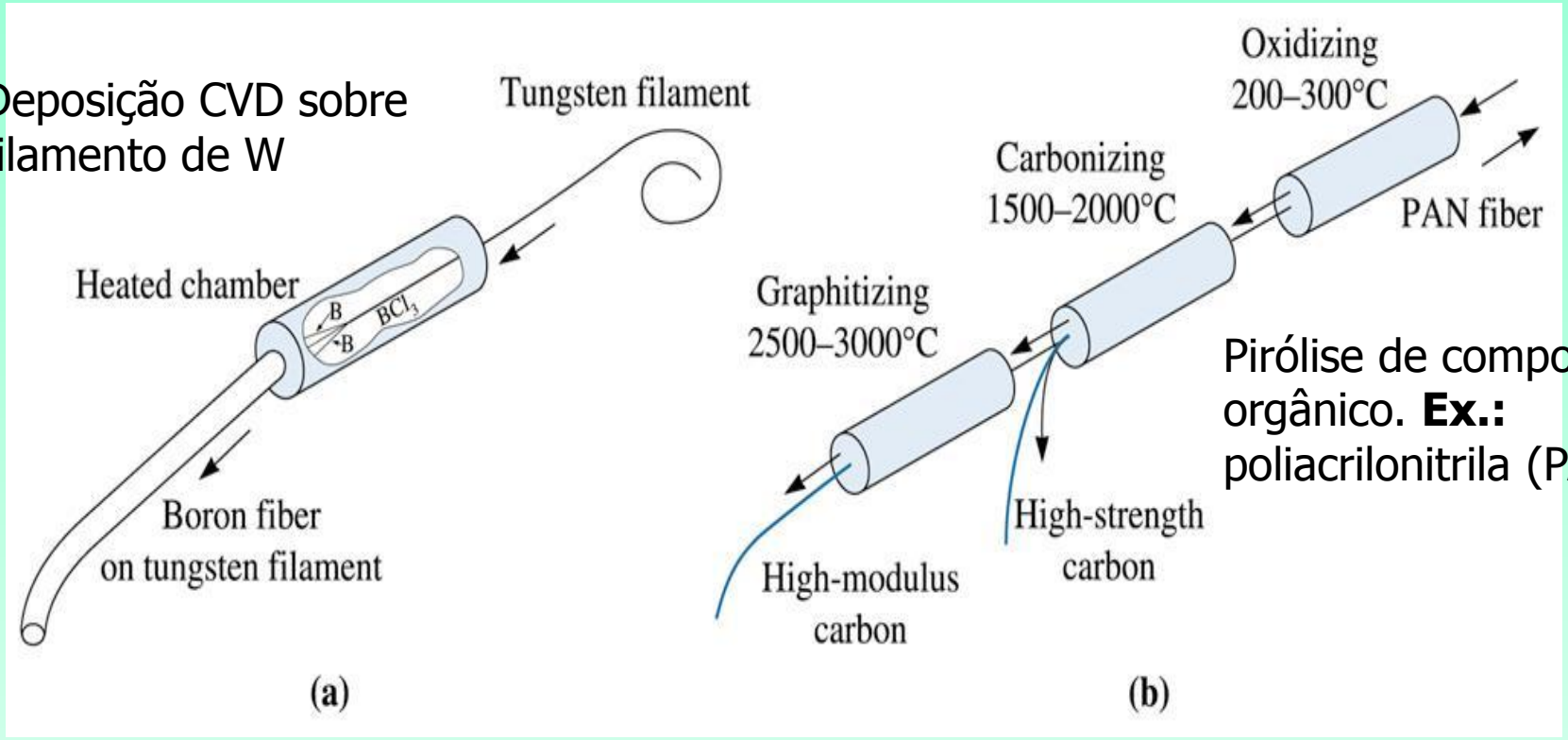




Adição e agitação de partículas de reforço no estado semi-sólido (Tixofundição)

Processamento de Fibras

Deposição CVD sobre filamento de W

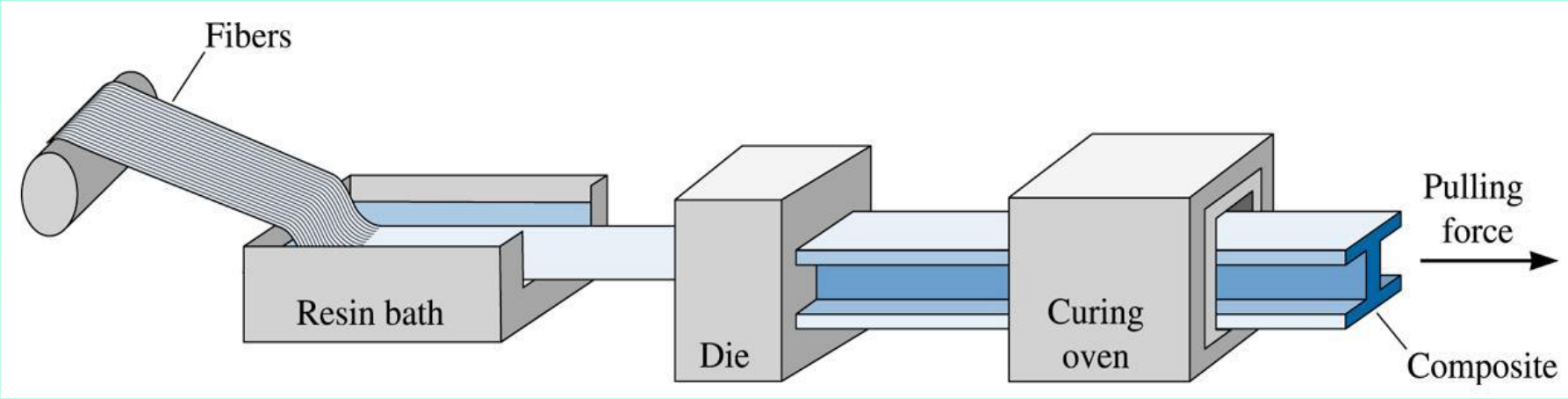


Pirólise de composto orgânico. **Ex.:** poliacrilonitrila (PAN)

©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

Figure 16.17 Methods for producing (a) boron and (b) carbon fibers.

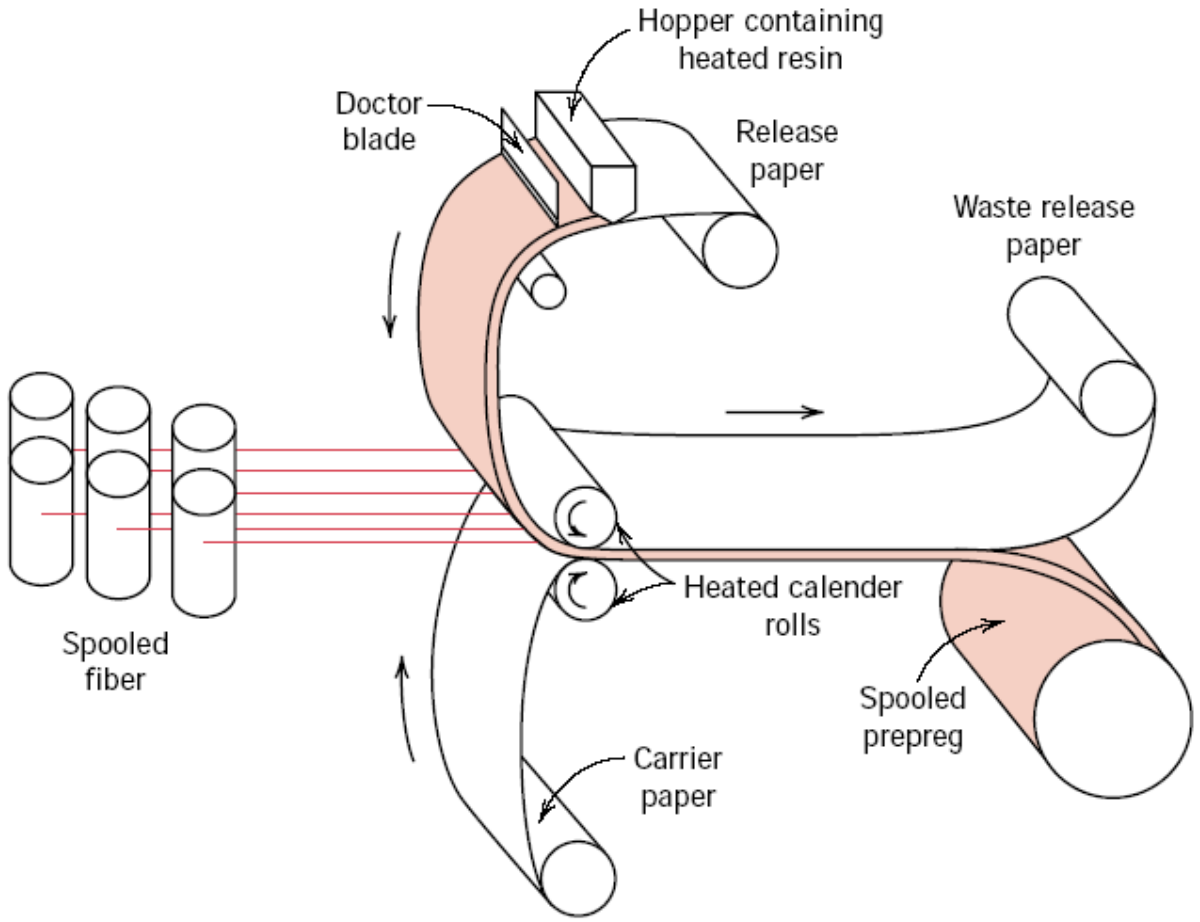
Pultrusão



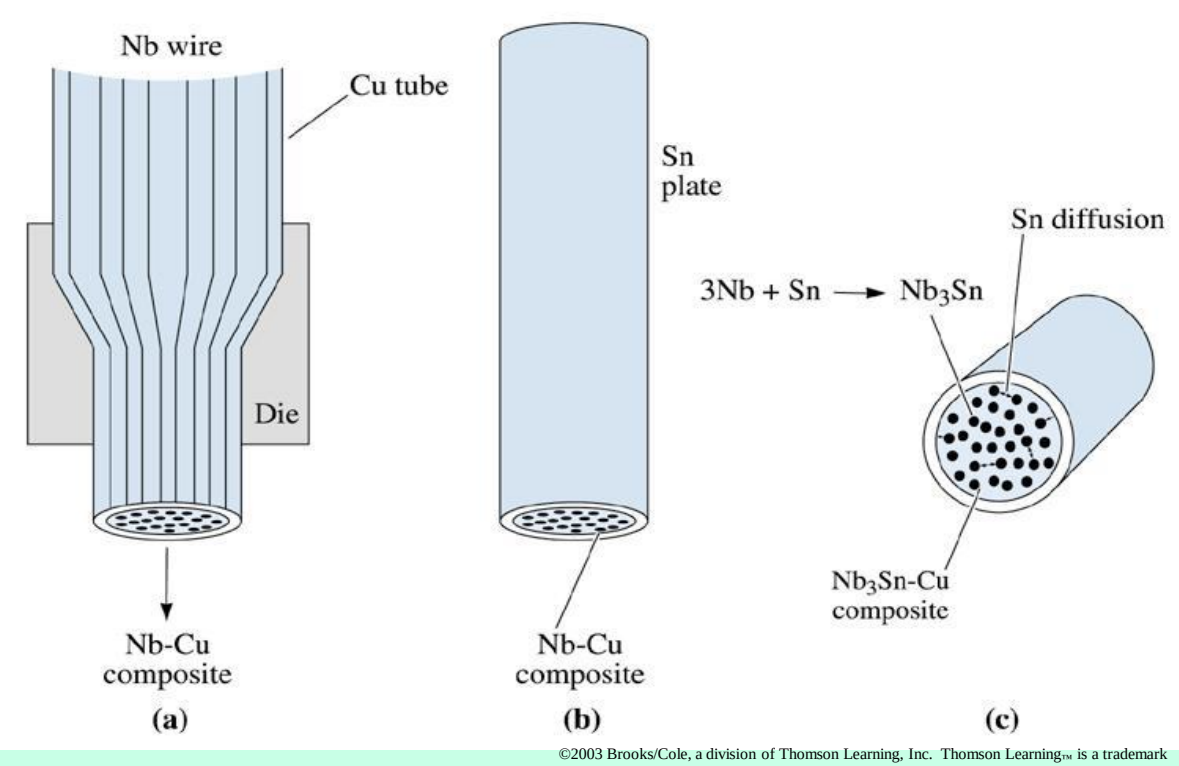
©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

Processamento de Fitas Reforçadas por Fibras (Preg-Preg)

FIGURE 15.13
Schematic diagram illustrating the production of prepreg tape using thermoset polymers.



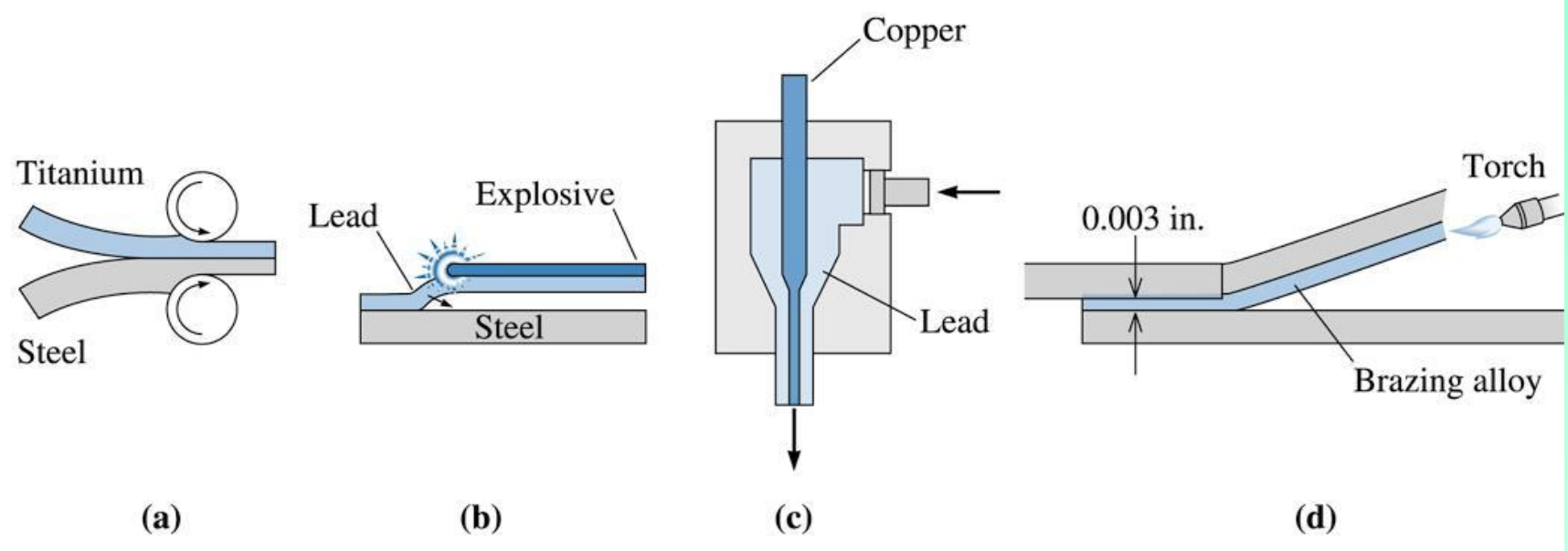
Processamento de Compósito Supercondutor



©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

Figure 16.27 The manufacturer of composite super-conductor wires: (a) Niobium wire is surrounded with copper during forming. (b) Tin is plated onto Nb-Cu composite wired. (c) Tin diffuses to niobium to produce the Nb_3Sn-Cu composite.

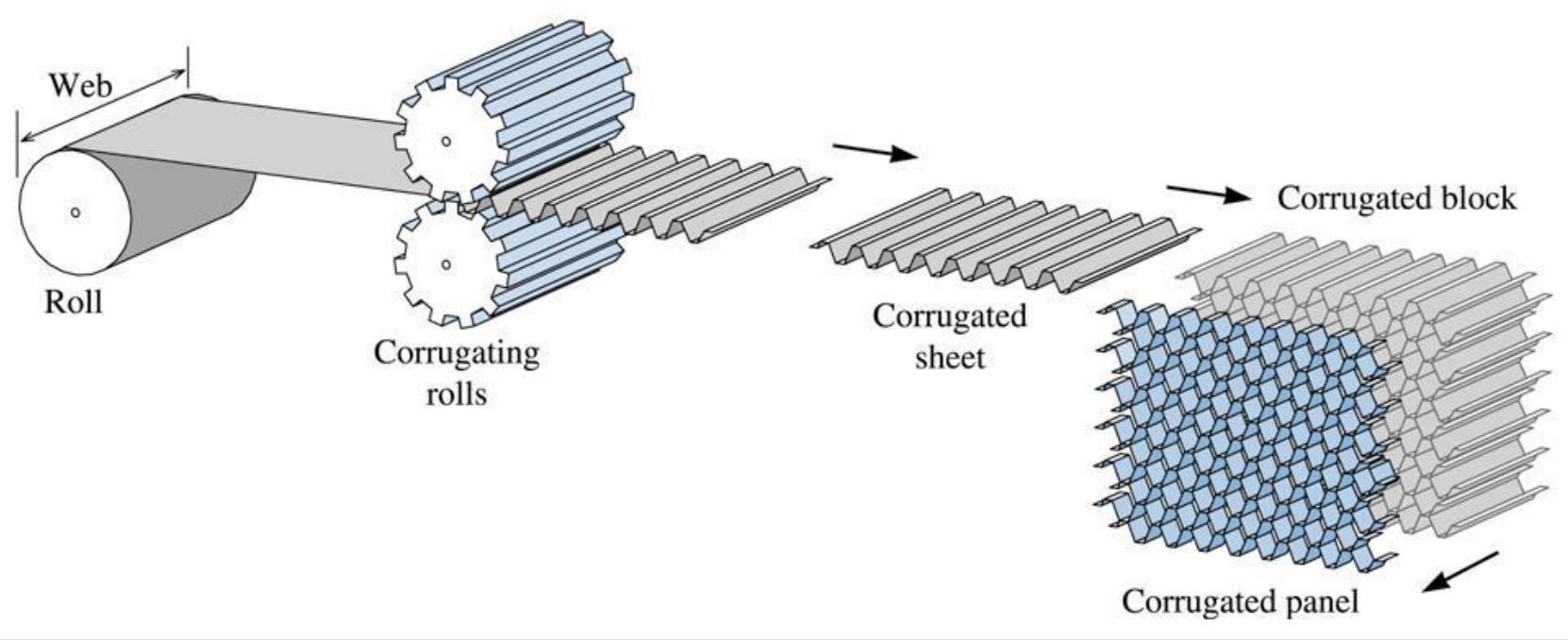
Processamento de Compósitos Laminares



©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

Figure 16.30 Techniques for producing laminar composites: (a) roll bonding, (b) explosive bonding, and (c) coextrusion, and (d) brazing.

Processamento de Estruturas em "Colméia"



©2003 Brooks/Cole, a division of Thomson Learning, Inc. Thomson Learning™ is a trademark used herein under license.

Figure 16.33 In the corrugation method for producing a honeycomb core, the material (such as aluminum) is corrugated between two rolls. The corrugated sheets are joined together with adhesive and then cut to the desired thickness.