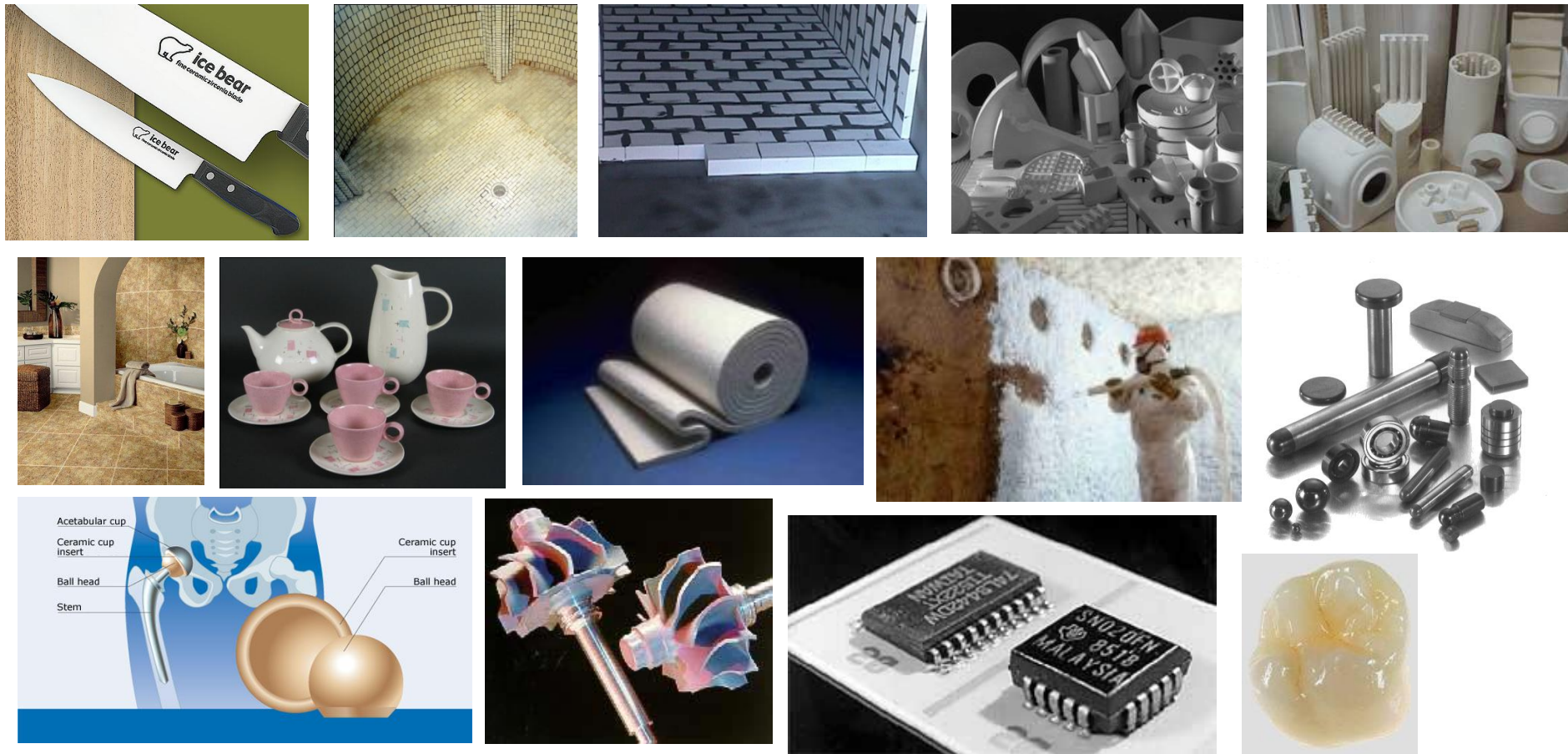


Materiais Cerâmicos

Aplicações e Processamento

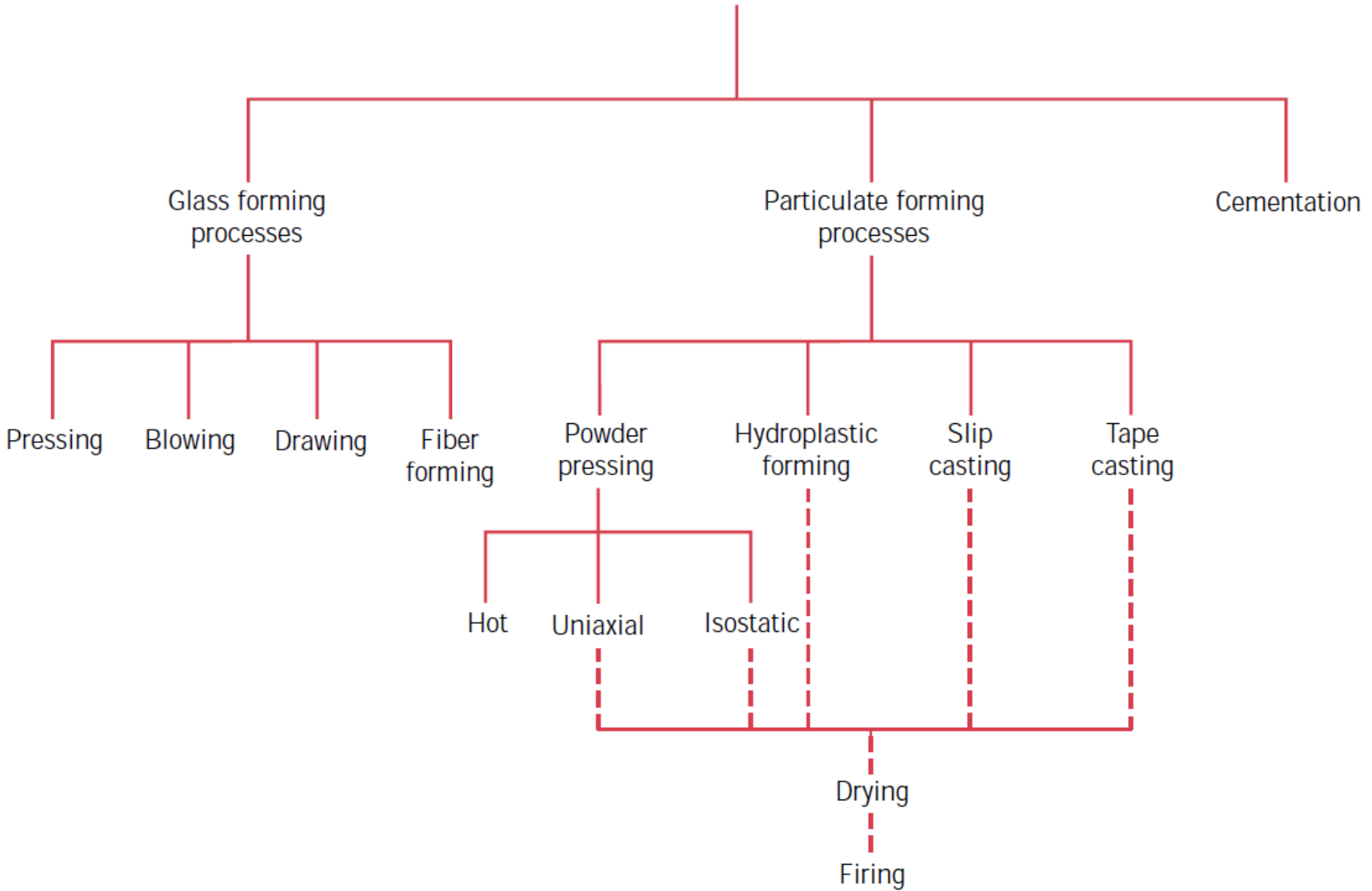


SMM0194 - Engenharia e Ciência dos Materiais 2
Prof. Eduardo Bellini Ferreira

Classificação dos materiais cerâmicos com base na aplicação

- Vidros (vidros, vitrocerâmicas)
- Produtos argilosos (produtos argilosos estruturais, louças brancas)
- Refratários (a base de argila, sílica, básico, especial)
- Abrasivos
- Cimentos
- Cerâmicas avançadas

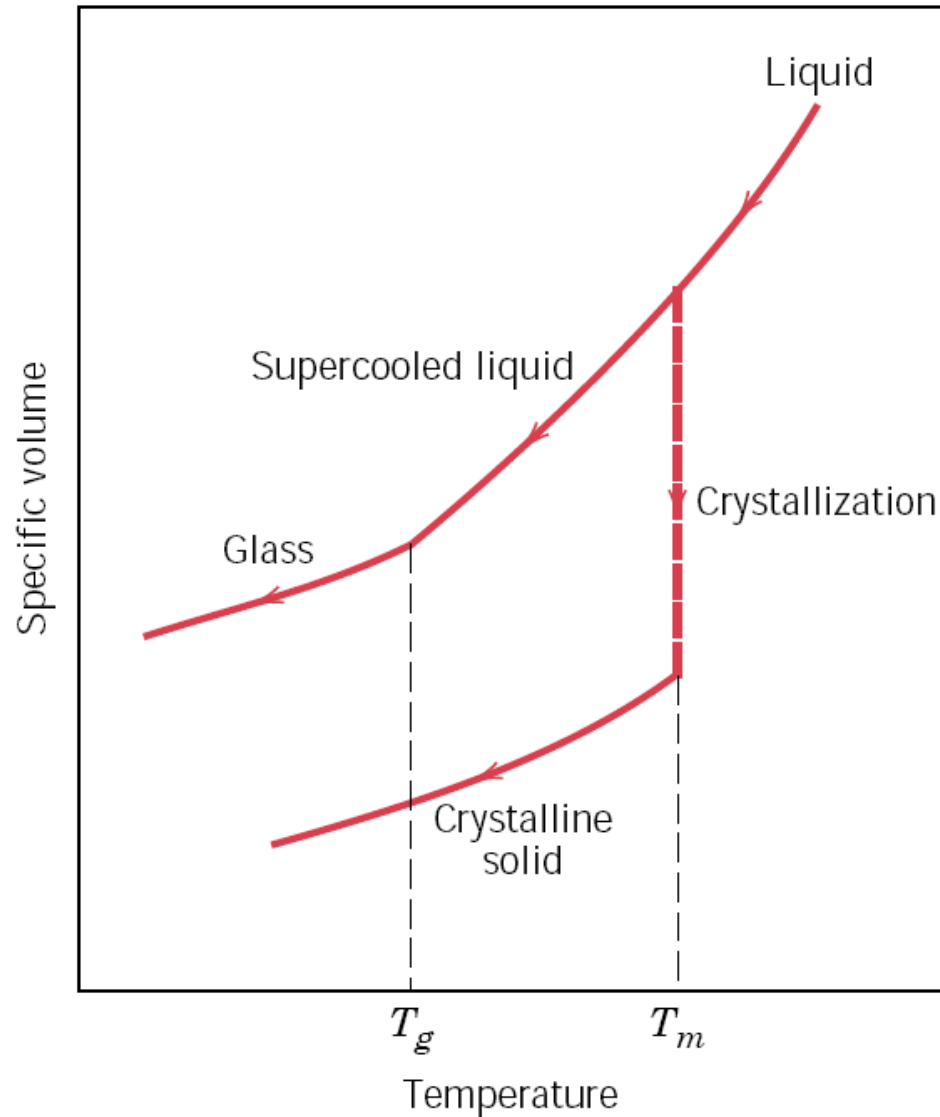
Ceramic fabrication techniques



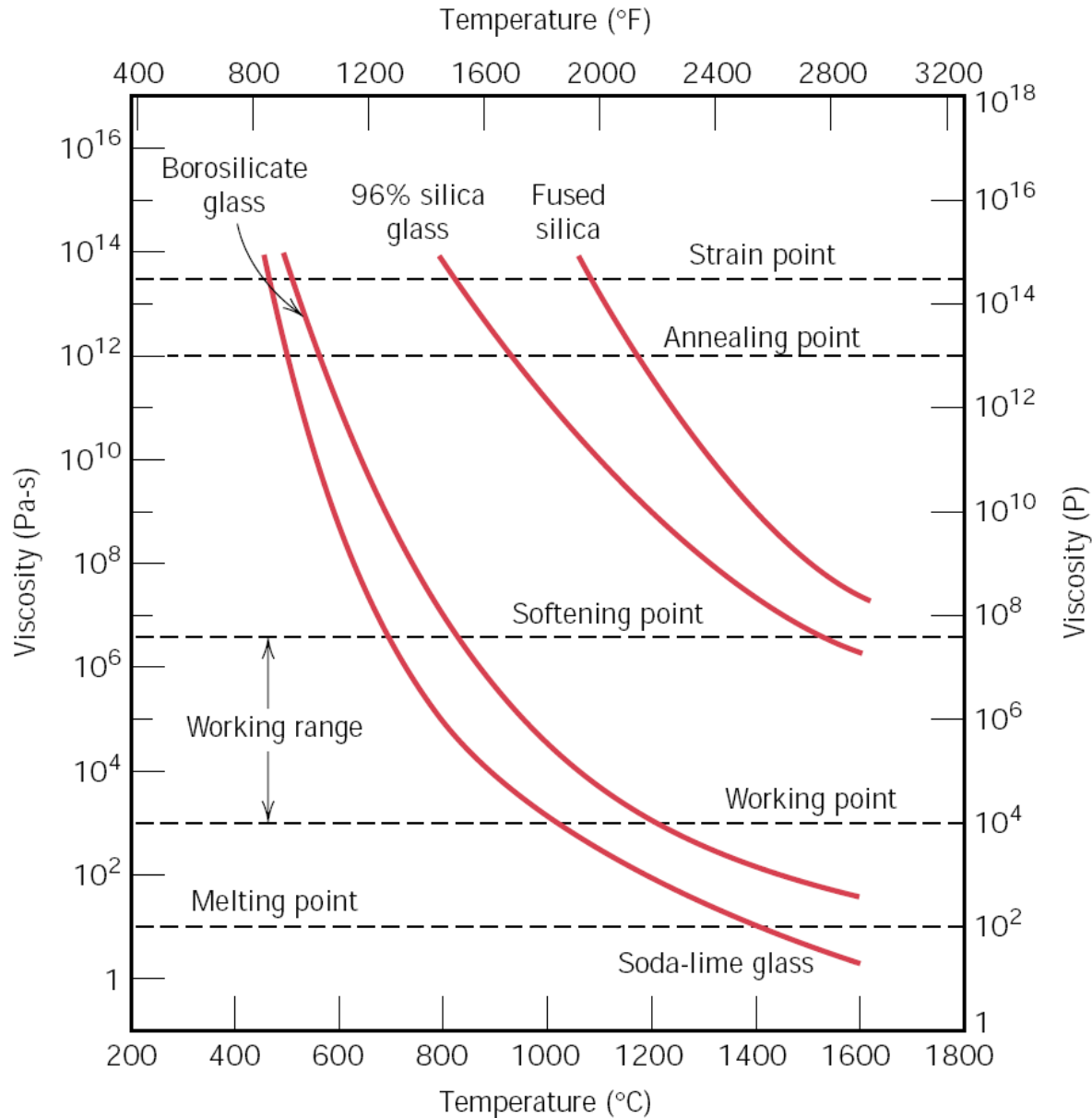
Técnicas de fabricação – vidros

- Fundição – conformação do vidro
 - Prensagem
 - Sopro (peças ocas, garrafas)
 - Estiramento
 - Estiramento de fibras
- Recozimento
- Cristalização e fabricação de vitrocerâmicas
- Têmpera e fabricação de vidros temperados

Técnicas de fabricação – vidros



Técnicas de fabricação – vidros

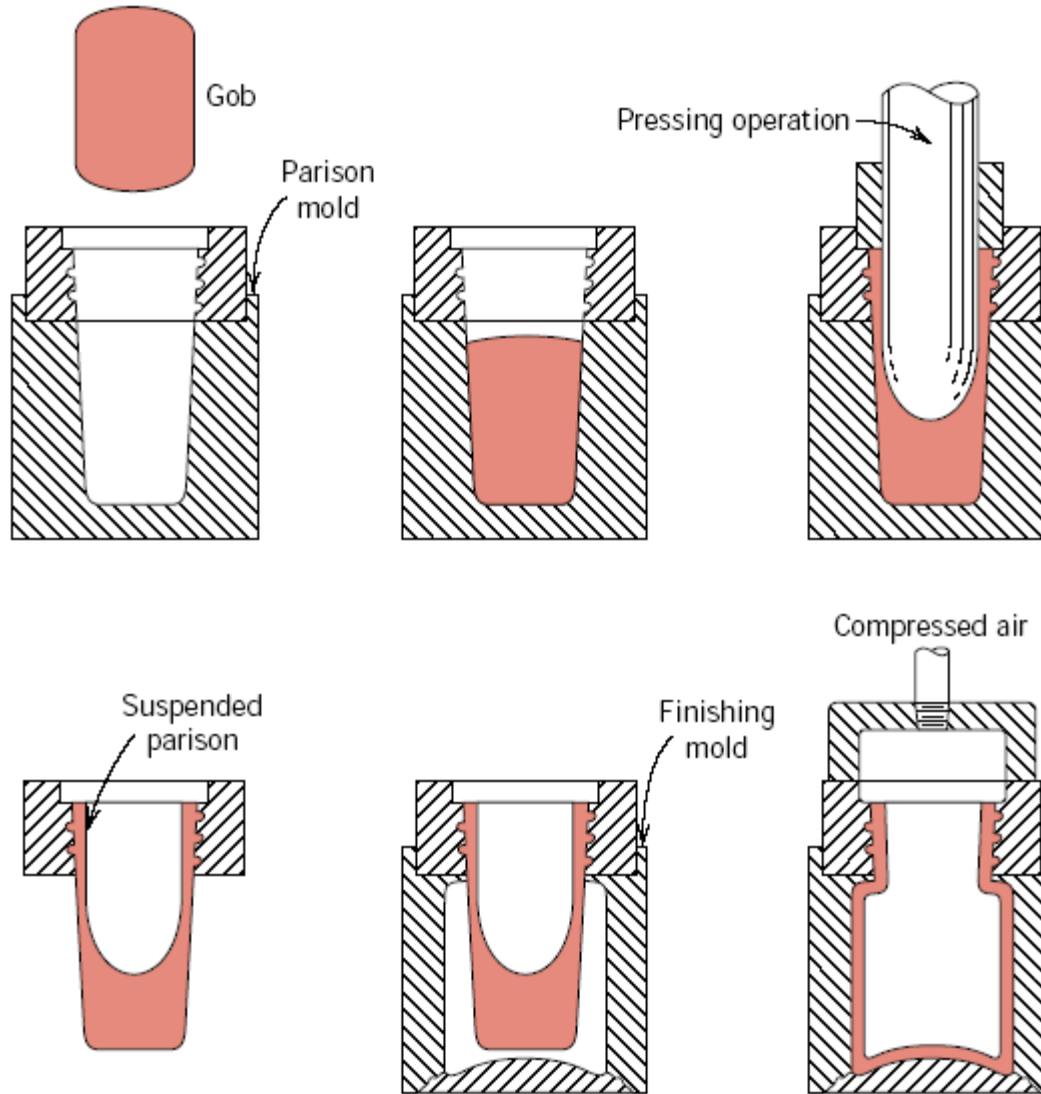


Tipos de vidros

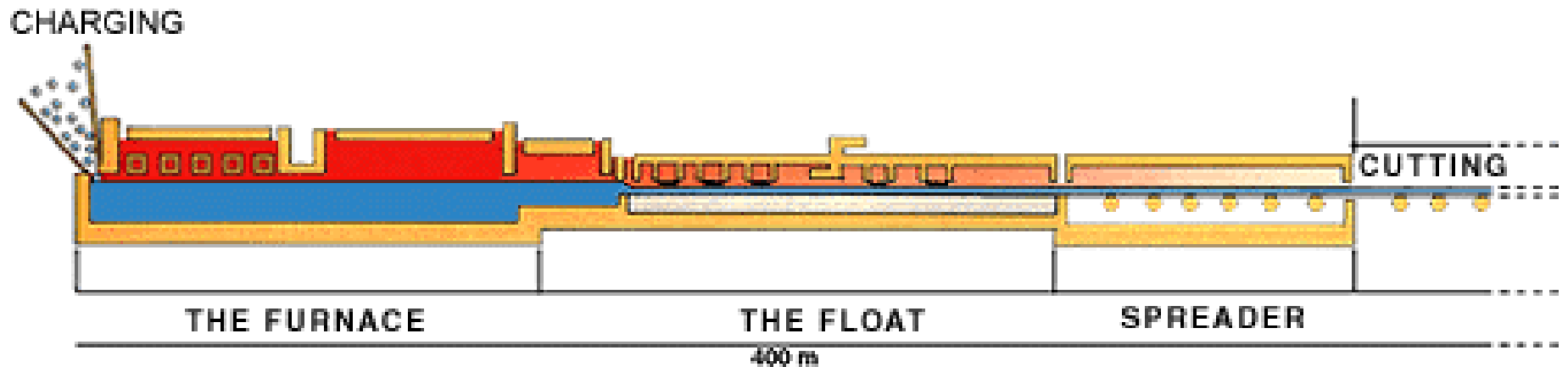
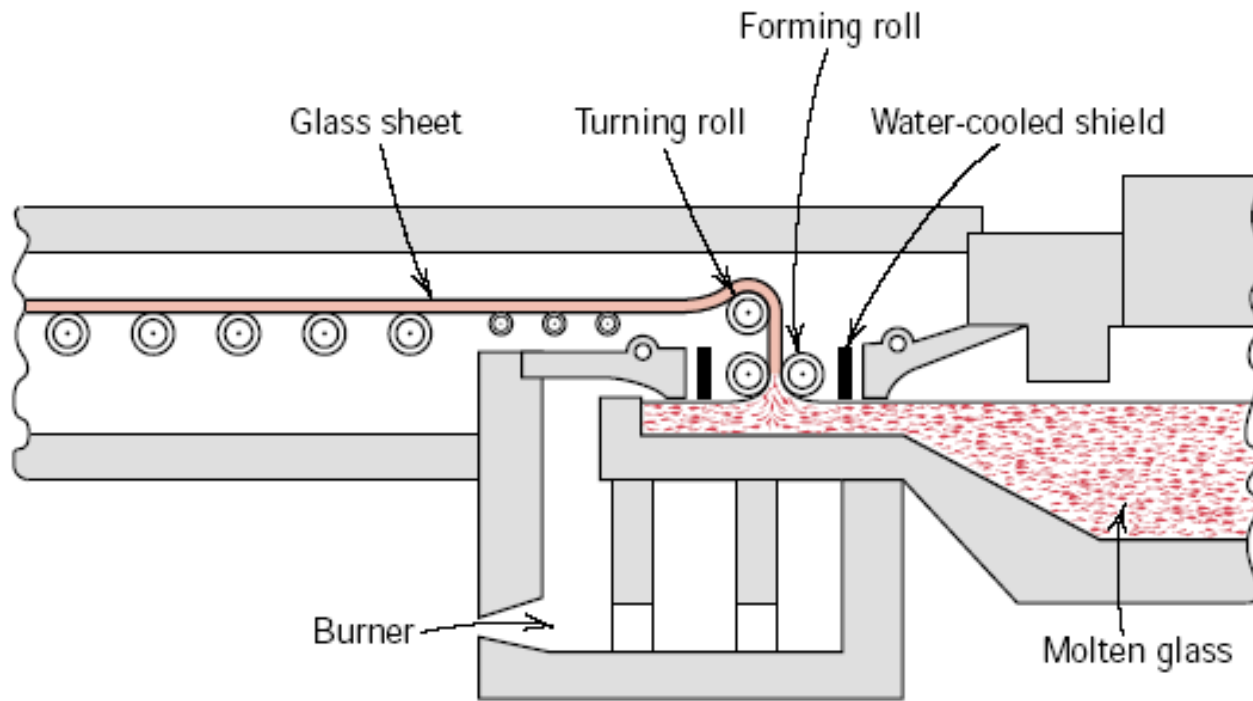
Table 13.10 Compositions and Characteristics of Some of the Common Commercial Glasses

<i>Glass Type</i>	<i>Composition (wt%)</i>						<i>Characteristics and Applications</i>
	<i>SiO₂</i>	<i>Na₂O</i>	<i>CaO</i>	<i>Al₂O₃</i>	<i>B₂O₃</i>	<i>Other</i>	
Fused silica	>99.5						High melting temperature, very low coefficient of expansion (shock resistant)
96% Silica (Vycor)	96				4		Thermally shock and chemically resistant—laboratory ware
Borosilicate (Pyrex)	81	3.5		2.5	13		Thermally shock and chemically resistant—ovenware
Container (soda–lime)	74	16	5	1		4MgO	Low melting temperature, easily worked, also durable
Fiberglass	55		16	15	10	4MgO	Easily drawn into fibers—glass–resin composites
Optical flint	54	1				37PbO, 8K ₂ O	High density and high index of refraction—optical lenses
Glass–ceramic (Pyroceram)	43.5	14		30	5.5	6.5TiO ₂ , 0.5As ₂ O ₃	Easily fabricated; strong; resists thermal shock—ovenware

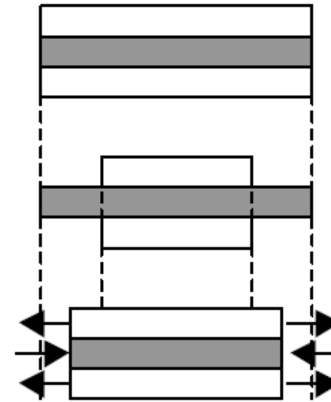
Técnicas de fabricação – vidros



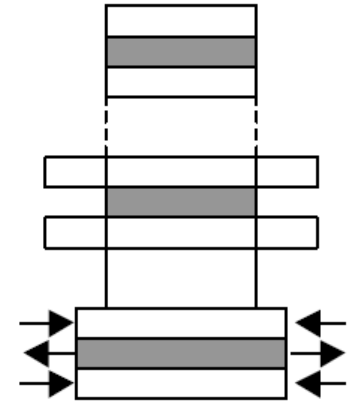
Técnicas de fabricação – vidros



Tensões residuais vs. Recozimento

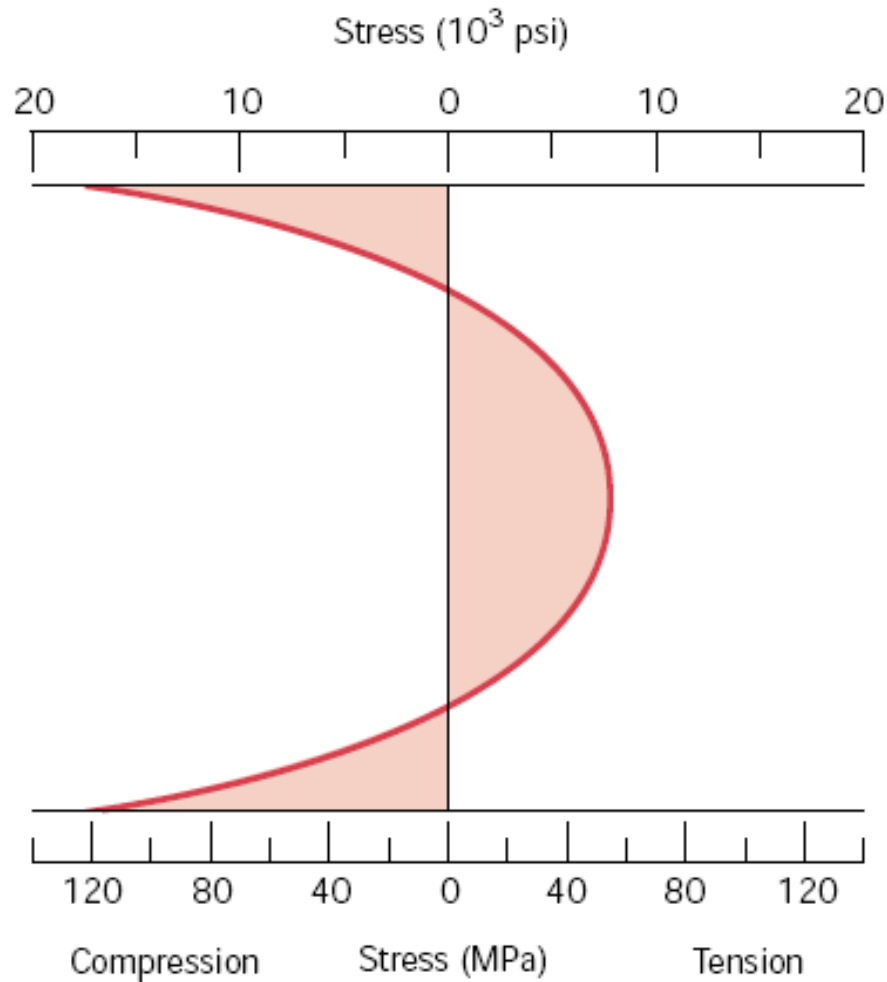


resfriamento



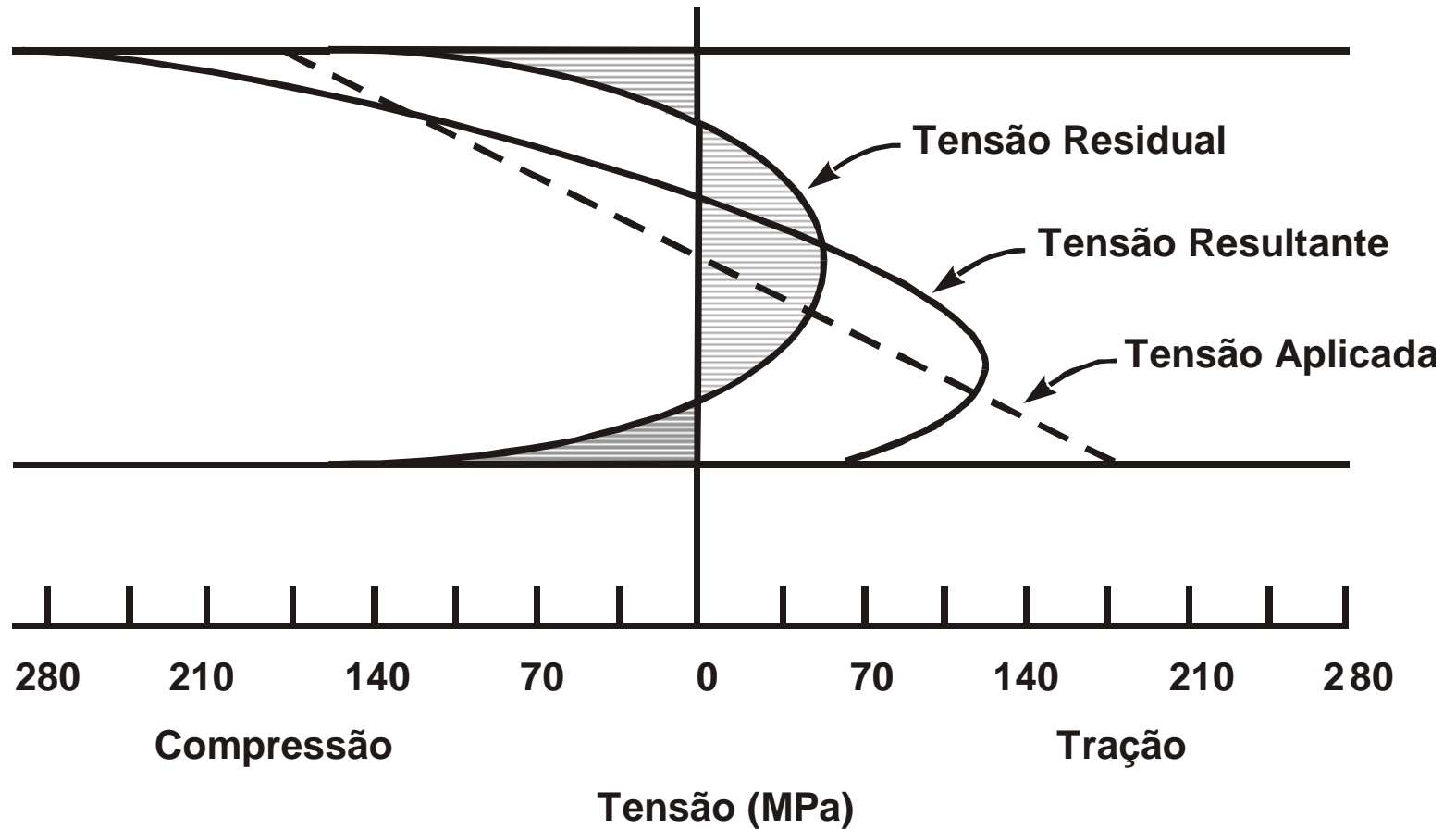
aquecimento

Técnicas de fabricação – vidros



Têmpera de vidros (resfriamento rápido da superfície): produz um estado de compressão superficial que aumenta sua resistência mecânica (50 a 100%)

Tenacificação de Vidros

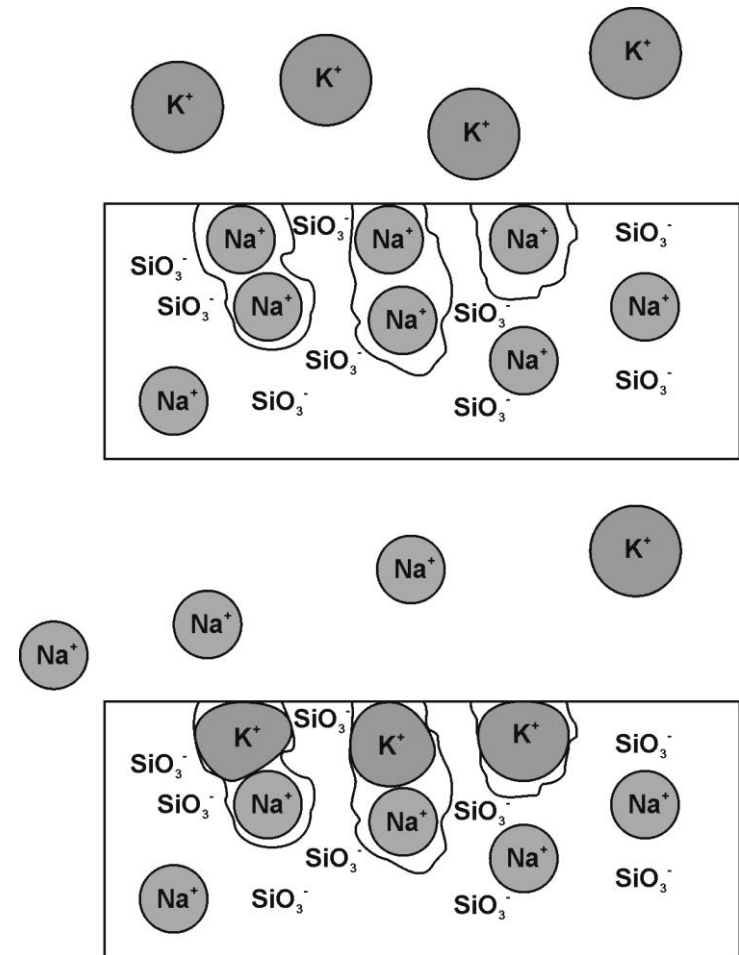


Têmpera térmica

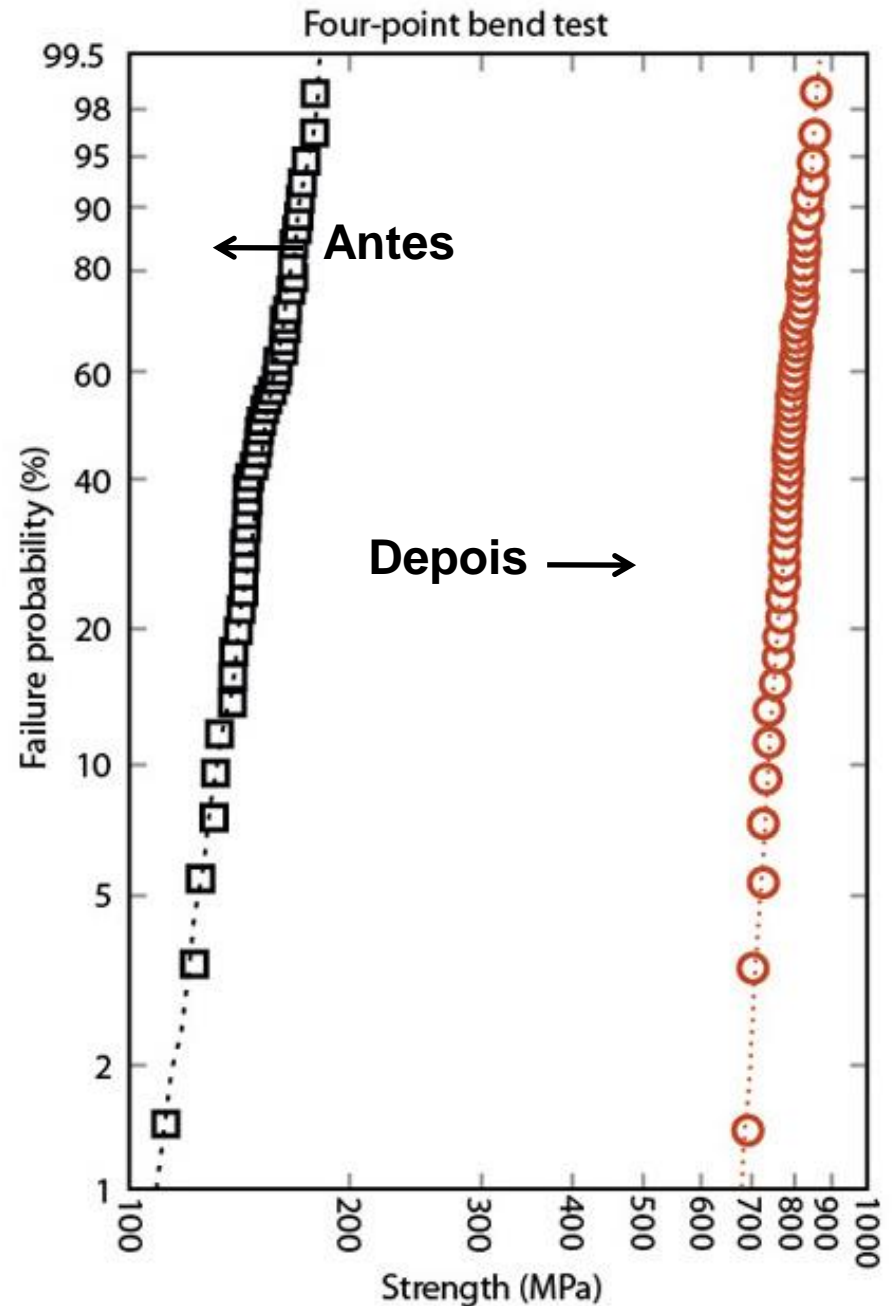


Têmpera química

- Troca iônica na superfície por íons (álcalis) de maior raio iônico:
- **Na⁺** (116 pm) no lugar de **Li⁺** (90 pm)
- **K⁺** (152 pm) no lugar de **Na⁺** (116 pm)
- Temperatura abaixo da transição vítrea



- Vidro (T_g)
 - de janela (550°C)
 - $\text{Al}_2\text{O}_3\text{-SiO}_2\text{-Li}_2\text{O}$ (800°C)
- Varshneya (SGT):
 - **650 MPa a 1 GPa**
 - **1 mm de espessura!**



Aplicações



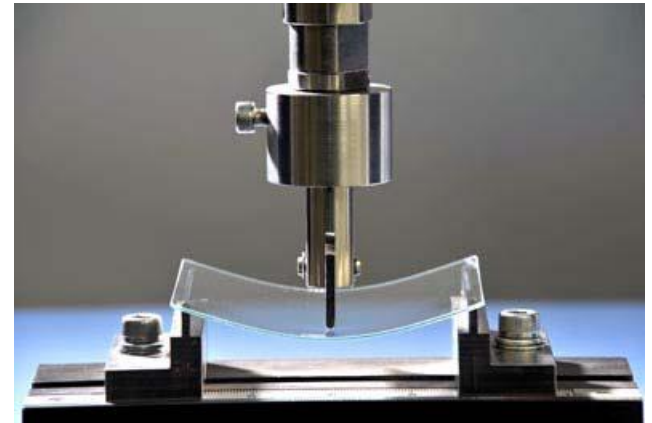
Proteção balística de alta segurança
Janelas em carros, trens, aviões
Janelas a prova de furacões



Têmpera química



Gorilla® glass – Corning/EUA



Dragontrail® glass – Asahi/Japão

USP 3.790.430 (1974): “ALKALI ALUMINOSILICATE GLASS ARTICLE HAVING AN ION-EXCHANGED SURFACE LAYER”

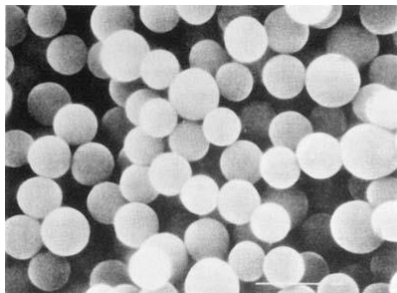
<http://www.csmonitor.com/Business/new-economy/2010/0802/Gorilla-glass-invented-in-US...>

<http://www.robaid.com/gadgets/asahi-glass-company-introduces-dragontrail-scratch-proof-glass.htm>

<http://www.youtube.com/watch?v=WpbOoQpwAFs>

Técnicas de fabricação – conformação do pó

- Conformação
 - Prensagem do pó
 - À quente
 - Uniaxial
 - Isostática
 - Conformação hidroplástica
 - Colagem de barbotina (suspensão aquosa)
 - Colagem de fita (tape casting)
- Secagem
- Queima



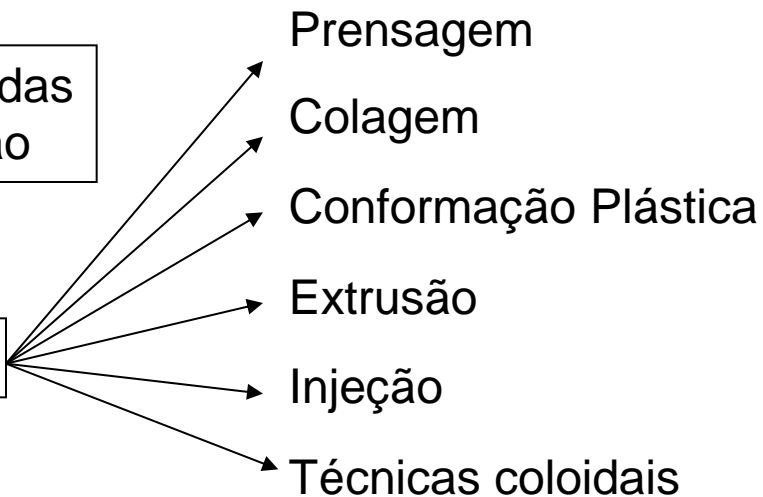
Matéria-prima
particulada



Dispersão e homogeneização das
partículas em uma suspensão



Conformação



Secagem

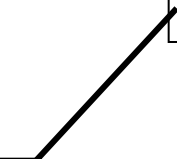


Queima

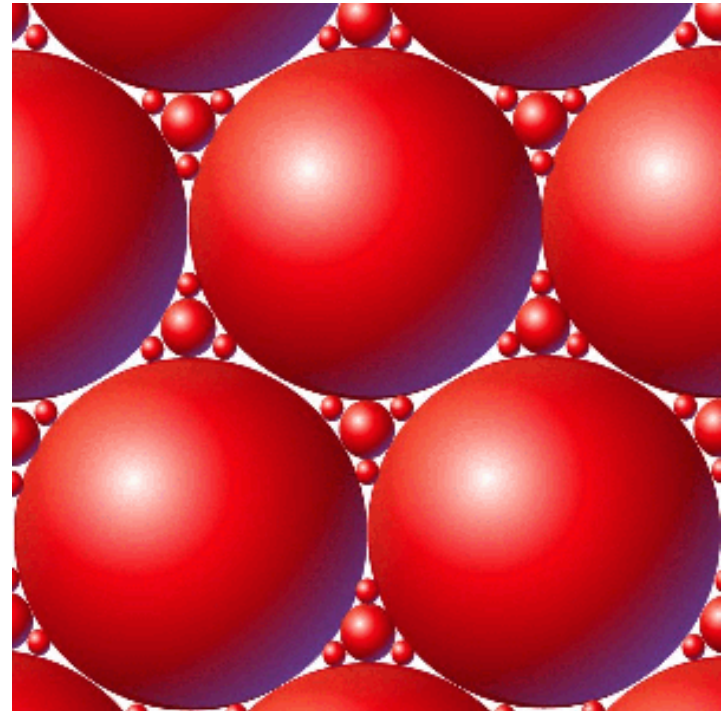
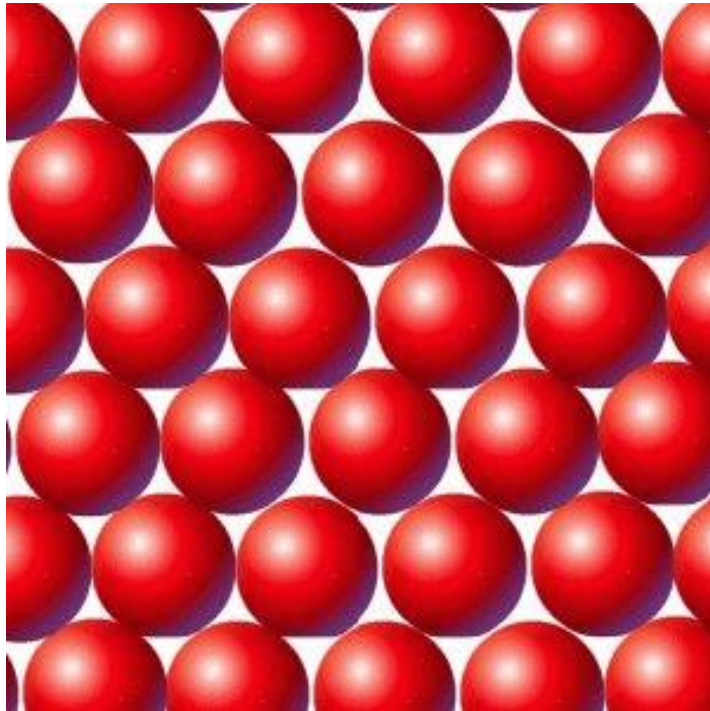


Retífica e
acabamento

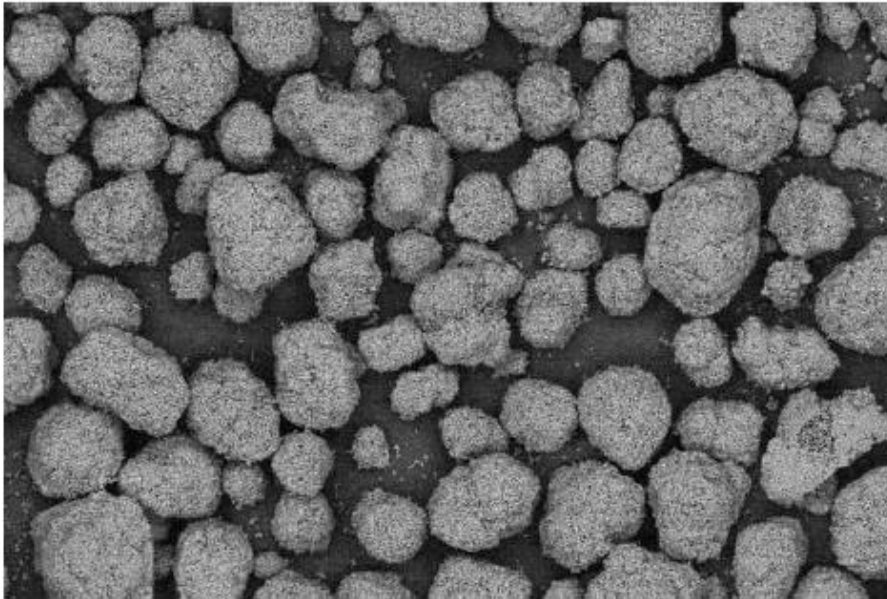
Produtos cerâmicos



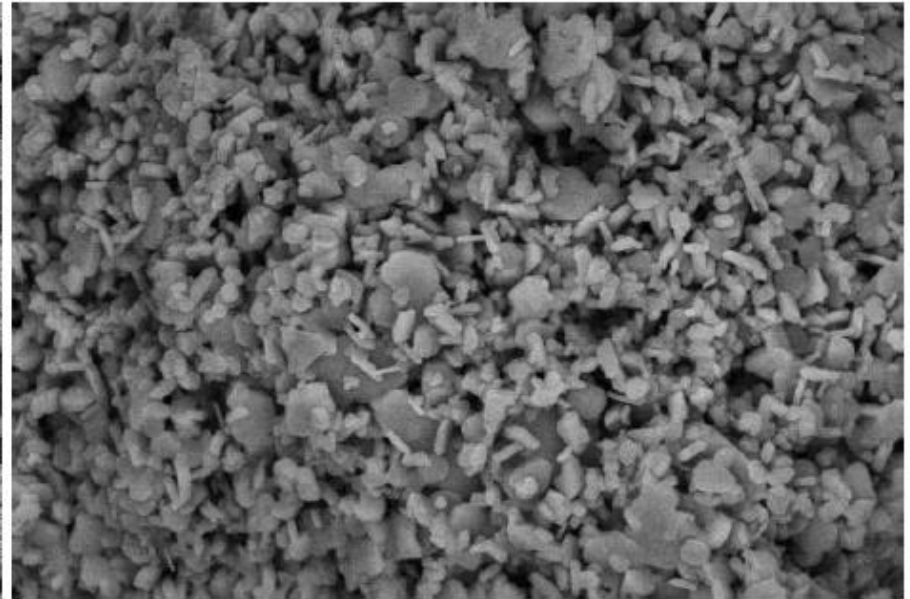
Empacotamento de partículas



Alumina calcinada APC Alcoa

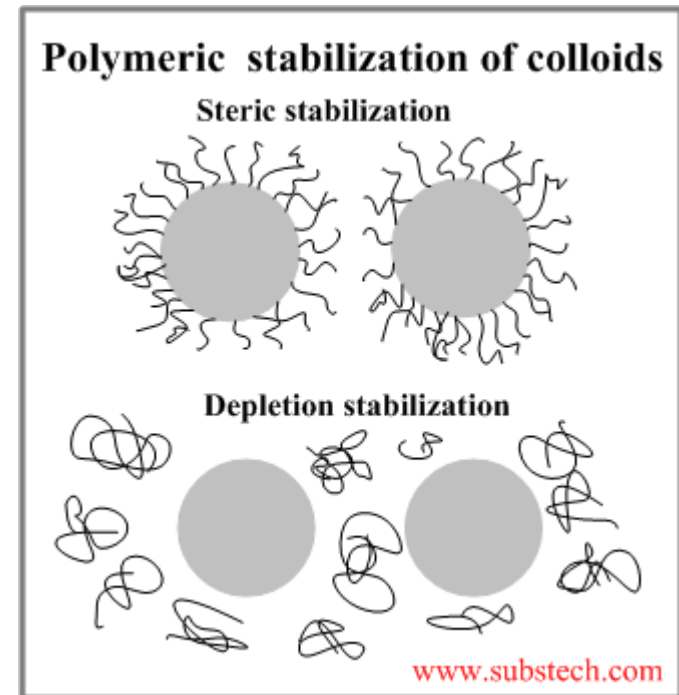
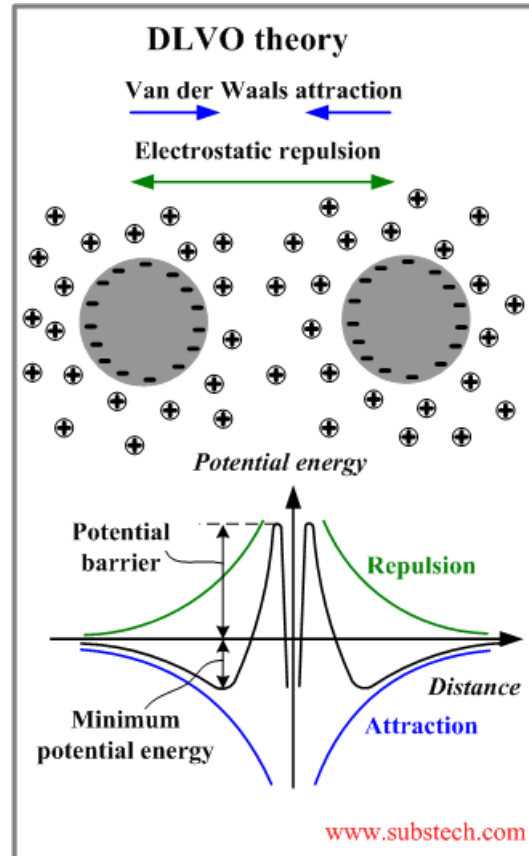
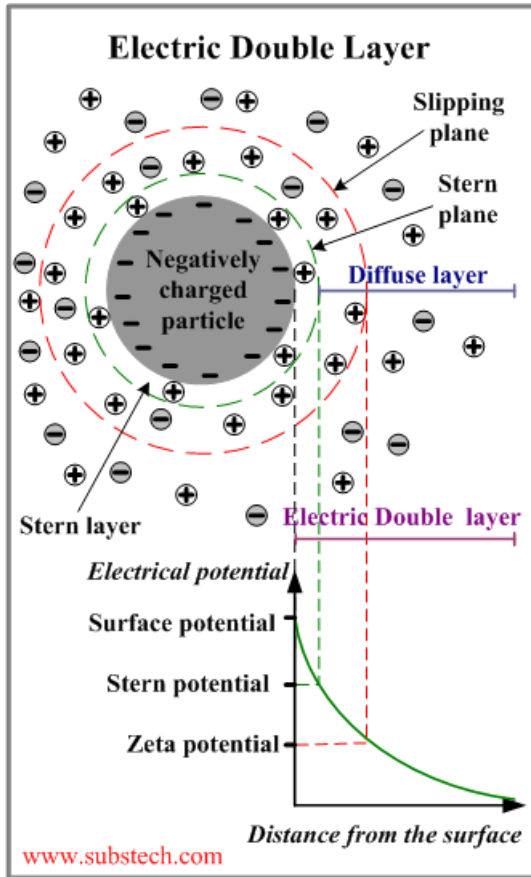


APC - MEV Ampliação de 300 X , 50 μ \longleftarrow

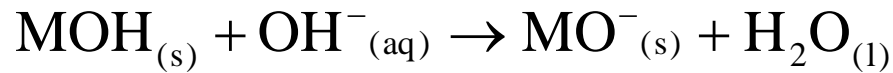
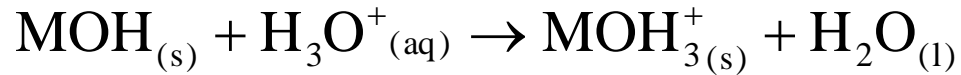


APC - MEV : -Ampliação de 3000 X , 5 μ \longleftarrow

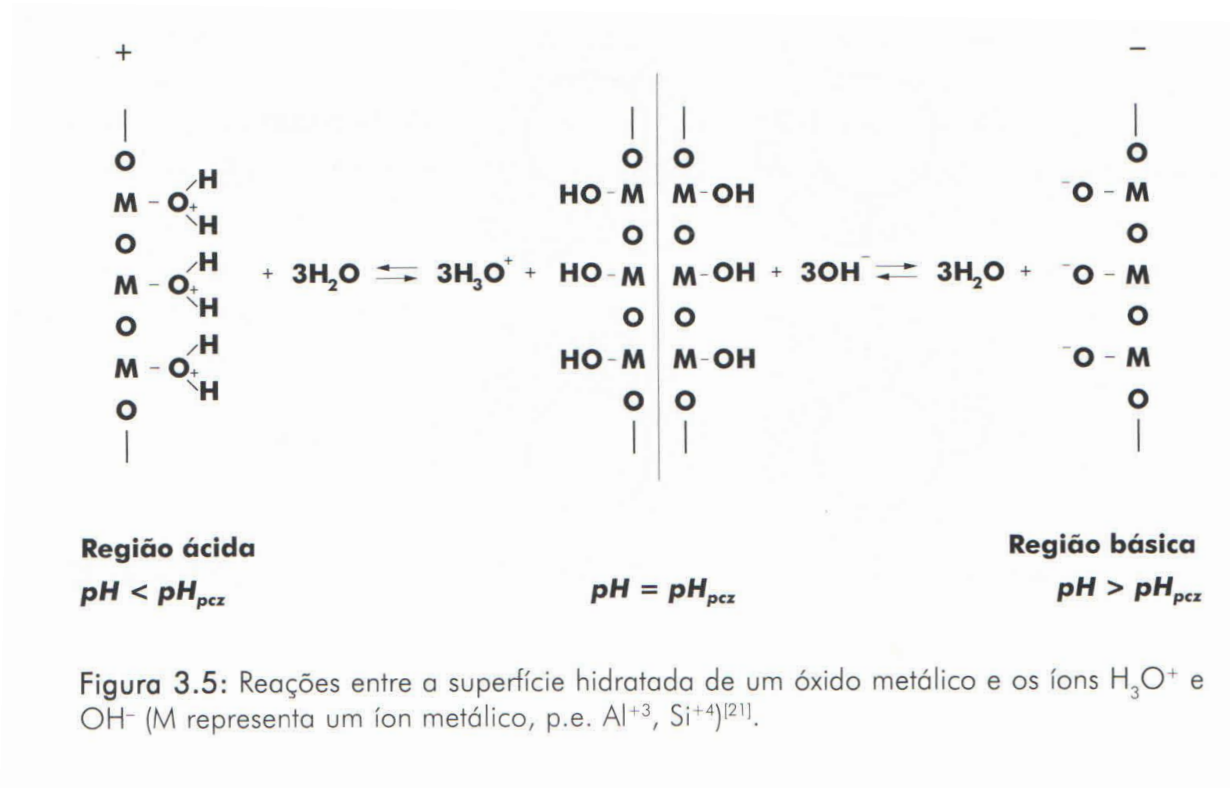
Dispersão de partículas em suspensão



Dispersão de partículas em suspensão



onde M é o cátion metálico



Dispersão de partículas em suspensão

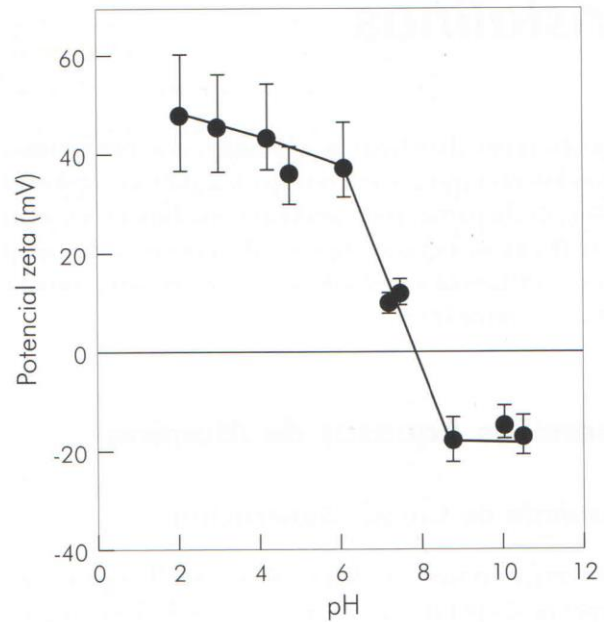


Figura 4.1: Variação do potencial zeta para suspensão de alumina em função do pH^[32].

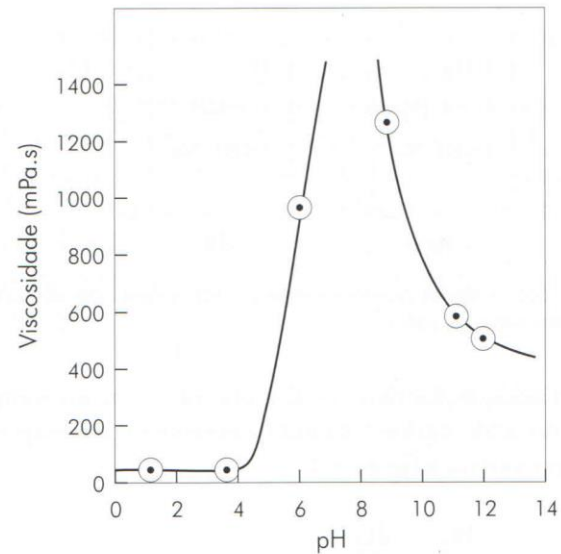


Figura 4.2: Variação da viscosidade para suspensão de alumina em função do pH^[33].

Dispersão de partículas em suspensão

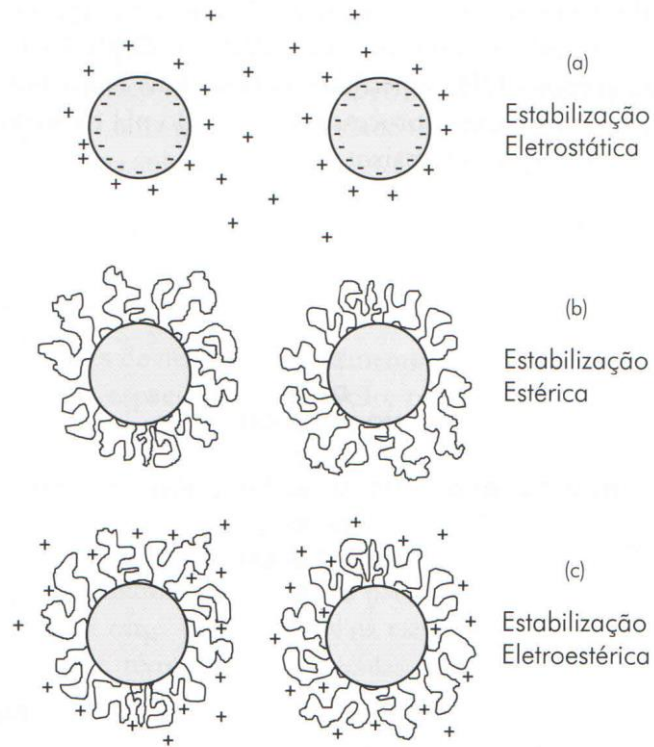


Figura 3.4: Ilustração dos mecanismos de estabilização de suspensões: (a) através de cargas nas superfícies das partículas, (b) da adsorção de polímeros e (c) da adsorção de moléculas ionizadas ou polieletrólitos^[12].

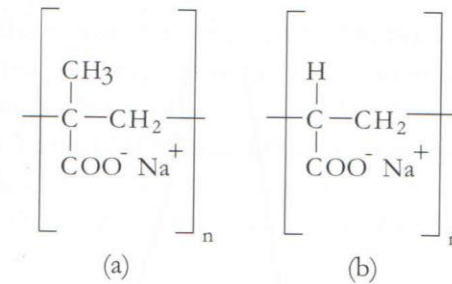


Figura 4.3: Esquema das unidades repetitivas (meros) das cadeias do (a) polimetacrilato de sódio e do (b) poliacrilato de sódio^[36].

Conformação cerâmica

- Pós adequadamente preparados (distribuição de tamanhos, dispersos, aditivados, em aglomerados moles) para a conformação nos formatos desejados
- **Objetivo:** promover a máxima aproximação entre partículas e eliminar ao máximo espaços vazios

Os principais métodos incluem

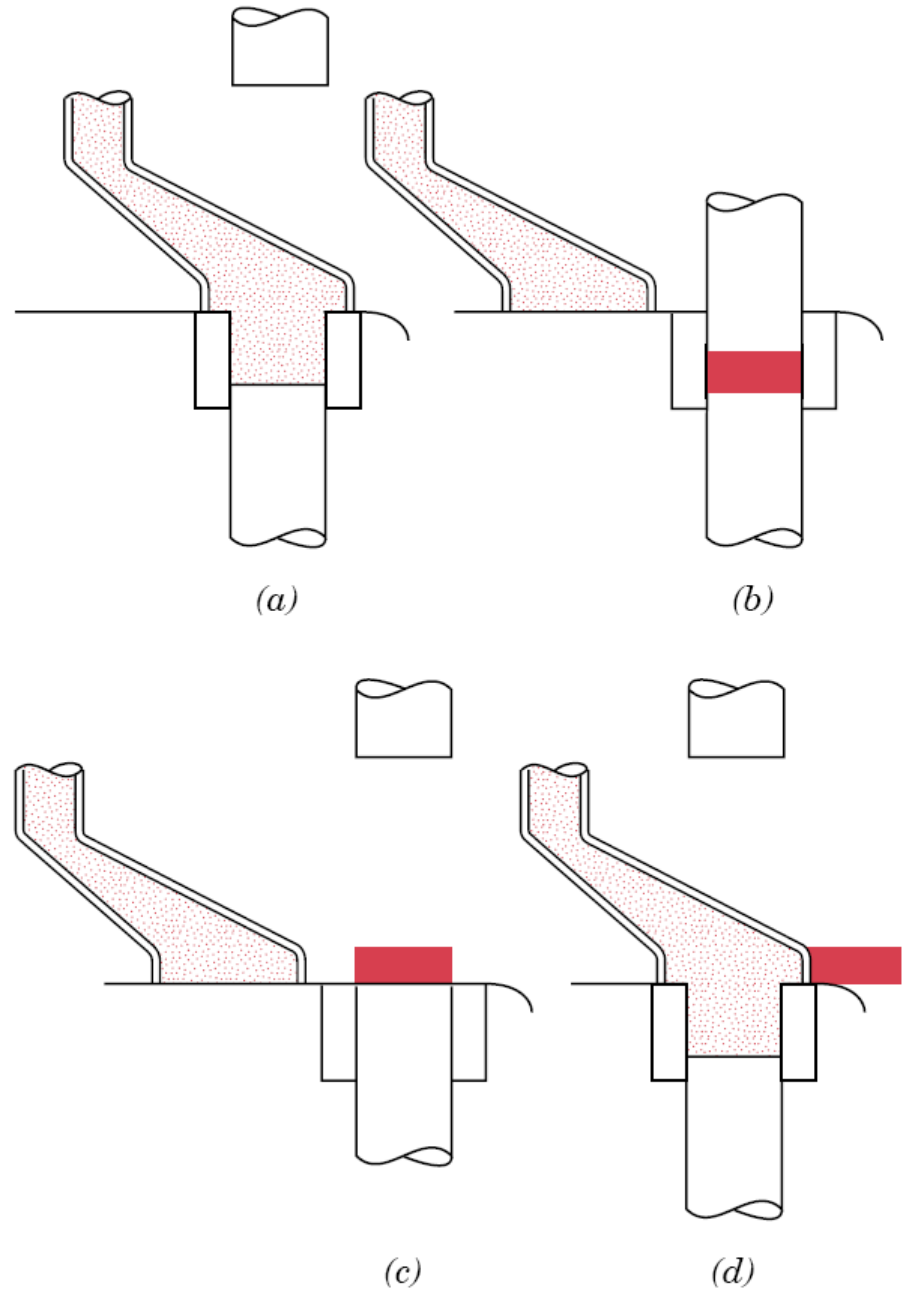
- Prensagem do pó semi-seco
- Mistura do pó com água e/ou polímeros orgânicos produzindo uma massa plástica, conformada por prensagem, deformação, extrusão ou injeção (conformação plástica)
- Vertimento de uma suspensão concentrada ou barbotina em molde poroso (colagem e “tape casting”)

Podemos relacionar os processos de conformação à consistência da massa

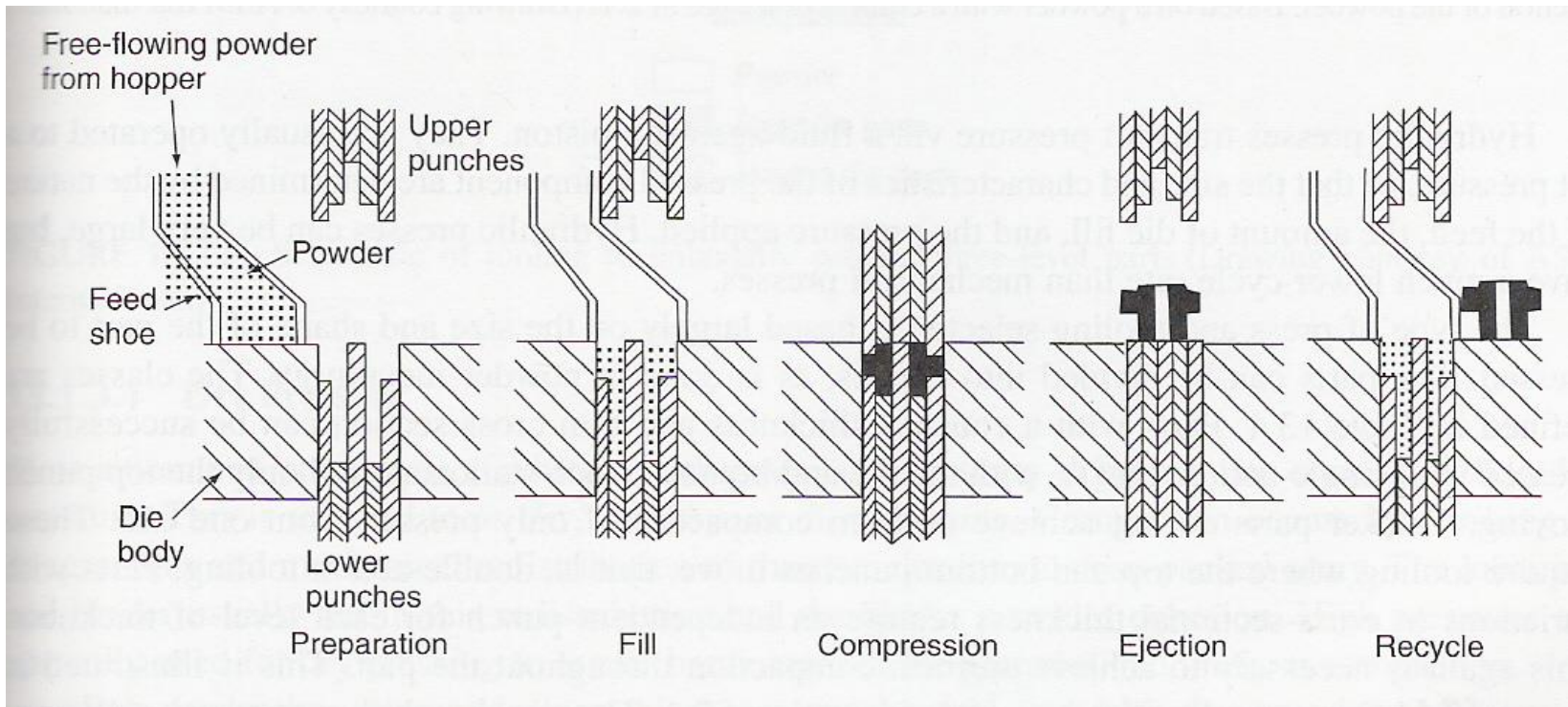
Processo	Pressão utilizada	% água
Via líquida	Zero ou hidrostática	20-25%
Massa plástica	Baixa	25-30
Extrusão	Média	15-20
Prensagem à seco	Alta	5-10
Prensagem do pó	Muito alta	1-2
Prensagem hidrostática	Muito alta	0-17

Técnicas de fabricação – conformação do pó

Prensagem

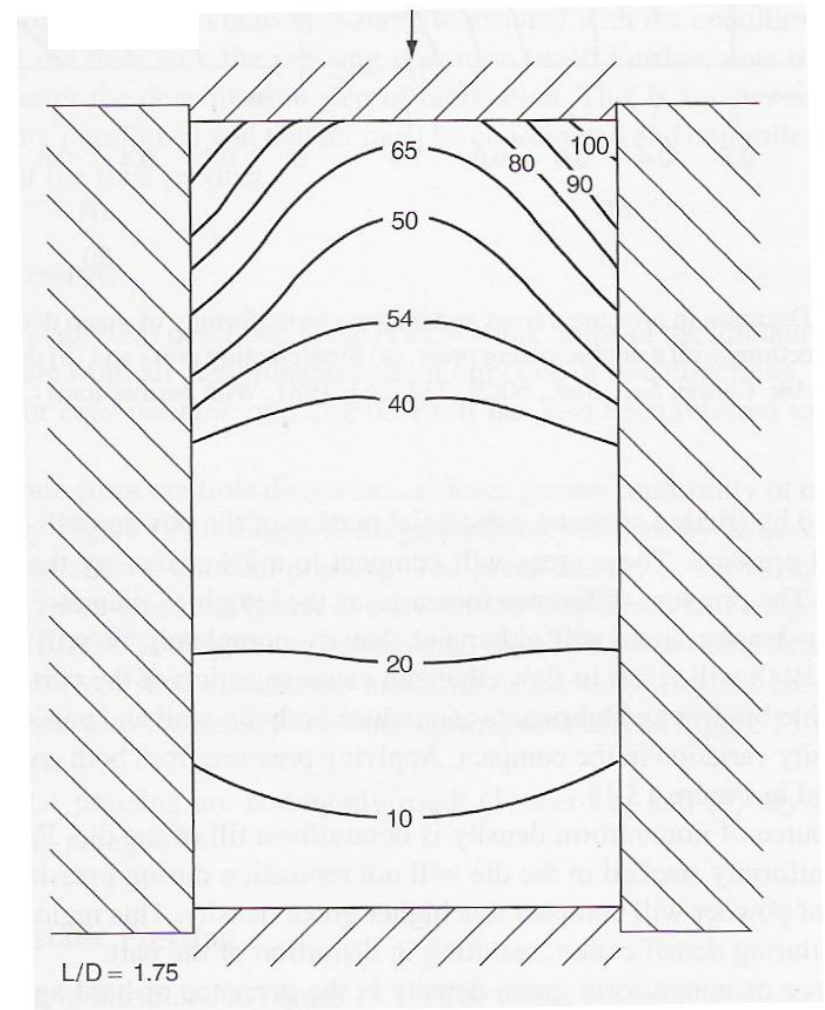
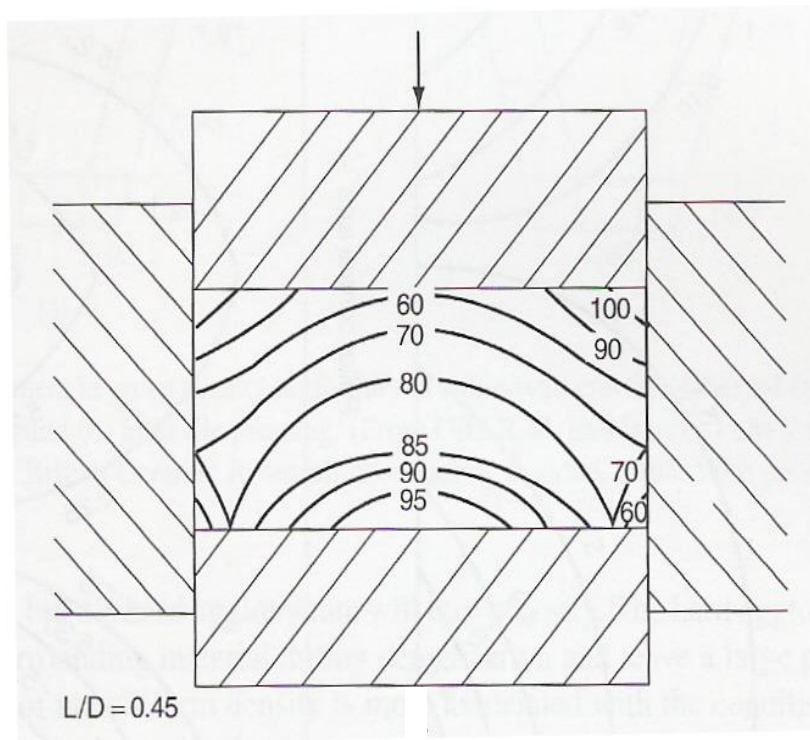


Prensagem uniaxial

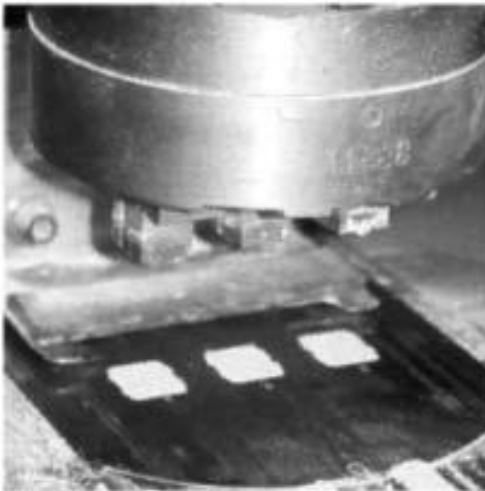


6-100/min!!

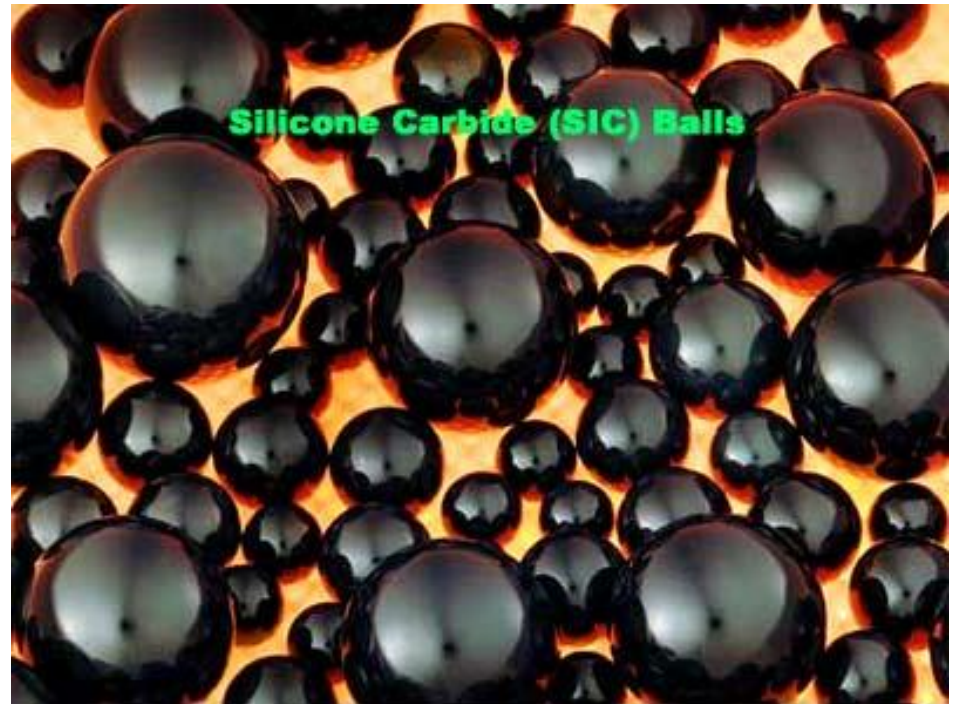
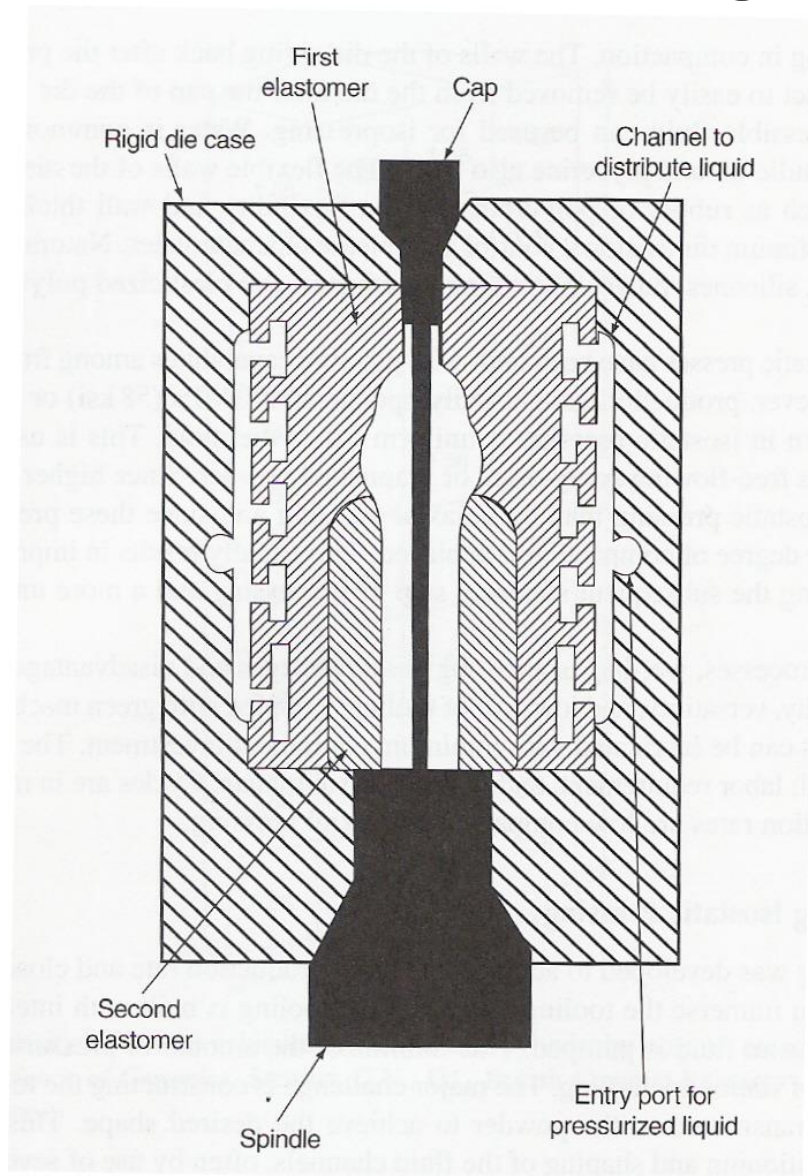
Prensagem uniaxial – efeito da espessura



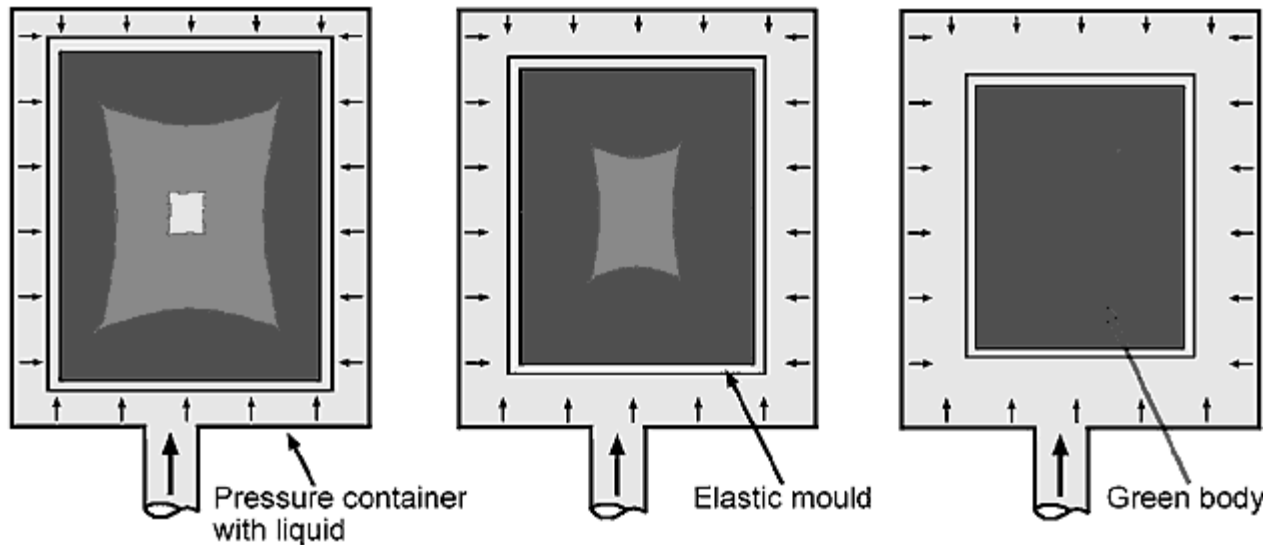
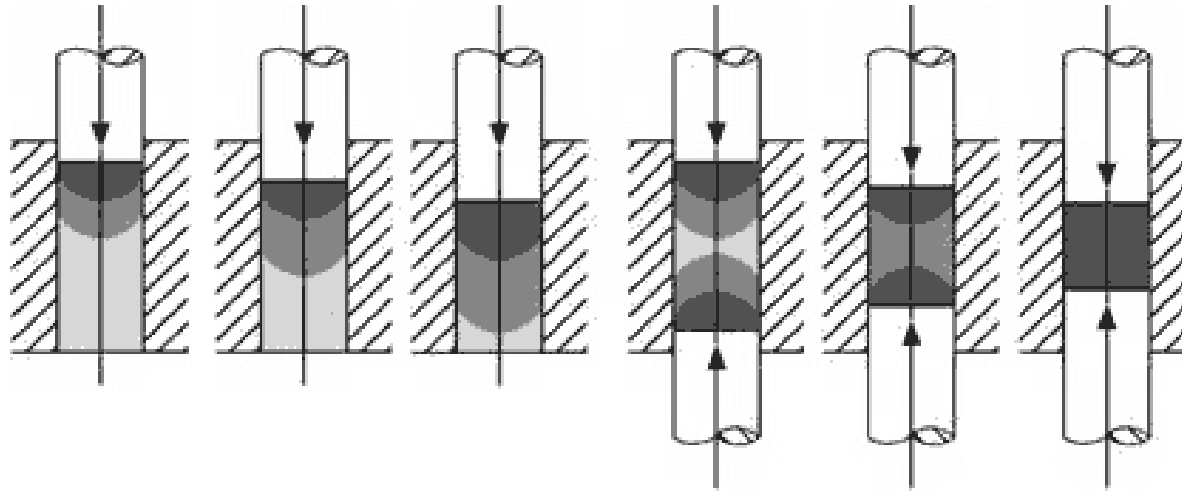
Prensagem uniaxial



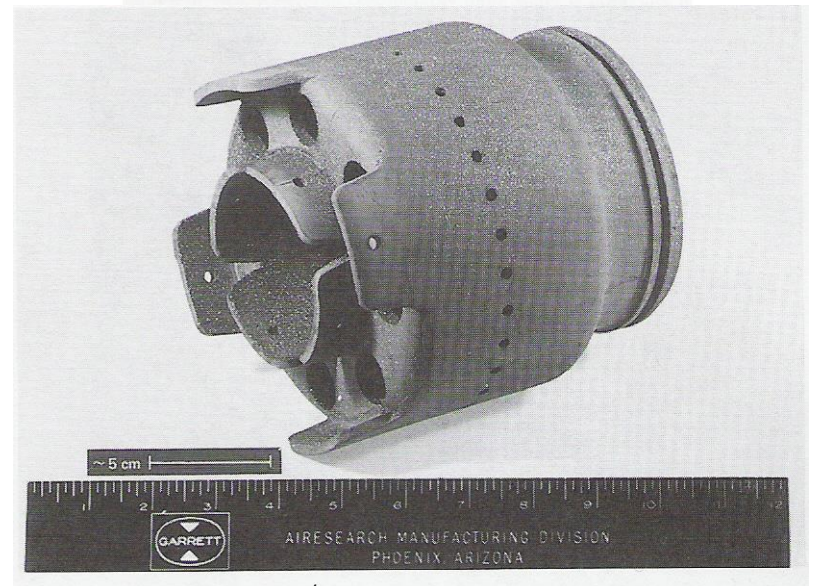
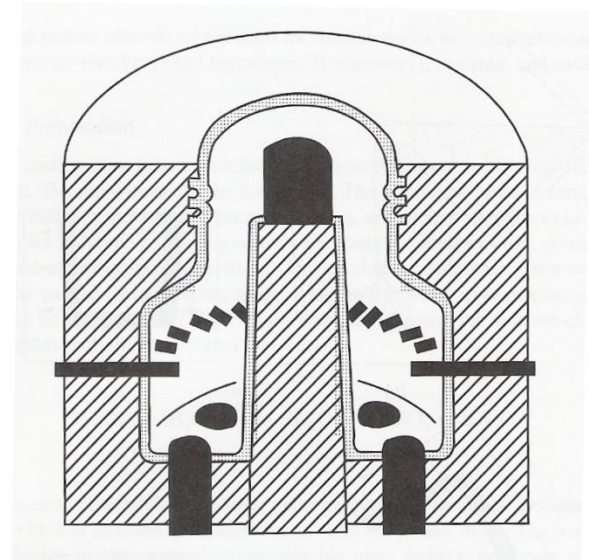
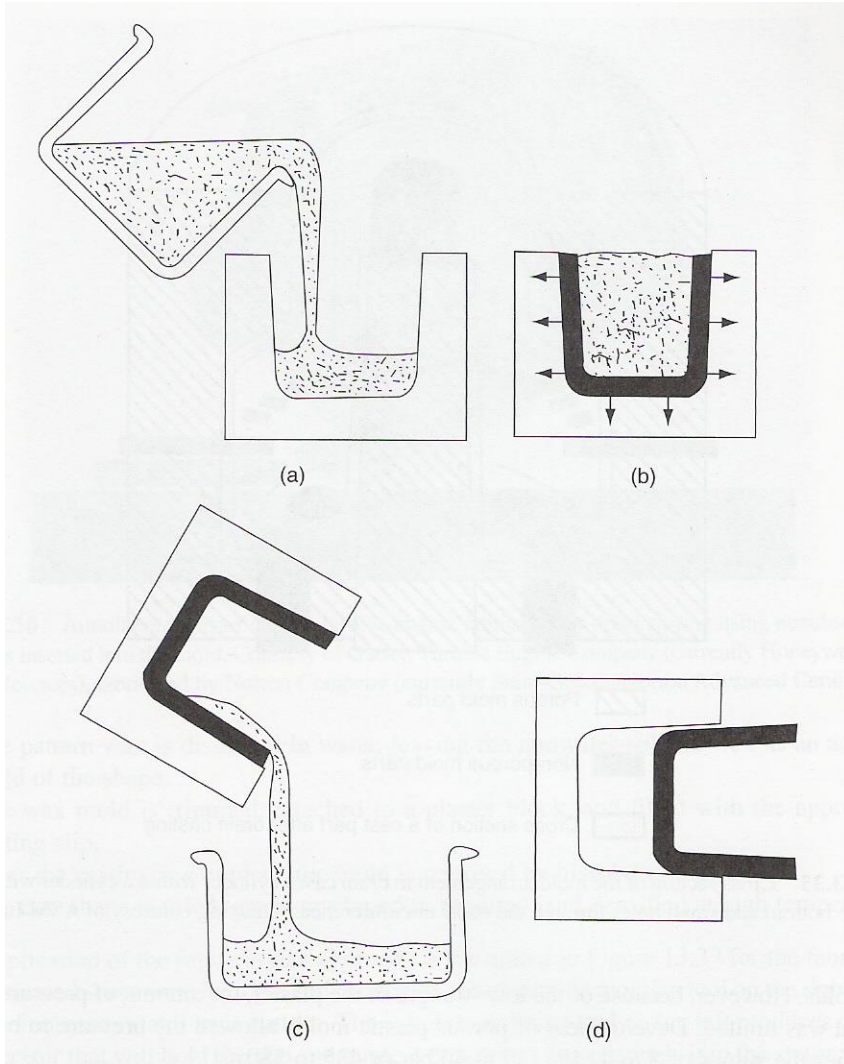
Prensagem isostática



Prensagem cerâmica – uniaxial x biaxial x isostática

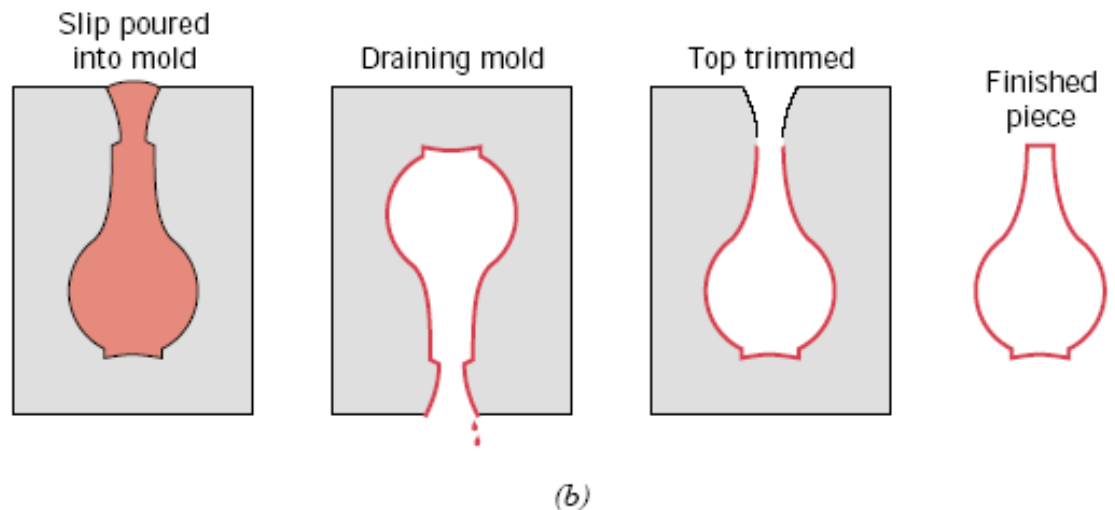
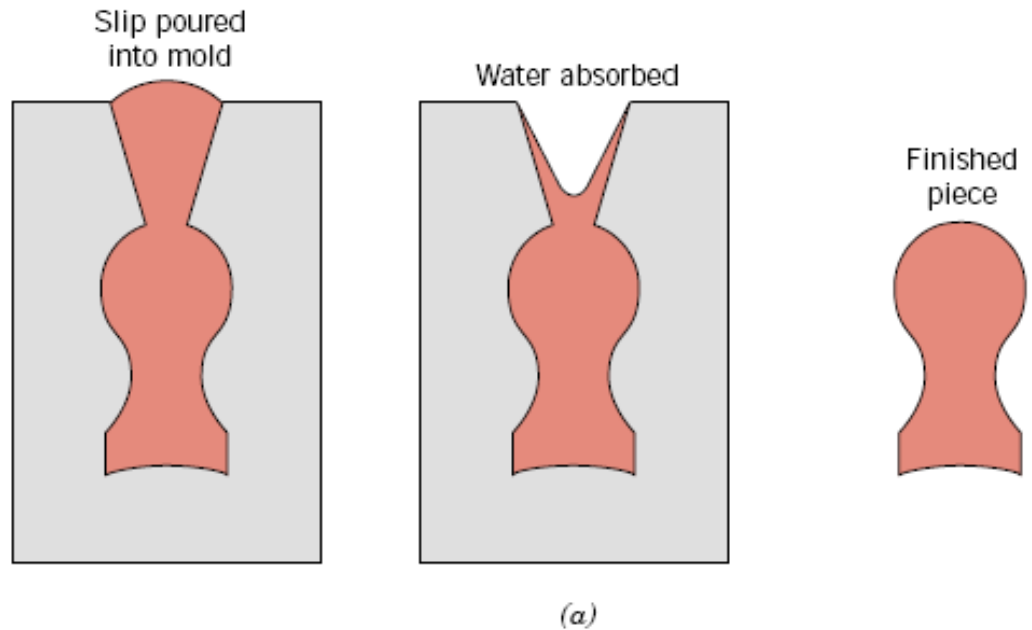


Colagem de barbotina

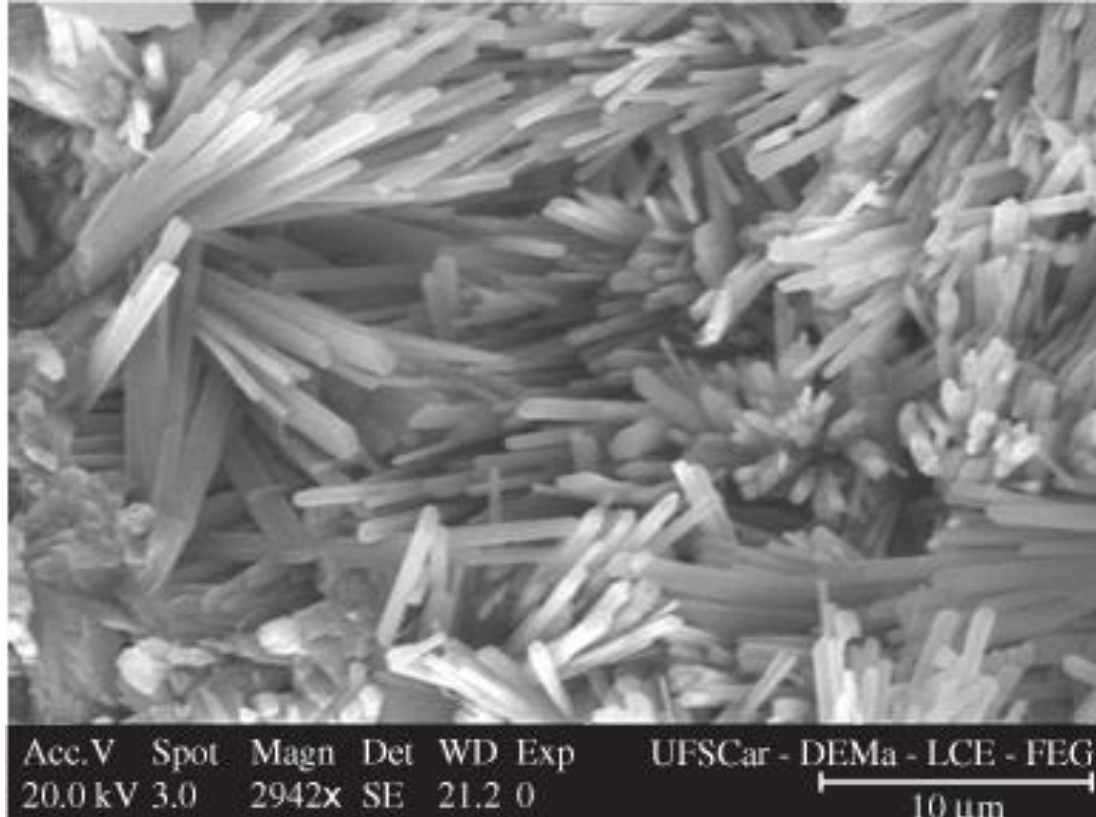


Técnicas de fabricação – conformação do pó

Colagem de barbotina



Técnicas de fabricação – colagem de barbotina



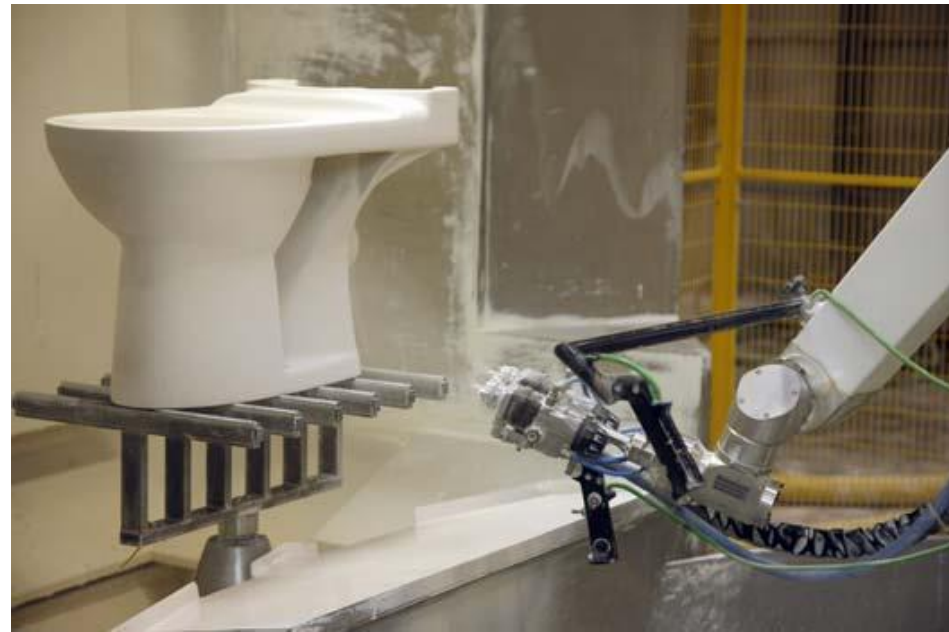
Microestrutura do gesso após a hidratação.

sulfato de cálcio hidratado ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) → hemidrato ($\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$)
calcinação

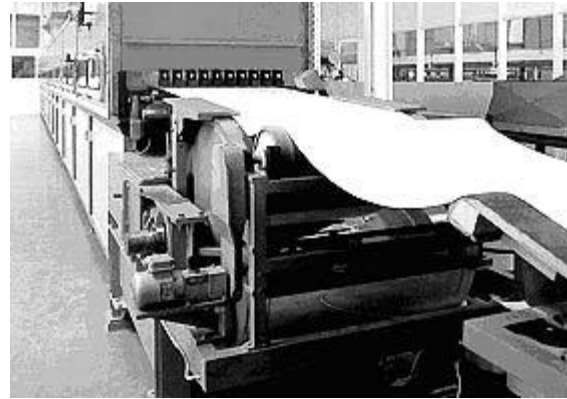
Técnicas de fabricação – colagem de barbotina



Porcelana sanitária



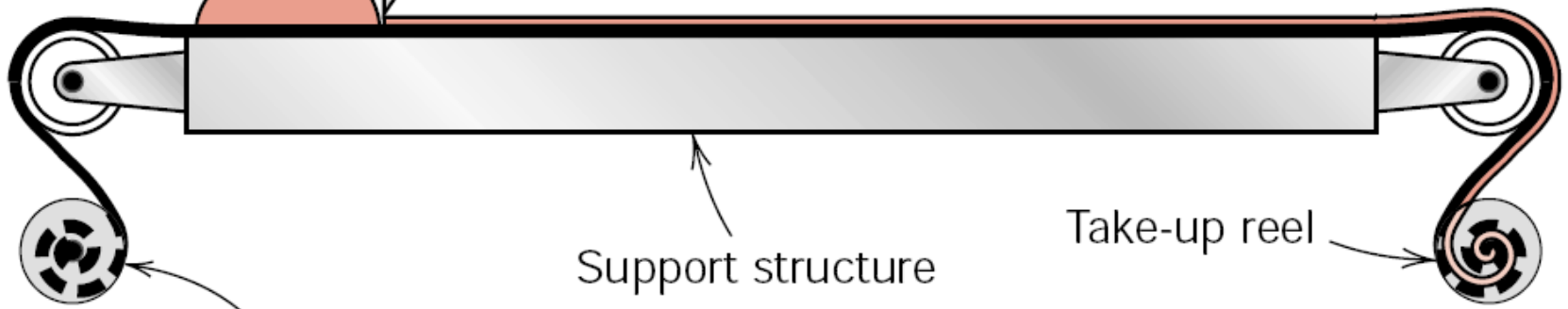
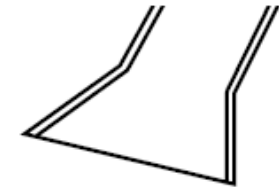
Tape casting (colagem de fita)



Slip source

Doctor blade

Warm air source

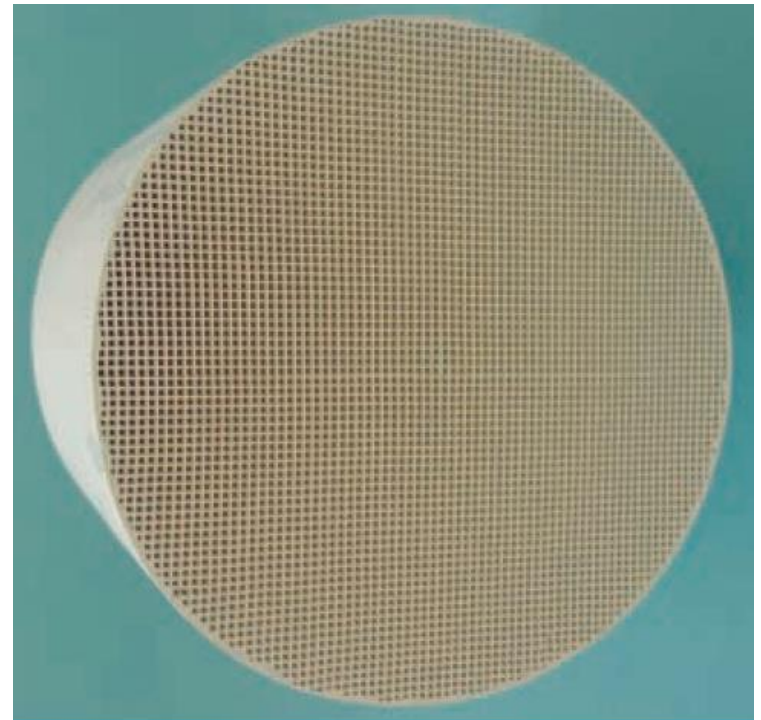
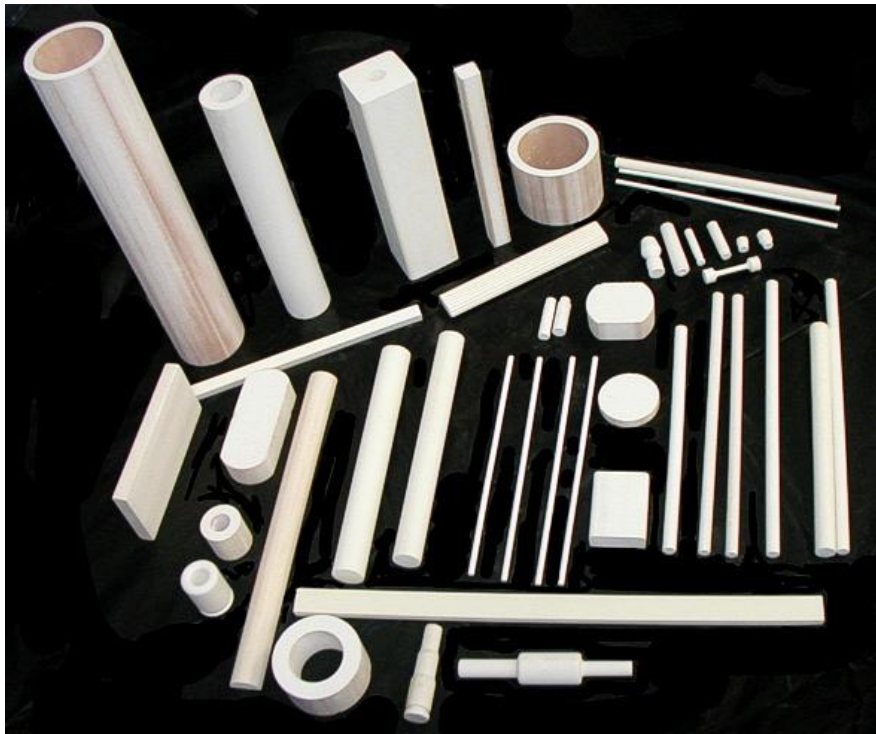
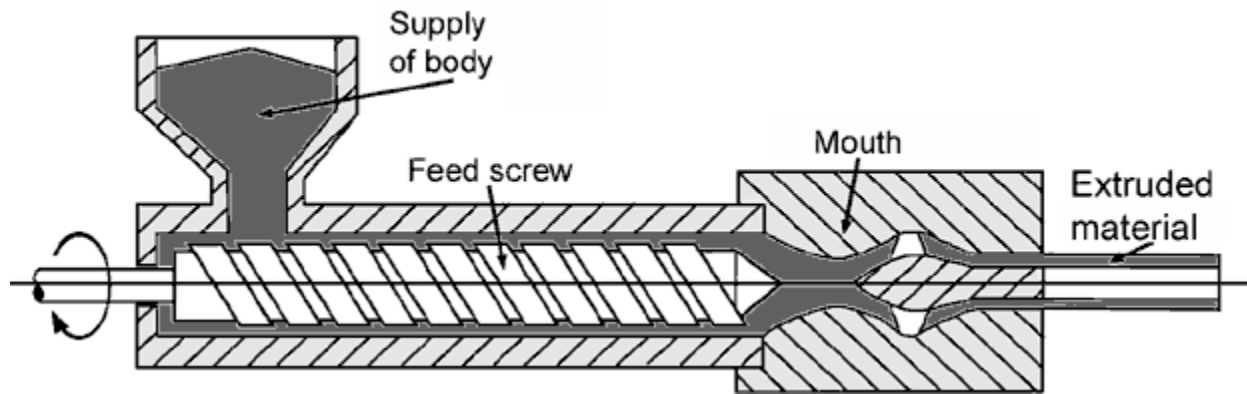


Reel of carrier film

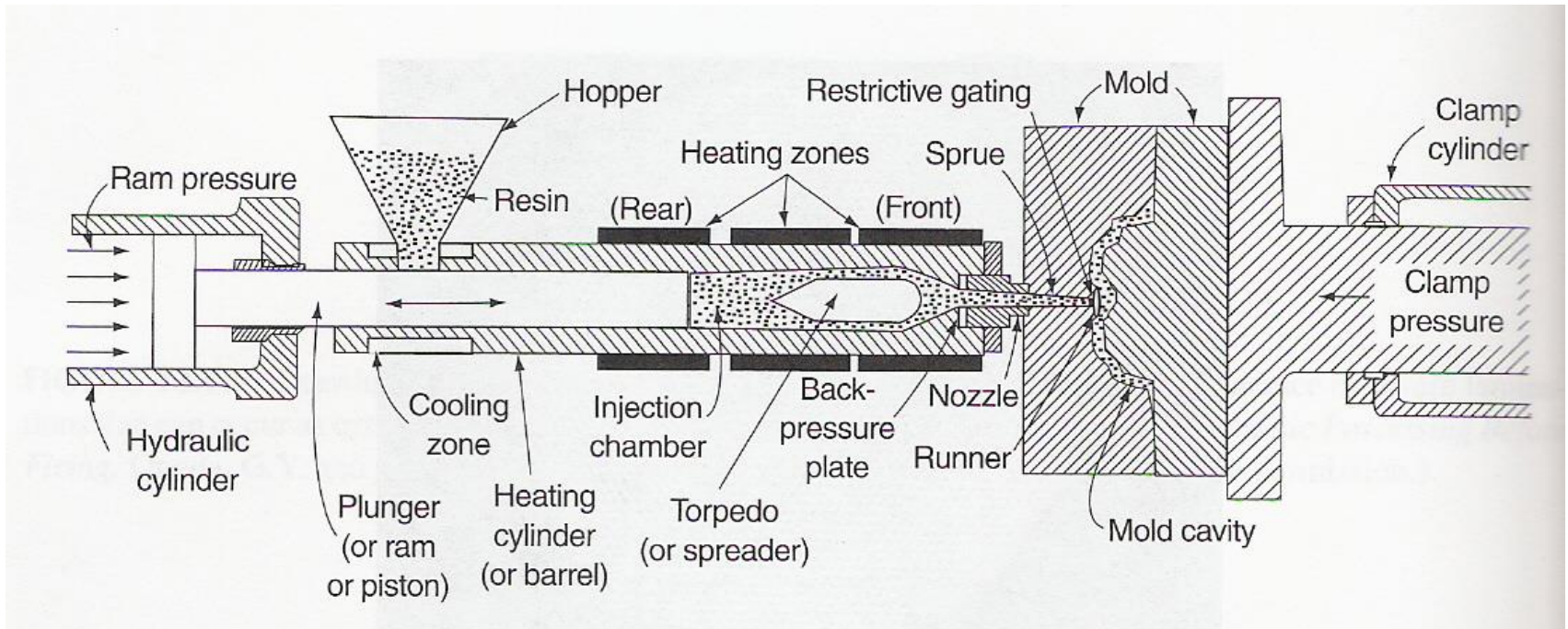
Support structure

Take-up reel

Extrusão



Injeção



Técnicas de fabricação – secagem

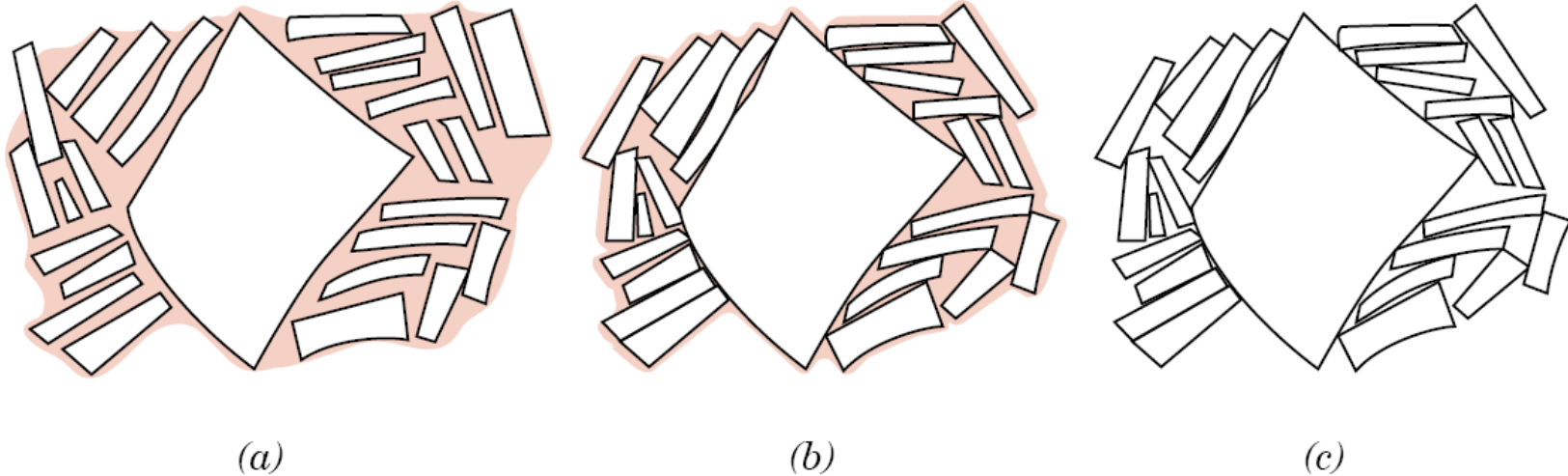
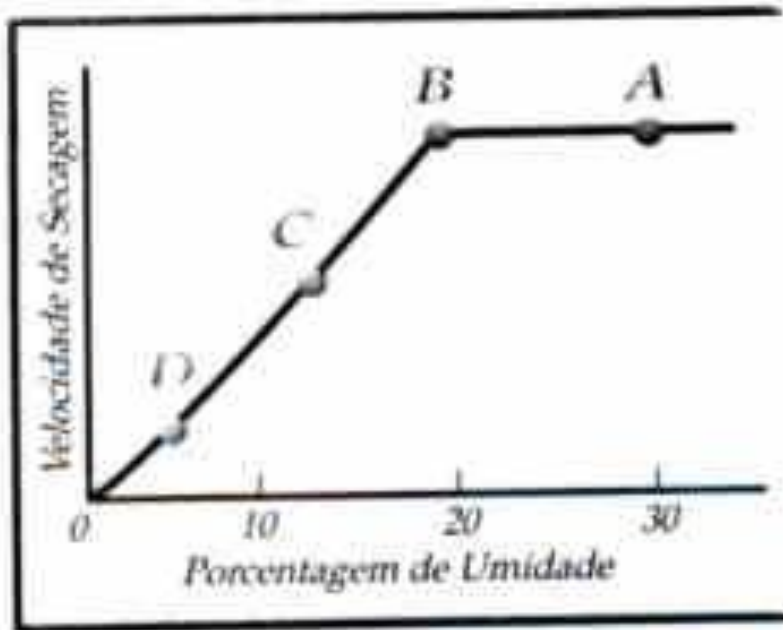


FIGURE 14.21 Several stages in the removal of water from between clay particles during the drying process. (a) Wet body. (b) Partially dry body. (c) Completely dry body. (From W. D. Kingery, *Introduction to Ceramics*. Copyright © 1960 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

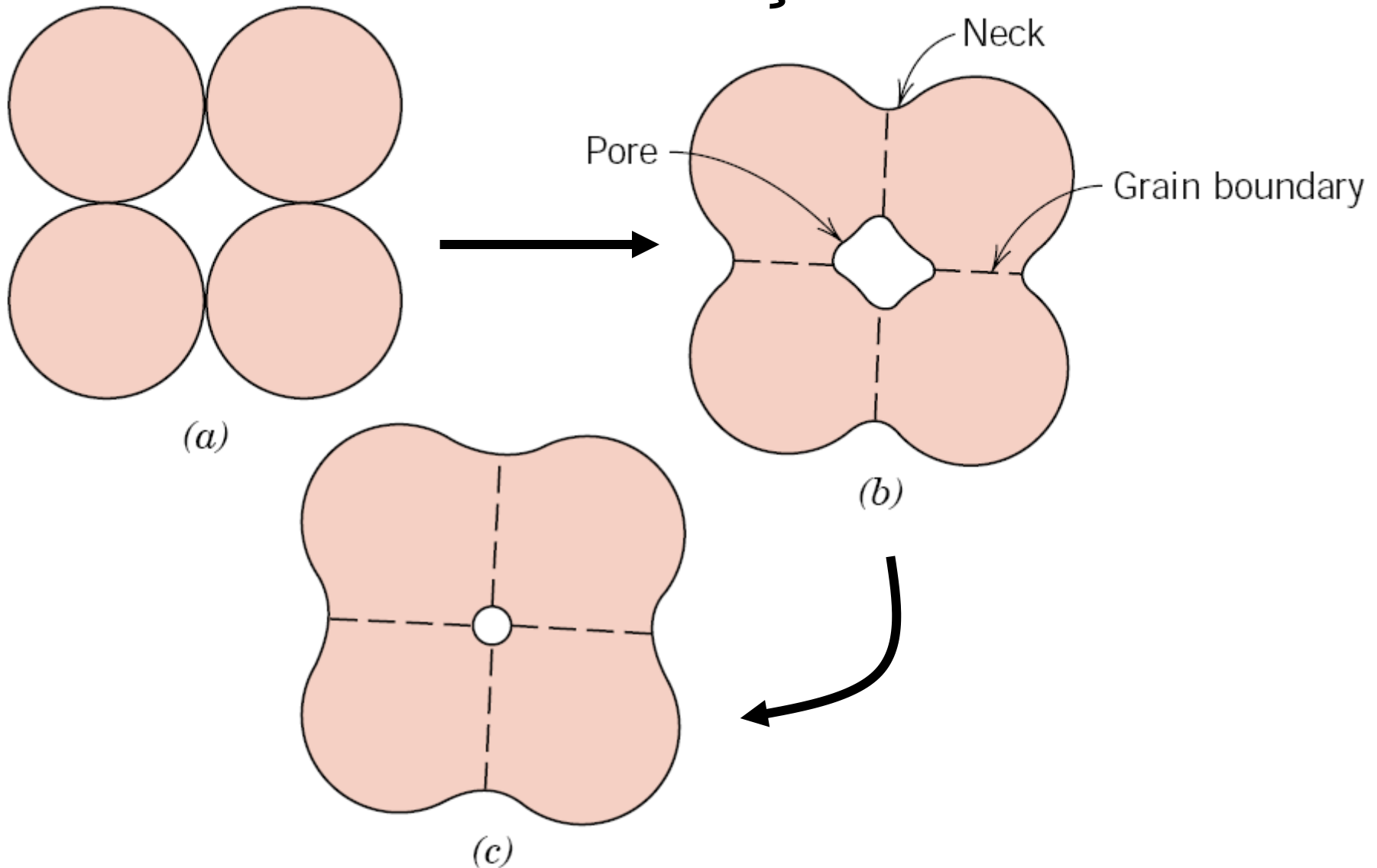
Secagem



- Enquanto houver uma película (ou filme) de água entre as partículas, a secagem é acompanhada de retração da peça (aproximação das partículas e diminuição do tamanho do corpo).
- Após a eliminação da água entre as partículas não ocorre mais retração, mas ainda há umidade para ser removida.



Técnicas de fabricação – queima ou sinterização



Microestrutura cerâmica

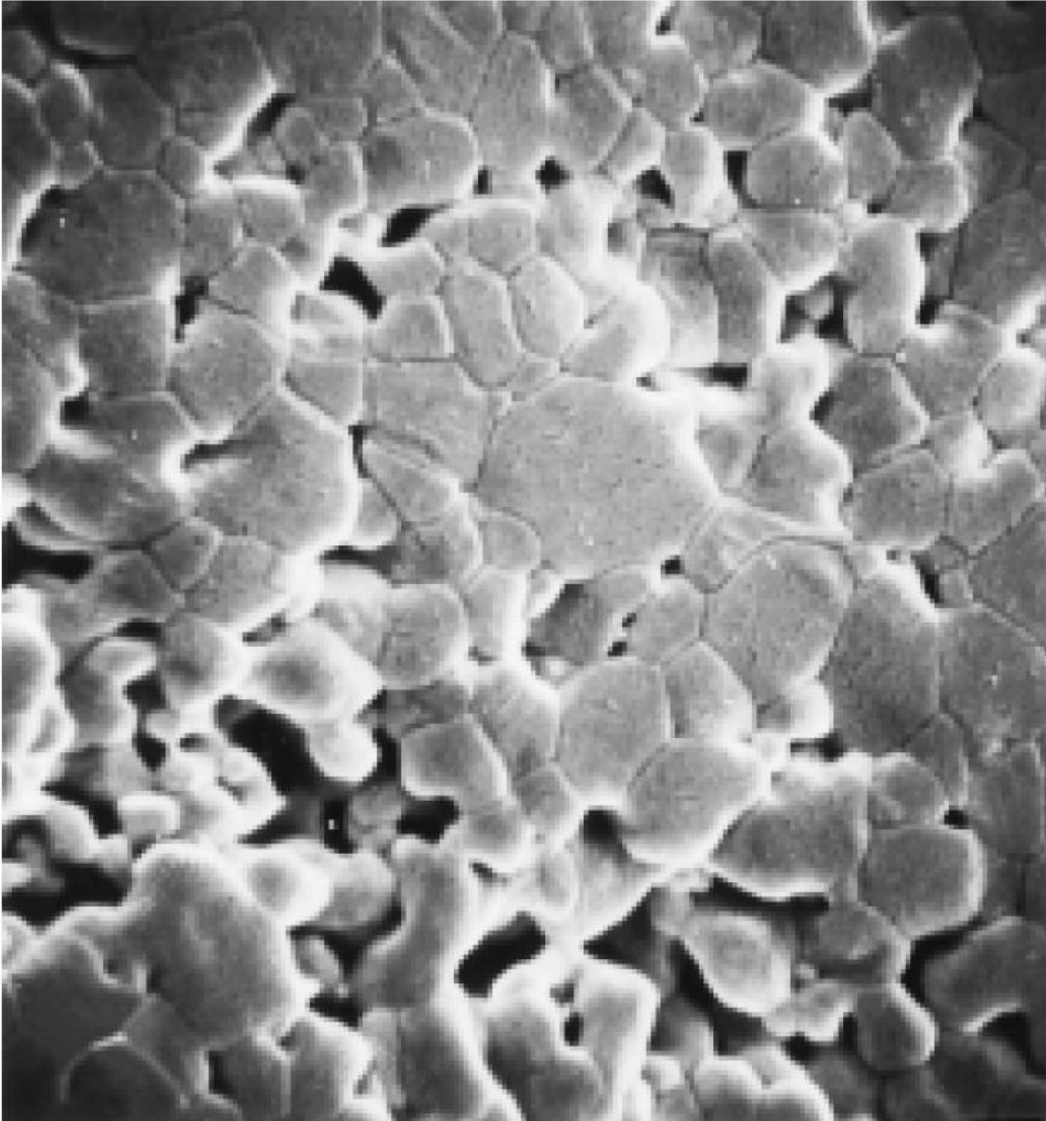


FIGURE 14.25 Scanning electron micrograph of an aluminum oxide powder compact that was sintered at 1700°C for 6 min. 5000×. (From W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, *Introduction to Ceramics*, 2nd edition, p. 483. Copyright © 1976 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.)

Microestrutura cerâmica – porcelana

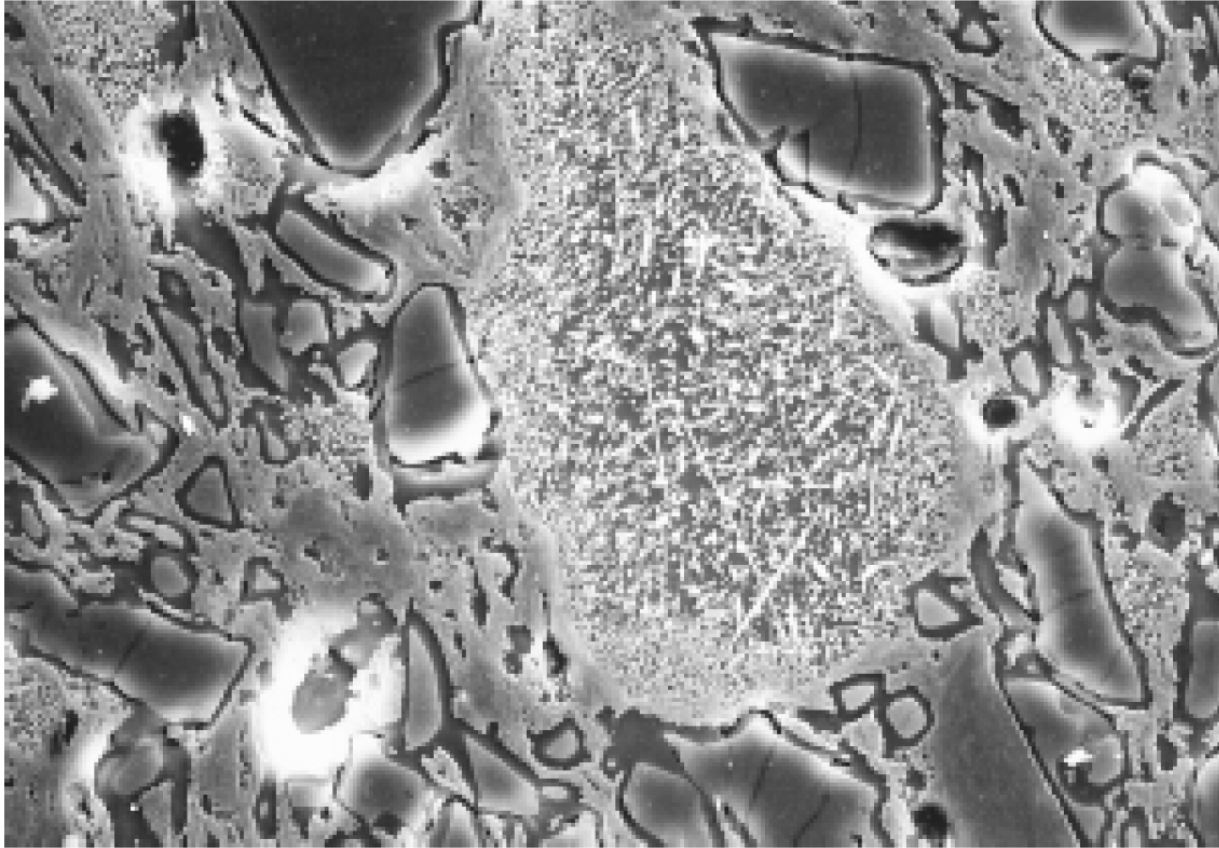


FIGURE 14.22 Scanning electron micrograph of a fired porcelain specimen (etched 15 s, 5°C, 10% HF) in which may be seen the following features: quartz grains (large dark particles) which are surrounded by dark glassy solution rims; partially dissolved feldspar regions (small unfeatured areas); mullite needles; and pores (dark holes with white border regions). Also, cracks within the quartz particles may be noted, which were formed during cooling, as a result of the difference in shrinkage between the glassy matrix and the quartz. 1500×. (Courtesy of H. G. Brinkies, Swinburne University of Technology, Hawthorn Campus, Hawthorn, Victoria, Australia.)

Microestrutura cerâmica – abrasivo

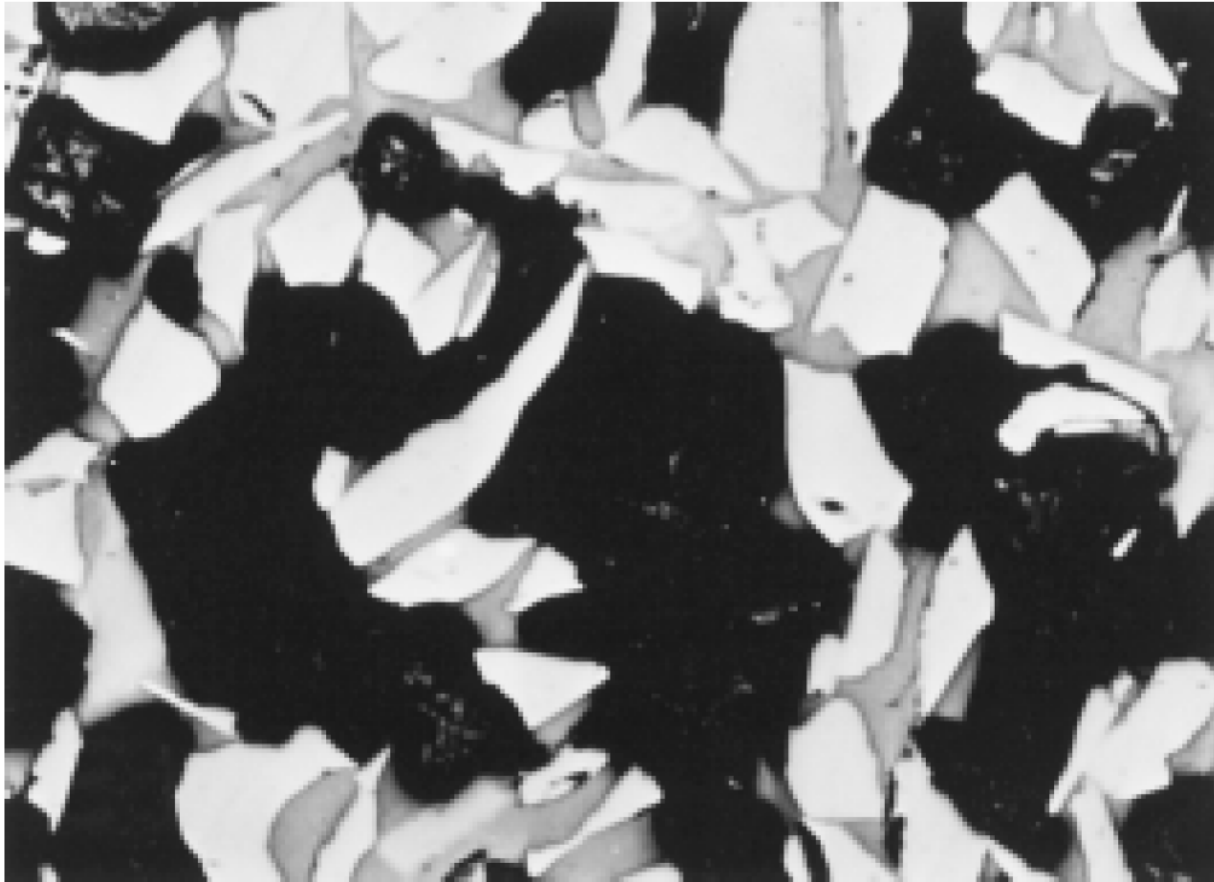
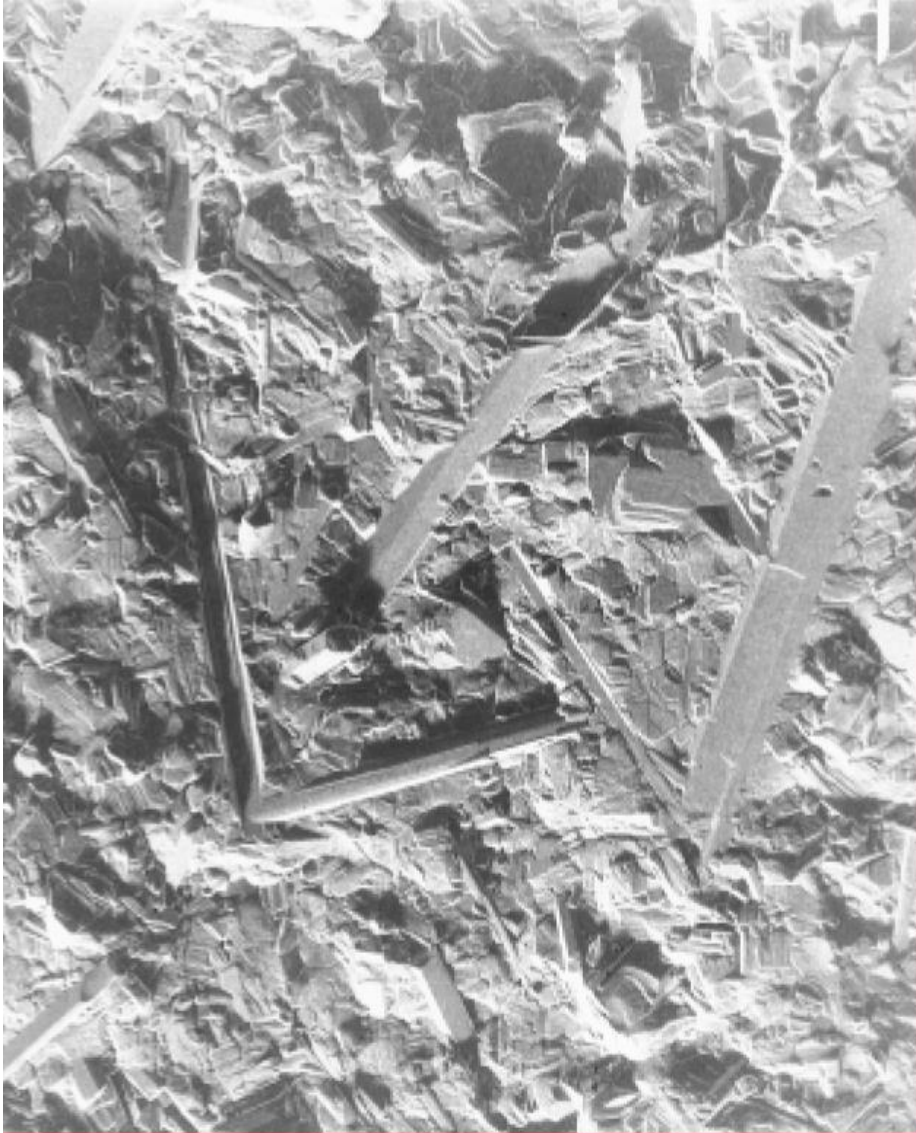


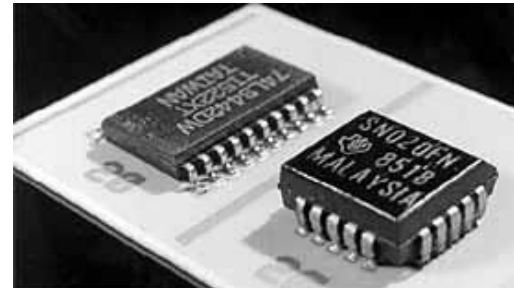
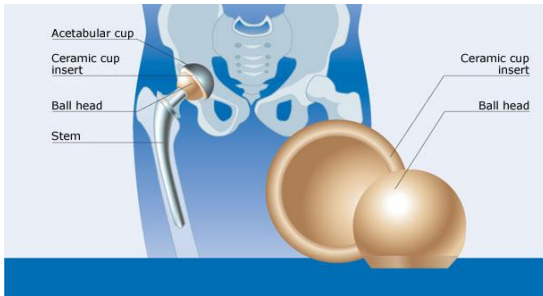
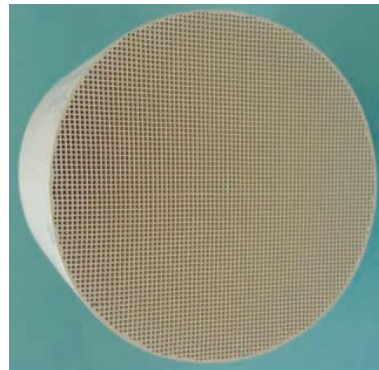
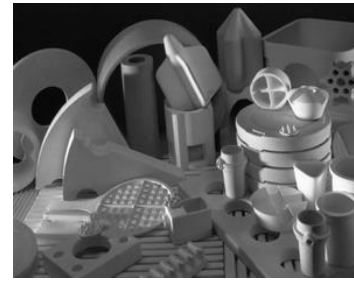
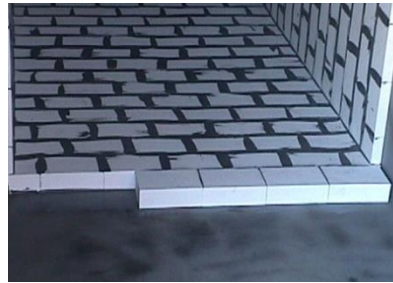
FIGURE 13.7 Photomicrograph of an aluminum oxide bonded ceramic abrasive. The light regions are the Al_2O_3 abrasive grains; the gray and dark areas are the bonding phase and porosity, respectively. 100 \times . (From W. D. Kingery, H. K. Bowen, and D. R. Uhlmann, *Introduction to Ceramics*, 2nd edition, p. 568. Copyright © 1976 by John Wiley & Sons. Reprinted by permission of John Wiley & Sons, Inc.)

Microestrutura cerâmica – vitrocerâmica



Scanning electron micrograph showing the microstructure of a glass-ceramic material. The long acicular blades yield a material with unusual strength and toughness. 65,000 \times . (Photograph courtesy of L. R. Pinckney and G. J. Fine of Corning Incorporated.)

Exemplos de materiais cerâmicos



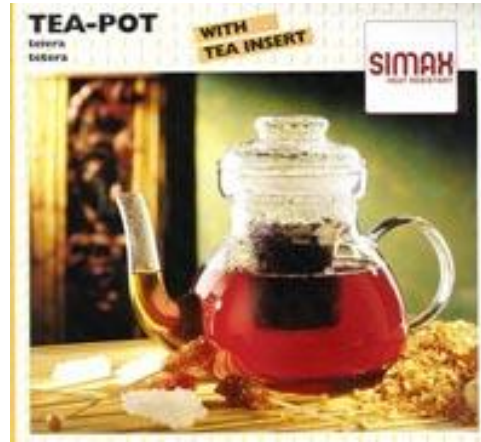
Vidro soda-cal ou vidro de janela



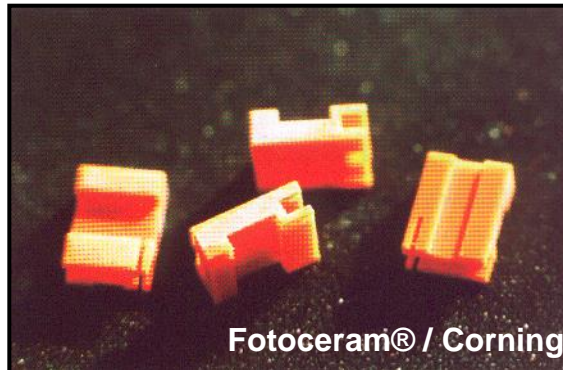
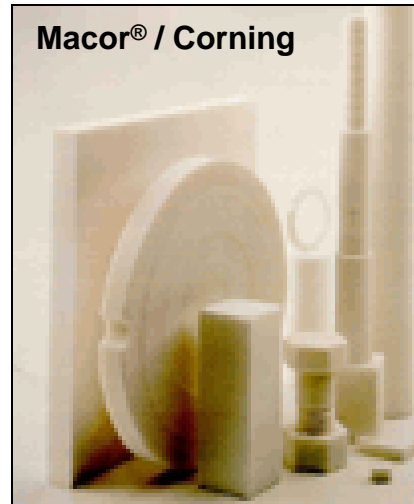
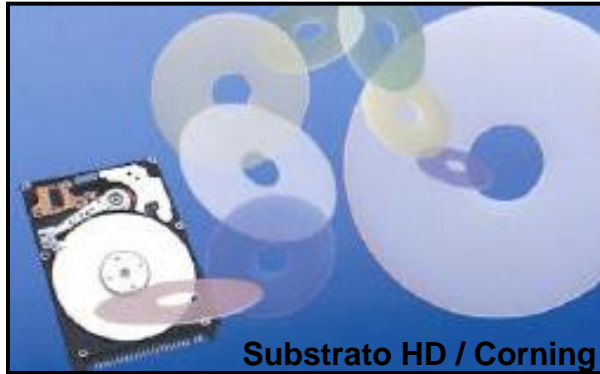
Vidros ao chumbo (“*cristais*”)



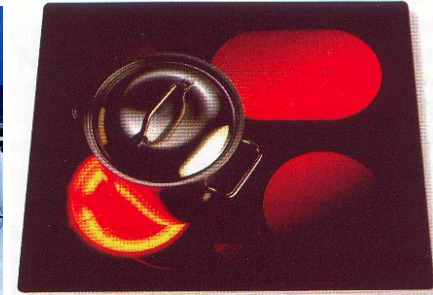
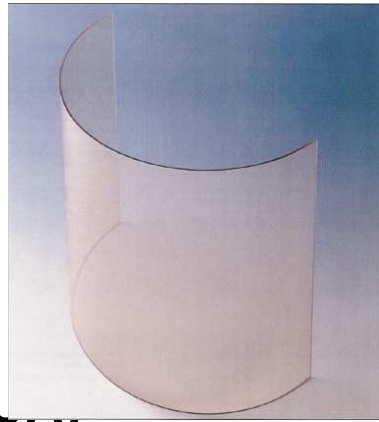
Vidros borosilicatos



Exemplos de Vitrocerâmicas



β -Quartzo_{SS} – (Li,R)O.Al₂O₃.nSiO₂ onde R = Mg²⁺, Zn²⁺ e n = 2 a 10



- Vision ® - Corning (EUA)
- Zerodur ® - Schott (Alemanha)
- Narumi ® - Nippon Electric Glass (Japão)
- Neoceram™ N-0 – NEG (Japão)
- Ceram ® - Schott (Alemanha)
- Keraglas ® - Eutokera (Corning/St. Gobain)
- Robax ® - versão sem cor do Ceram ®
- Eclair ® - versão sem cor do Keraglas ®

VLT telescope in Chile (8.2 m mirrors with adaptive optics)

Dr. Mark J. Davis



Mirror fabrication
in Mainz, Germany

(www.eso.org)

On the road to Cerro
Paranal, Chile



Neoparies™ - Nippon Electric Glass Co.,Ltd.

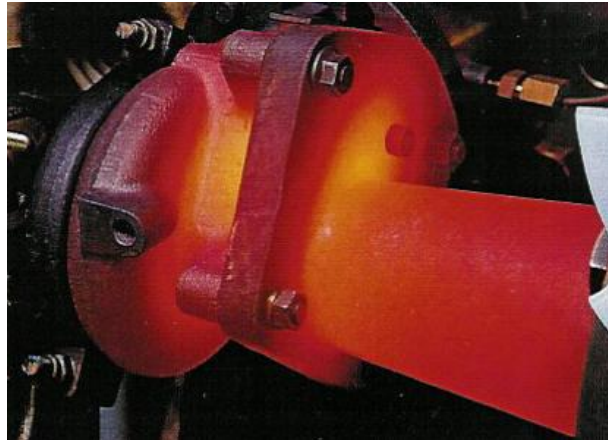
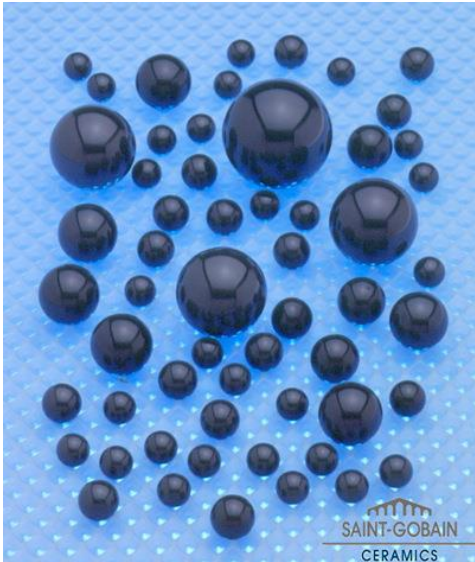


Clínica Kaneko - Tóquio (Japão)

Airside Terminal A
Tampa International Airport, U.S.



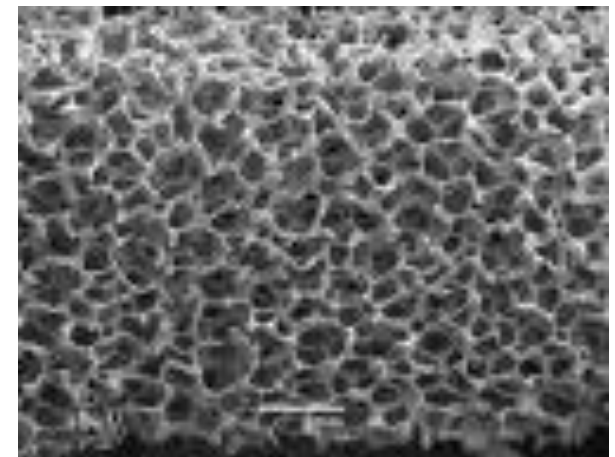
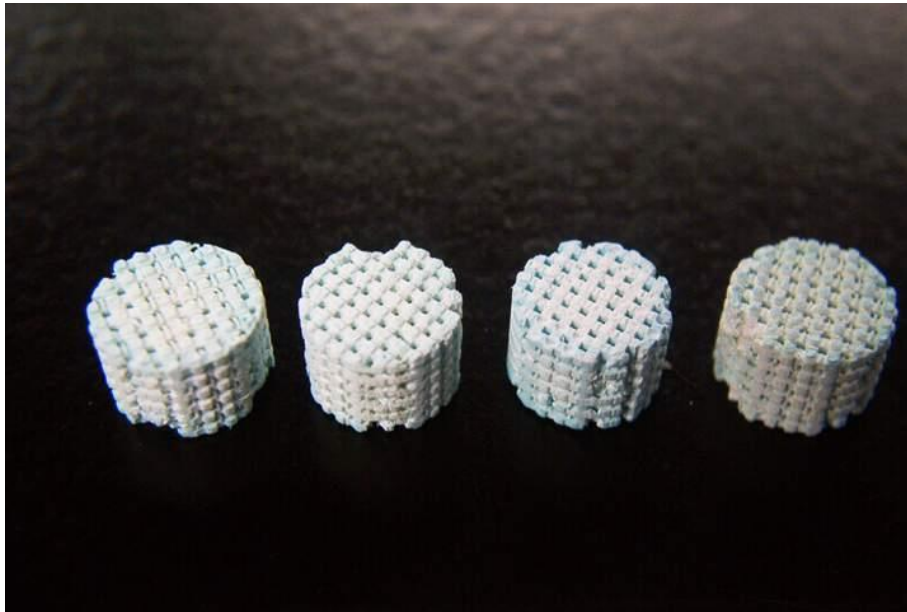
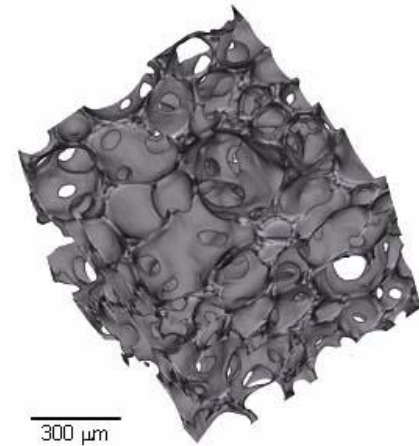
SiC/Si₃N₄



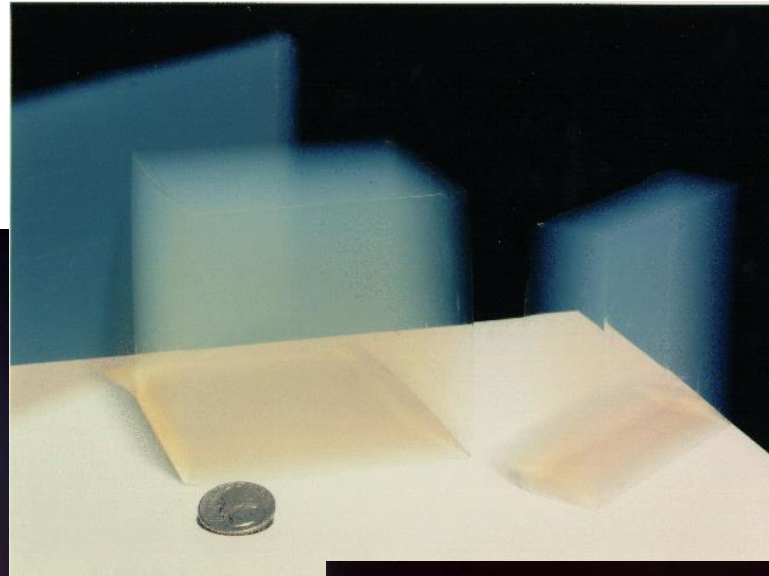
Aplicações modernas e futuristas



Bioglass



Aerogel

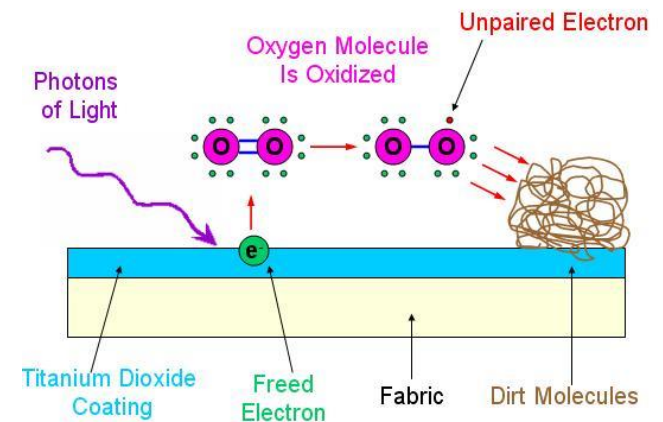


O Aerogel é um material extremamente leve, porém muito resistente. Na foto vemos um pequeno bloco de aerogel de 2,38 gramas sustentando um tijolo de 2,5 kg.

Aplicações modernas e futuristas



Vidros auto-limpantes e que não molham.



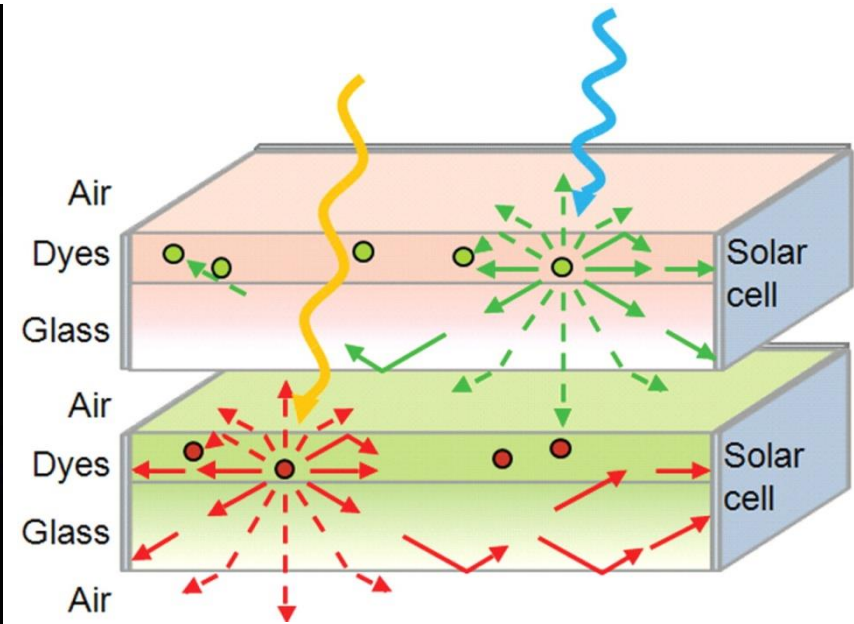
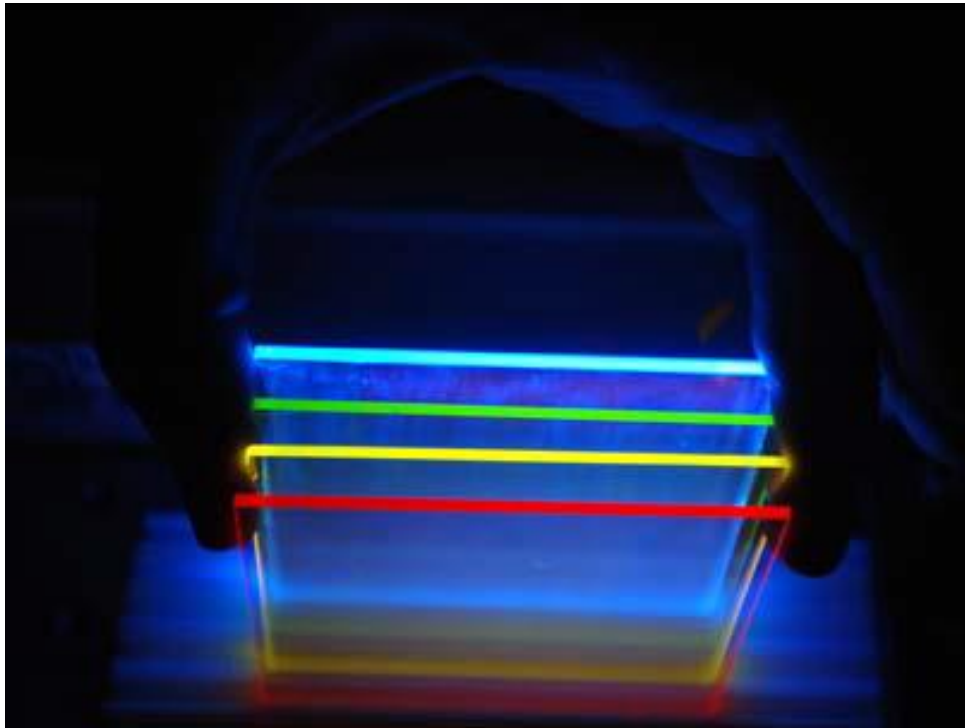
Aplicações modernas e futuristas



Concretos translúcidos!



Aplicações modernas e futuristas



Guias de luz para janelas, concentram a luz solar em células fotovoltaicas para geração de energia elétrica.

High-Efficiency Organic Solar Concentrators for Photovoltaics

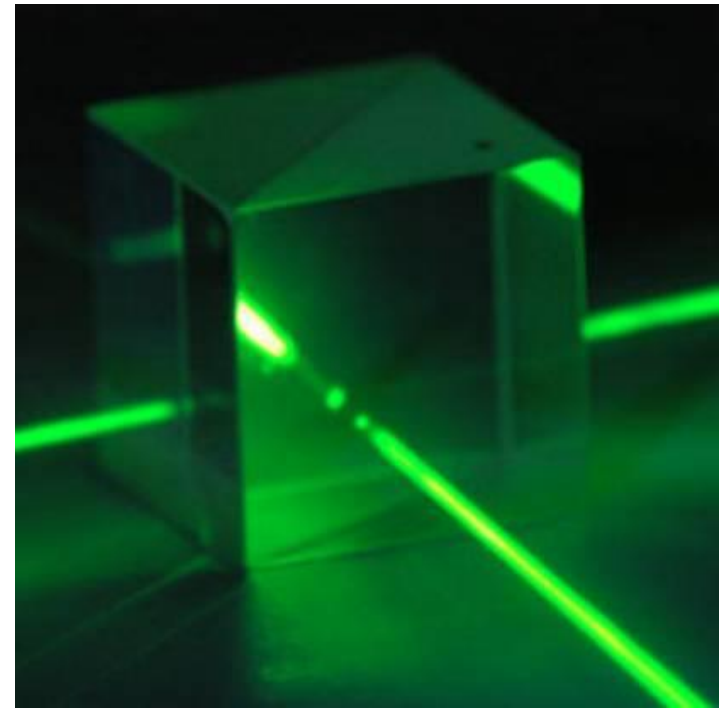
Science 11 July 2008:

Vol. 321. no. 5886, pp. 226 - 228

Photo-thermo-refractive (PTR) glass

Applications

- laser and opto-electronic devices
- narrow band filters
- attenuators
- beam splitters
- samplers
- multiplexers
- optical communication
- high power lasers



Ultimate efficiency of multi-channel spectral beam combiners by means of volume Bragg gratings

*Armen Sevian, Oleksiy Andrusyak, Igor Ciapurin, George Venus, and Leonid Glebov

Proc. of SPIE Vol. 6453 64530R-1

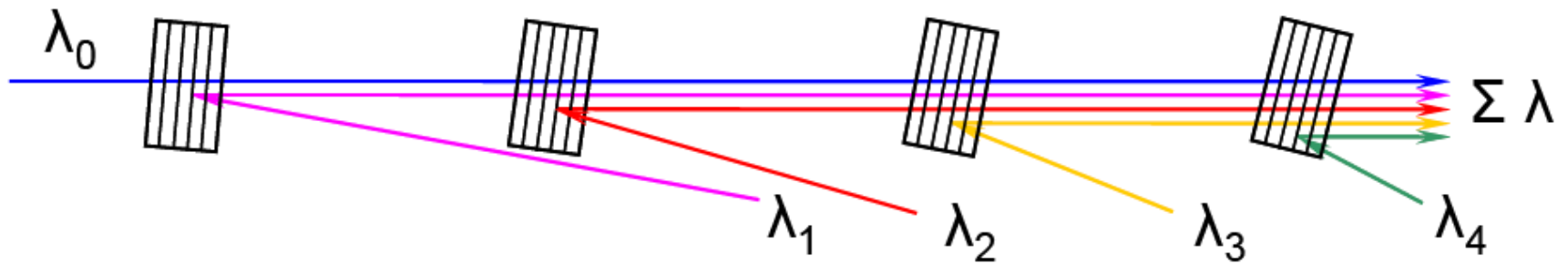


Fig. 4. Schematic of beam combining setup with five distinct laser sources and identical reflection VBGs.

