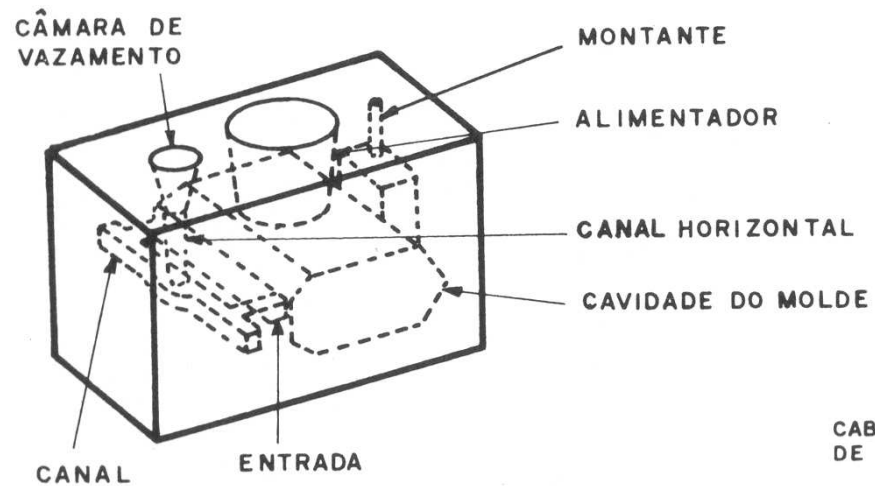




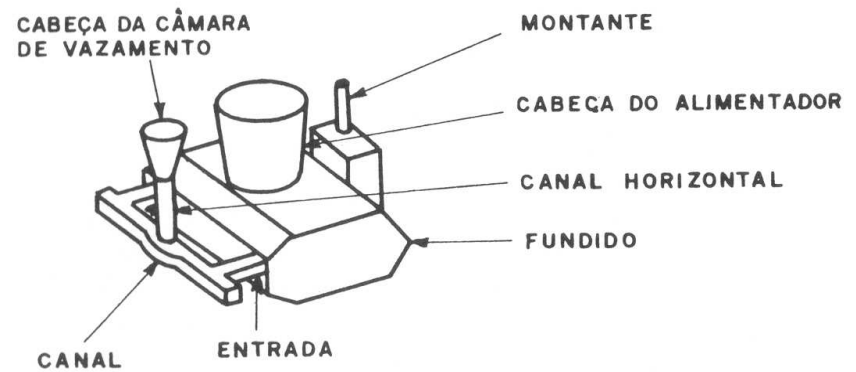
# Processos de Fundição

---

# O Molde

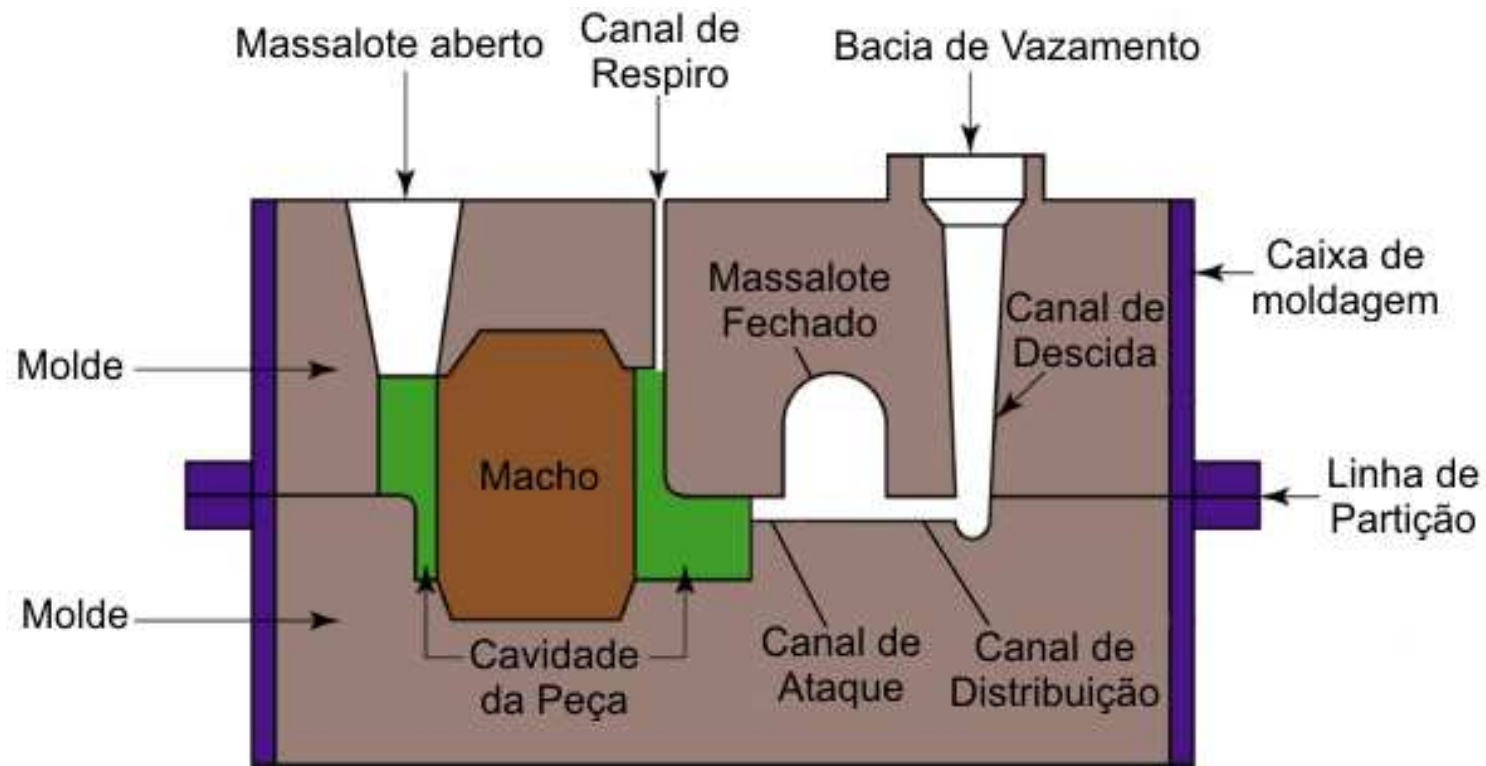


CAVIDADE DO MOLDE



PEÇA FUNDIDA

# O Molde (partes básicas)





# Tipos de Moldes

---

- Colapsáveis – são quebrados para retirada das peças
  - 1 molde = 1 peça ou conjunto de peças
- Permanentes – são abertos para retirada das peças e reutilizados
  - 1 molde = milhares de peças



# Tipos de Moldes

---

- Colapsáveis (as cavidades são feitas utilizando-se modelos)
  - Areia
  - Gesso
  - Cerâmicos
- Permanentes (as cavidades são feitas por usinagem)
  - Aço
  - FoFo
  - Cobre
  - etc.



# Moldagem em areia

---

- Areia com ligantes:
  - Areia + bentonita (areia verde)
  - Areia + cimento
  - Areia + ligante de cura a frio
    - Silicato de sódio, resinas orgânicas
  - Areia + ligante de cura a quente
    - Resinas orgânicas
- Areia sem ligantes



# Modelos

---

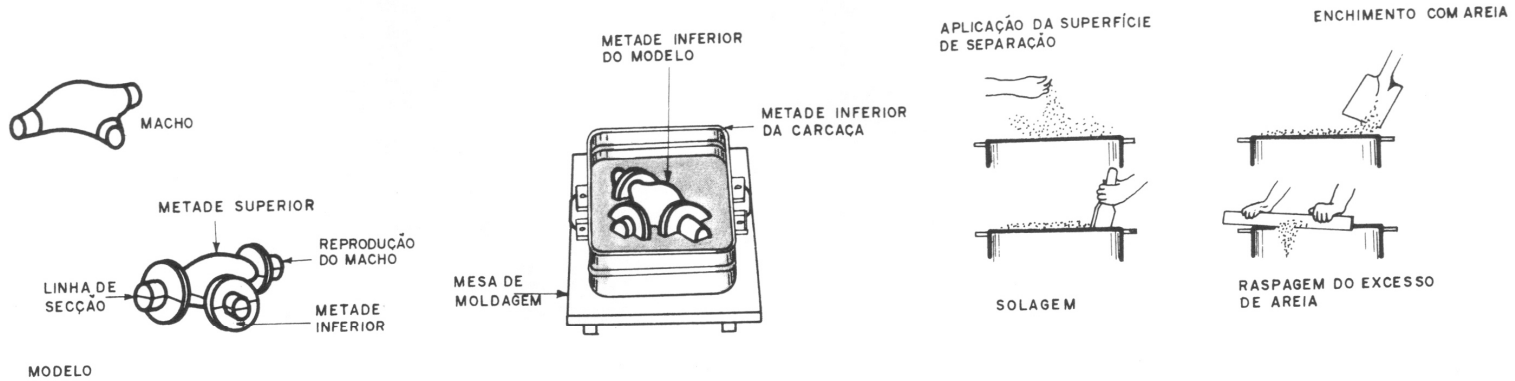
- Materiais
  - Madeira
  - Metálicos
  - Poliméricos
- São montados em placas de moldagem, os mais comuns são os bipartidos

# Características dos materiais usados em modelos

TABLE 11.3					
Characteristic	Rating <sup>a</sup>				
	<i>Wood</i>	<i>Aluminum</i>	<i>Steel</i>	<i>Plastic</i>	<i>Cast iron</i>
Machinability	E	G	F	G	G
Wear resistance	P	G	E	F	E
Strength	F	G	E	G	G
Weight <sup>b</sup>	E	G	P	G	P
Repairability	E	P	G	F	G
Resistance to:					
Corrosion <sup>c</sup>	E	E	P	E	P
Swelling <sup>c</sup>	P	E	E	E	E
aE, Excellent; G, good; F, fair; P, poor.					
bAs a factor in operator fatigue.					
cBy water.					
<i>Source: D.C. Ekey and W.R. Winter, Introduction to Foundry Technology. New York.</i>					
McGraw-Hill, 1958.					

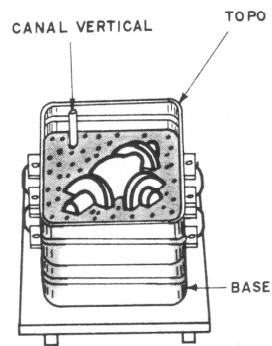


# Moldagem em Caixa (*areia verde ou cura a frio*)

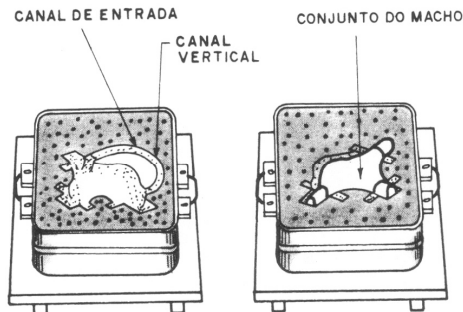


1. A PARTE INFERIOR DO MODELO É COLOCADA SOBRE A MESA DE MOLDAGEM, NA PARTE INFERIOR DA CARÇA

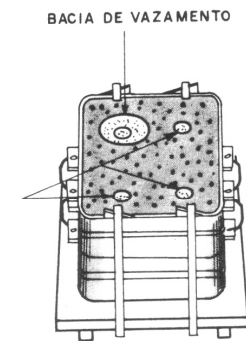
2. PREPARAÇÃO DA METADE INFERIOR DO MOLDE



3. A METADE INFERIOR DO MOLDE É INVERTIDA, E A METADE SUPERIOR DO MODELO E DA CARÇA SÃO FIXADAS NA POSIÇÃO.



5. A CARÇA É SEPARADA, OS MODELOS SÃO REMOVIDOS, O MACHO É POSICIONADO E ENTÃO, AS CAIXAS SÃO FECHADAS.



6. QUANDO AS CAIXAS SÃO FECHADAS E FIXADAS LATERALMENTE, O CONJUNTO ESTÁ PRONTO PARA O VAZAMENTO.

4. A METADE SUPERIOR DO MOLDE É PREPARADA DA MESMA FORMA QUE ANTERIORMENTE.



# Areia verde

---

- Areia lavada e com granulometria controlada (classificada segundo a AFS)
- Bentonita (mistura de argilominerais, principalmente montmorilonita)
- Água
- Aditivos: grafite (lubrificante), amido, etc.
- Composição típica: 80% areia, 15% bentonita e 5% água



# Variações

---

- Molde estufado
  - molde originalmente de areia verde mas seco em estufa
- Molde seco ao ar
  - molde originalmente de areia verde mas com a superfície seca ao ar
- Molde seco à chama ou ar quente
  - molde originalmente de areia verde mas com a superfície seca por chama ou passagem forçada de ar quente



# Vantagens e desvantagens da areia verde

<b>Vantagens</b>	<b>Desvantagens</b>
<ul style="list-style-type: none"><li>- É o molde mais barato de todos</li><li>- Há menor distorção porque não precisa ser aquecido</li><li>- As caixas de moldagem podem ser rapidamente reutilizadas</li><li>- Boa estabilidade dimensional</li><li>- Menor incidência de trincas a quente</li><li>- A areia é mais facilmente reciclada</li></ul>	<ul style="list-style-type: none"><li>- Controle da areia é mais difícil do que nos outros processos</li><li>- Maior erosão quando as peças fundidas são de maior tamanho</li><li>- Menor acabamento superficial que piora para peças maiores</li><li>- Menor precisão dimensional que diminui com o tamanho da peça</li></ul>



# Areia com resina de cura a frio

---

- Areia + Resina + catalisador
- Exemplos de resinas usadas
  - Fenólicas
  - Furânicas
  - Poliuretânicas
  - Resol-éster
  - Alquídica-uretânica
  - Poliuretano vegetal (biodegradável)



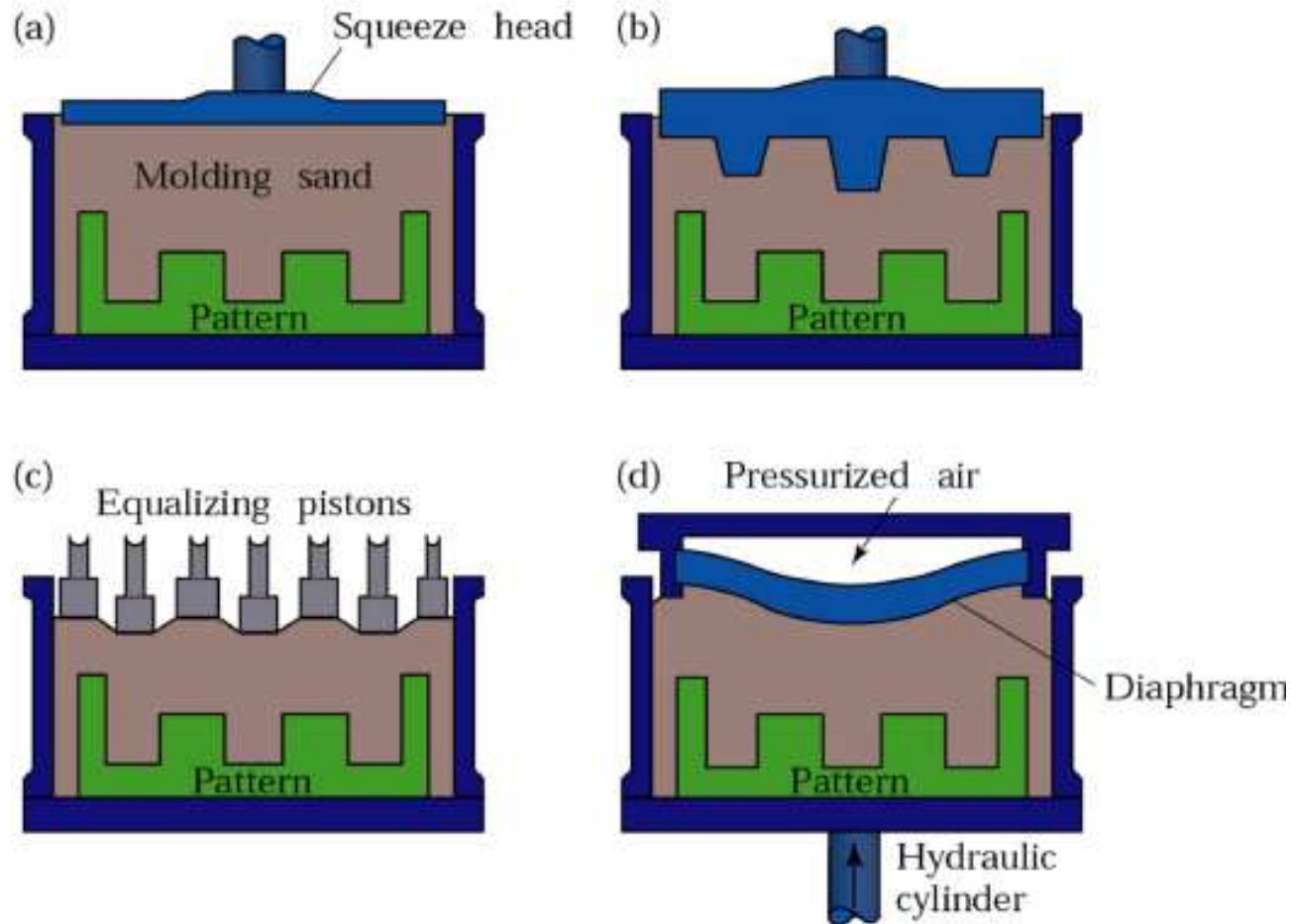
# Vantagens e Desvantagens

---

- Vantagens
  - Melhor acabamento superficial
  - Maior resistência do molde (peças maiores)
  - Maior resistência à erosão
- Desvantagens
  - Maior custo do molde
  - Maior tempo de moldagem
  - Várias resinas são tóxicas
  - Dificulta a reciclagem da areia
  - Problemas ambientais com descarte

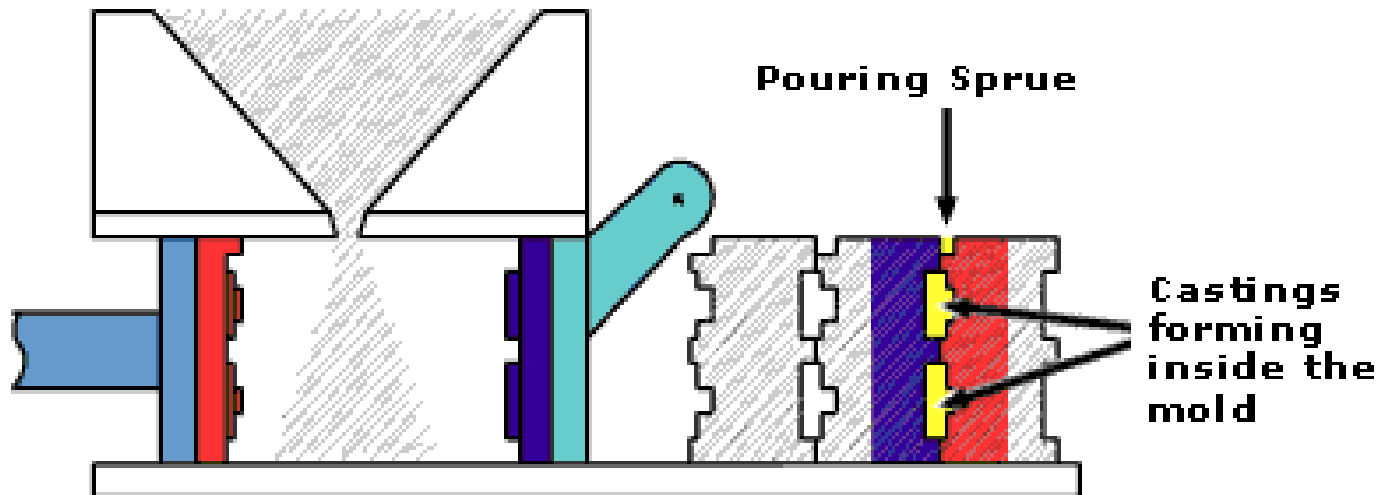
# Moldagem em areia

## *Compactação Automatizada*



# Moldagem em areia sem caixa

## *Automação (processo Disamatic)*



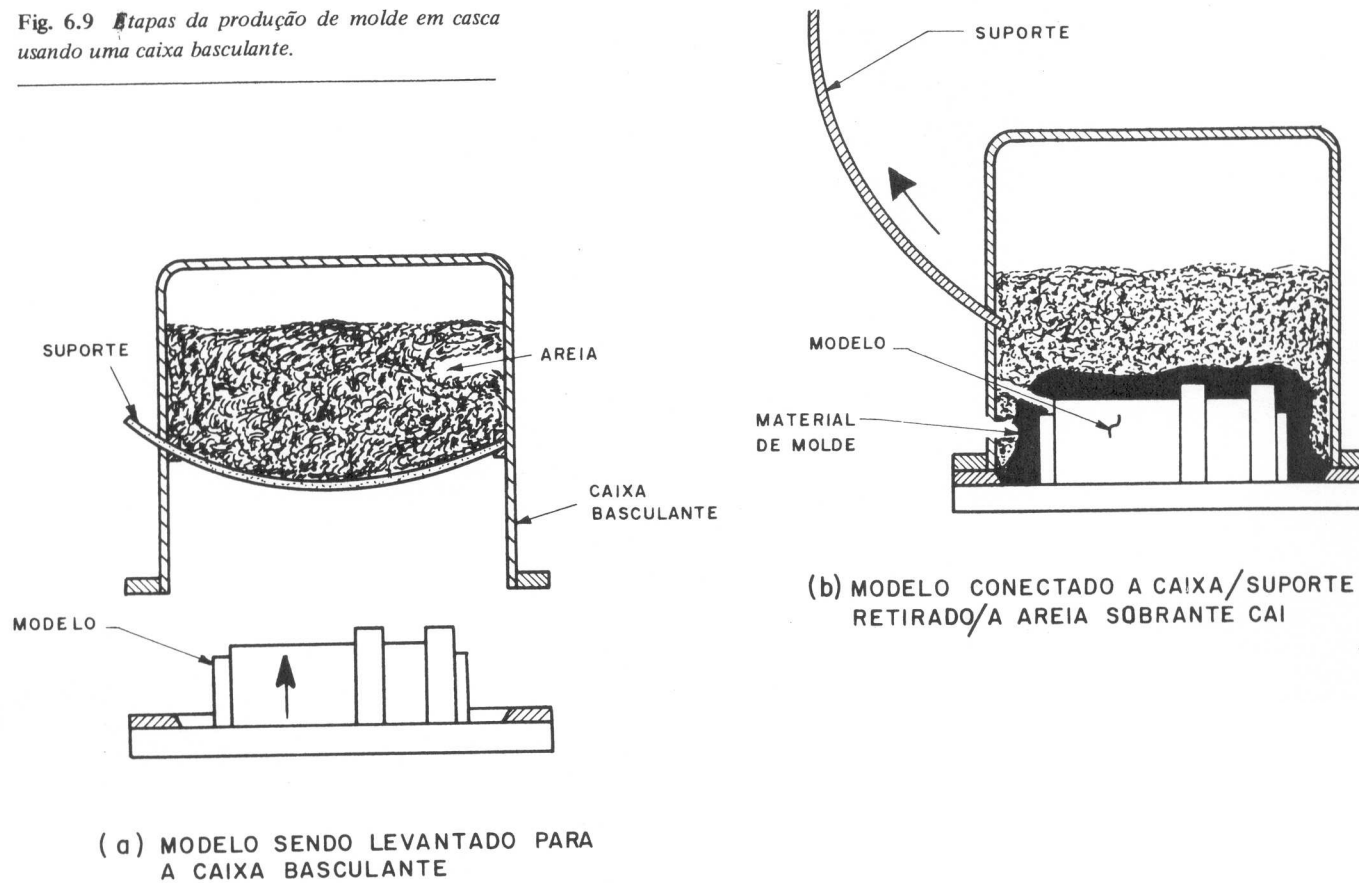
Sand enters the Molding Chamber for the next mold.  
Iron is poured into the pouring sprue on top of the  
formed molds.



# Moldagem em Casca

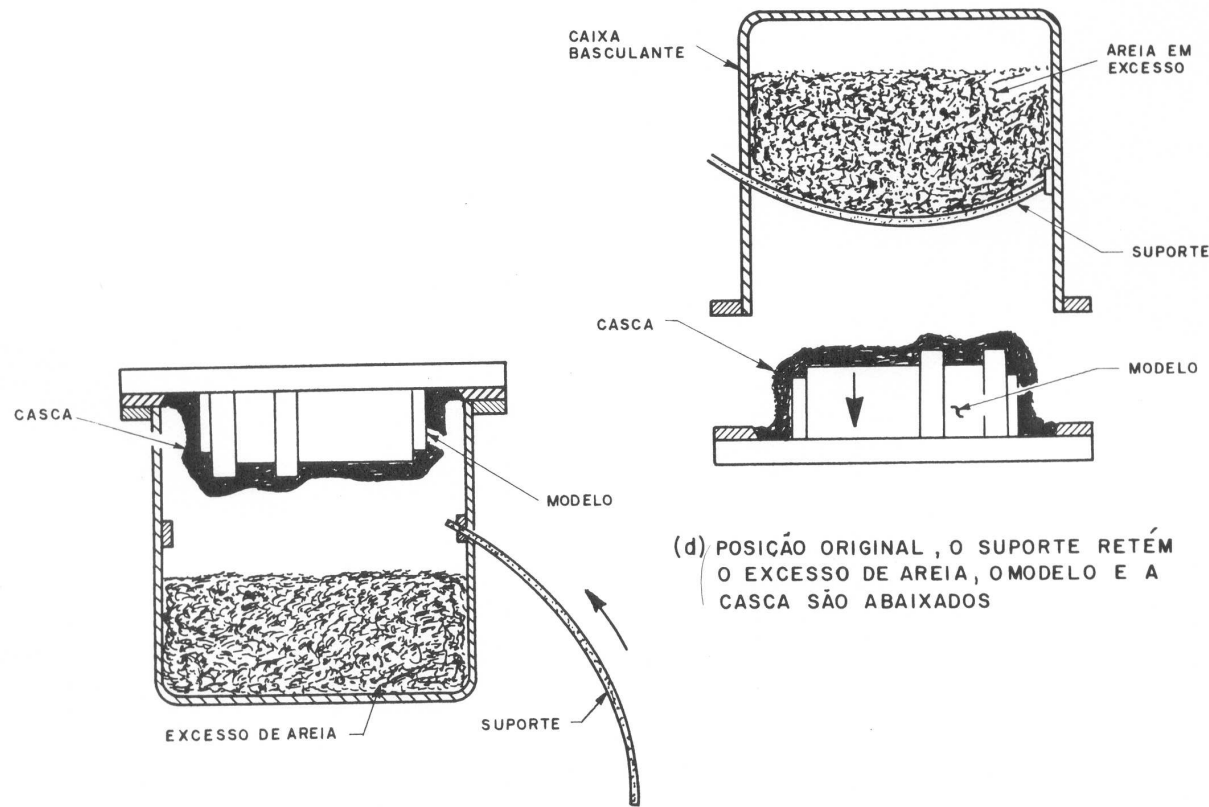
## *Shell Molding (cura a quente)*

Fig. 6.9 Etapas da produção de molde em casca usando uma caixa basculante.



# Moldagem em Casca

## *Shell Molding (cura a quente)*



Exemplo



Molde para virabrequim fundido



# Vantagens e Desvantagens

---

- Vantagens

- Melhor acabamento superficial
- Maior velocidade de produção
- Pode ser automatizado
- Maior resistência à erosão
- Menor quantidade de areia na moldagem
- Moldes mais leves

- Desvantagens

- Maior custo de equipamento e modelos
- Limitado a peças bipartidas
- Dificulta reciclagem da areia
- Resina é tóxica
- Problemas ambientais com descarte

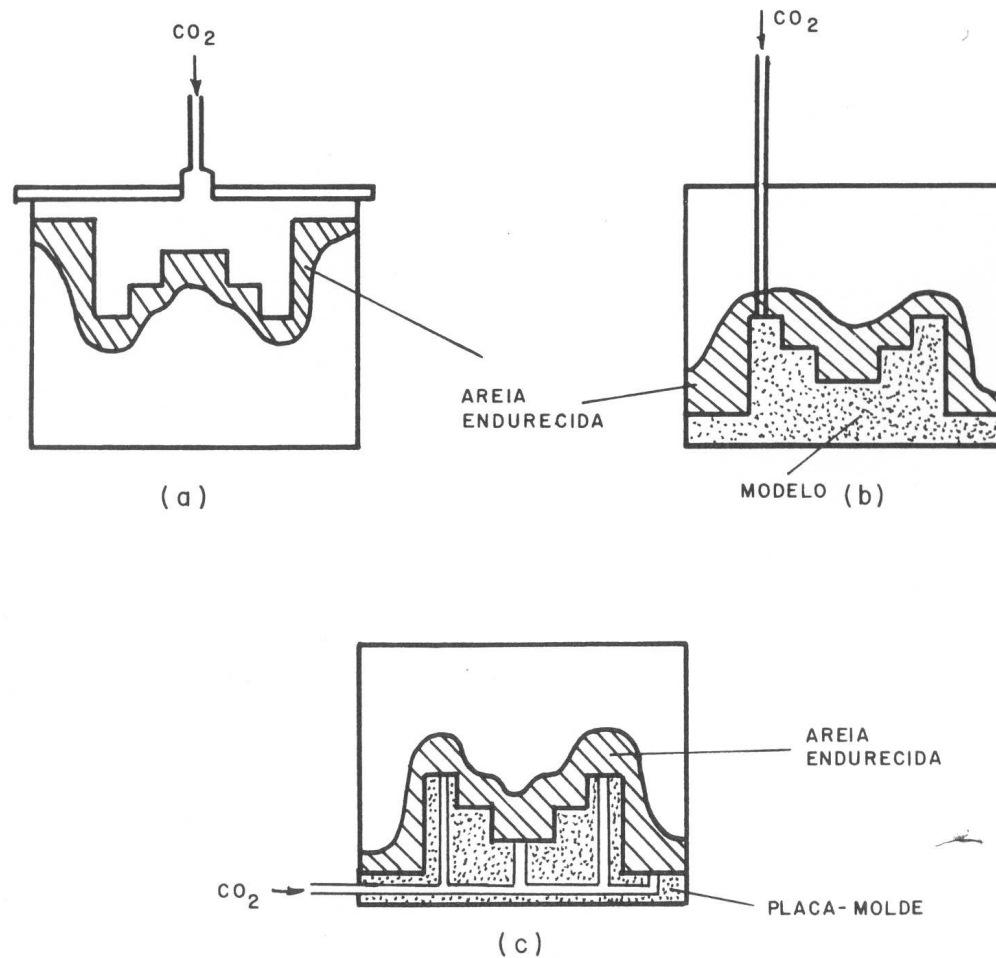


# Areia com resina de cura a quente

---

- Muito usada na confecção de machos
- Machos são moldados em caixas (box)
  - Warm-box (caixa-morna)
    - Resinas furânicas ou álcool furfurílico
    - Catalisadores: sais de cobre
  - Hot-box (caixa-quente), requer aquecimento posterior à moldagem
    - Resinas fenólicas ou furânicas
    - Catalisadores: cloretos e nitratos
      - Obs.: são resinas similares ao processo *shell*

# Molde Soprado (areia de cura a frio com gás)





# Areia de cura a frio com gás

---

- Muito usada da fabricação de machos
- Machos moldados em caixas (cold-box)
- Areia + ligante + gás
  - ligante inorgânico
    - Silicato de sódio + CO<sub>2</sub>
  - ligante orgânico
    - Resina Fenoluretânica + vapor de amina (dimetilamina ou trimetilamina)
    - Resina Epoxiacrílica + dióxido de enxofre



# Vantagens e desvantagens

---

- Vantagens
  - Melhor acabamento superficial
  - Melhor colapsabilidade do molde
  - Melhor resistência à erosão
  - Maior produtividade
  - Areia que não sofreu ação do gás pode ser reutilizada
- Desvantagens
  - Maior custo do molde e equipamento
  - Resinas e gases tóxicos
  - Difícil reciclagem da areia que foi curada
  - Problemas ambientais com descarte



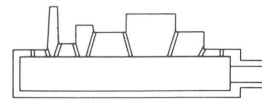
## *Filmes*

---

- [Link 1](#)
- [Link 2](#)

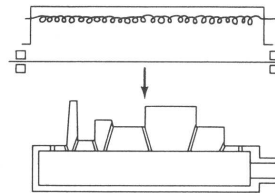


# Moldagem a vácuo (areia sem ligante)



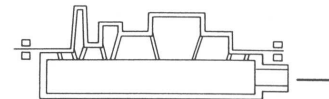
Set the pattern on the hollow carrier plate. The pattern has numerous vent holes, which help the plastic film conform when vacuum is applied.

Step 1



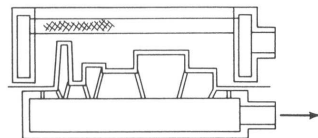
A heater softens the thin plastic film. It is 0.05 to 0.10 mm thick and has good elasticity and a high plastic deformation ratio.

Step 2



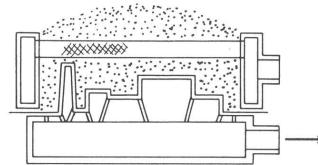
The softened film drapes over the pattern, and 200 to 400 torr vacuum suction acts through the vents to draw it down so that it adheres closely to the pattern.

Step 3



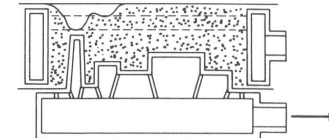
The flask is set on the film-coated pattern. Note that the flask has a suction pipe at right. This setup could also be vertical, with flask on both sides of the pattern.

Step 4



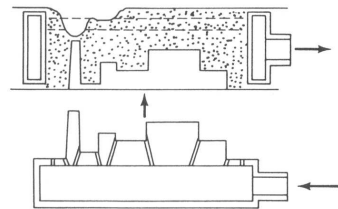
The flask is filled with dry sand (two-screen: 70 mesh and 270 mesh, for maximum compaction). Slight vibration quickly compacts the sand to peak density.

Step 5



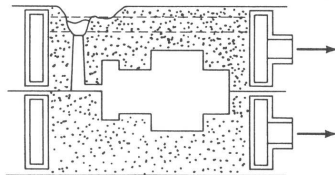
Form the sprue cup. Level the mold. Cover the sprue opening with plastic film and lay on plastic backing film to overlap flask.

Step 6



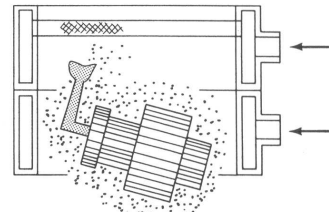
Apply vacuum to the flask. Atmospheric pressure hardens the sand, which retains the pattern form. Release the vacuum on pattern carrier plate and mold strips easily.

Step 7



Cope and drag (or left and right for vertical molding) are assembled, forming a sprued plastic-lined cavity. During pouring, molds are kept under vacuum.

Step 8



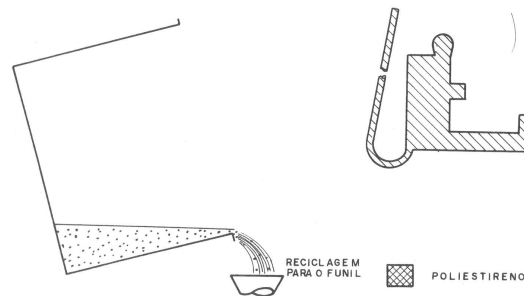
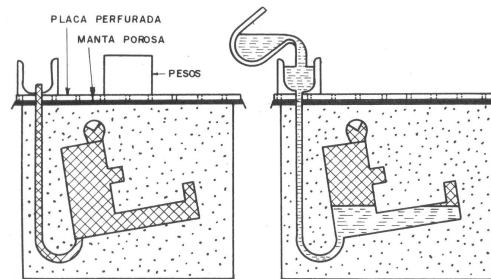
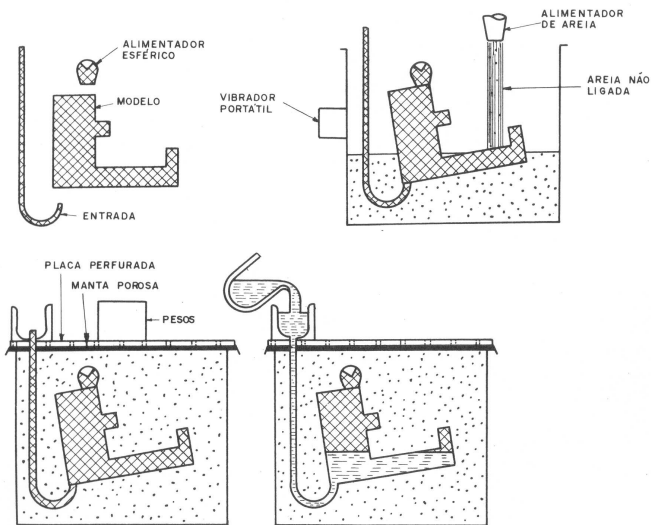
After cooling, the vacuum is released, and the free-flowing sand drops away, leaving a clean casting. There are no lumps, no burn-in. Sand is cooled for reuse.

Step 9





ig. 9 Elementary sequences in producing V-process molds

# Molde cheio *lost-foam* (areia sem ligante)

PS expandido  
(isopor)

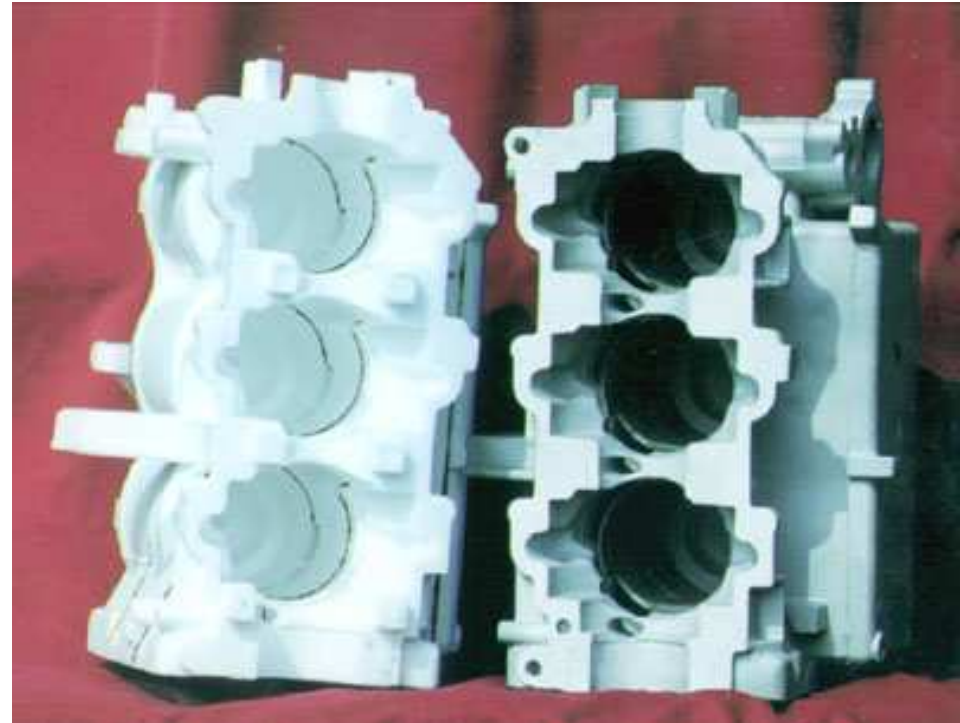


RECICLAGEM  
PARA O FUNIL

-  POLIESTIRENO
-  AREIA NÃO LIGADA (SÍLICA, ZIRCONITA, ETC)
-  METAL LÍQUIDO
-  PEÇA FUNDIDA



# Molde cheio (lost-foam)





# Comparação entre processos

Processo	Limites de peso	Menor secção (mm)	Acabamento superficial ( $\mu\text{m}$ )	Tolerância dimensional Dimensão de x (mm)
Areia	30g a 200T	3 a 6	4 a 8	0,005x a 0,03x
Casca	30g a 120Kg	1,5 a 3,5	2,5 a 6	0,01x a 0,025x
Gesso	100g a 50Kg	1,5	1	0,005x
Cera Perdida	2g a 25Kg	0,8 a 1	1	0,003x a 0,005x
Molde Cheio	-	-	-	0,002x a 0,007x
Molde Permanente	100g a 50Kg	3 a 5	2	0,01x a 0,025x
Sob pressão	15g a 50Kg	0,8	1	0,0015x

# Comparação entre processos p/ ligas de Al

Processo	Capacidade Produção	Tolerâncias	Acabamento da Superfície ( $\mu\text{m}$ )	Custo de Maquinário
Molde cheio	De 0,05 a 150 Kg	$\pm 0,001$ a 0,25 m $\pm 0,0007/\text{metro}$	63-250 RMS	\$8000 a \$120000
Cera Perdida	0,05 a 10 Kg	$\pm 0,001$ a 0,127m $\pm 0,0007/\text{metro}$	63-250 RMS	\$4000 a \$40000
Fundição em Areia	0,03 a toneladas	$\pm 0,007$ a 1,5 m $\pm 0,0007/\text{metro}$	200-550 RMS	\$1000 a \$10000
Injeção	0,05 a 10 Kg	$\pm 0,0005/\text{metro}$	32-63 RMS	\$10000 a \$300000
Molde Permanente	0,5 a 50 Kg	$\pm 0,003$ a 0,25 m $\pm 0,0005/\text{metro}$	150-300 RMS	\$12000 a \$100000

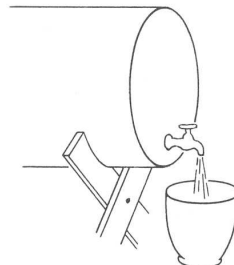
# Molde Cerâmico



## Refractory

Consists of a variety of specially blended groups of refractory powders.

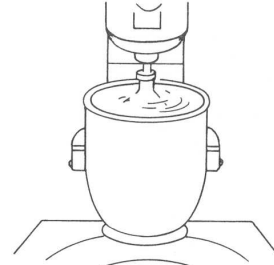
Step 1



## Binder

The liquid medium is usually based on ethyl silicate and is specifically produced to proprietary formulations.

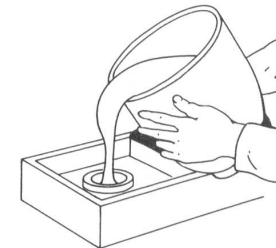
Step 2



## Mixing

A small percentage of gelling agent is added to the binder and mixed with the refractory powder to produce a creamy slurry.

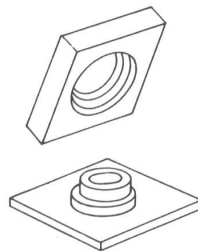
Step 3



## Pattern

The slurry is poured over a pattern made of wood, metal, plaster, plastic, and so on. It is then allowed to gel in about 2 to 3 min.

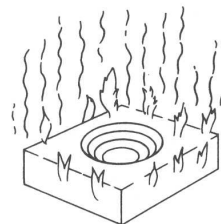
Step 4



## Stripping

The gelled refractory mass is stripped from the pattern by hand or with a mechanical stripping mechanism.

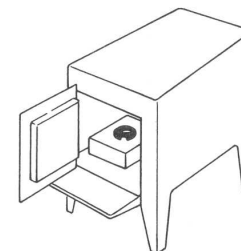
Step 5



## Burn-off

The mold is ignited. It burns until all volatiles are consumed; this sets up the microcrazed structure.

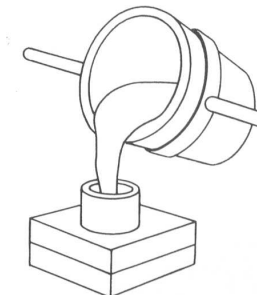
Step 6



## Baking

The Shaw mold, now immune to thermal shock, is placed in a high-temperature oven or skin heated with a torch until all traces of moisture are driven off.

Step 7



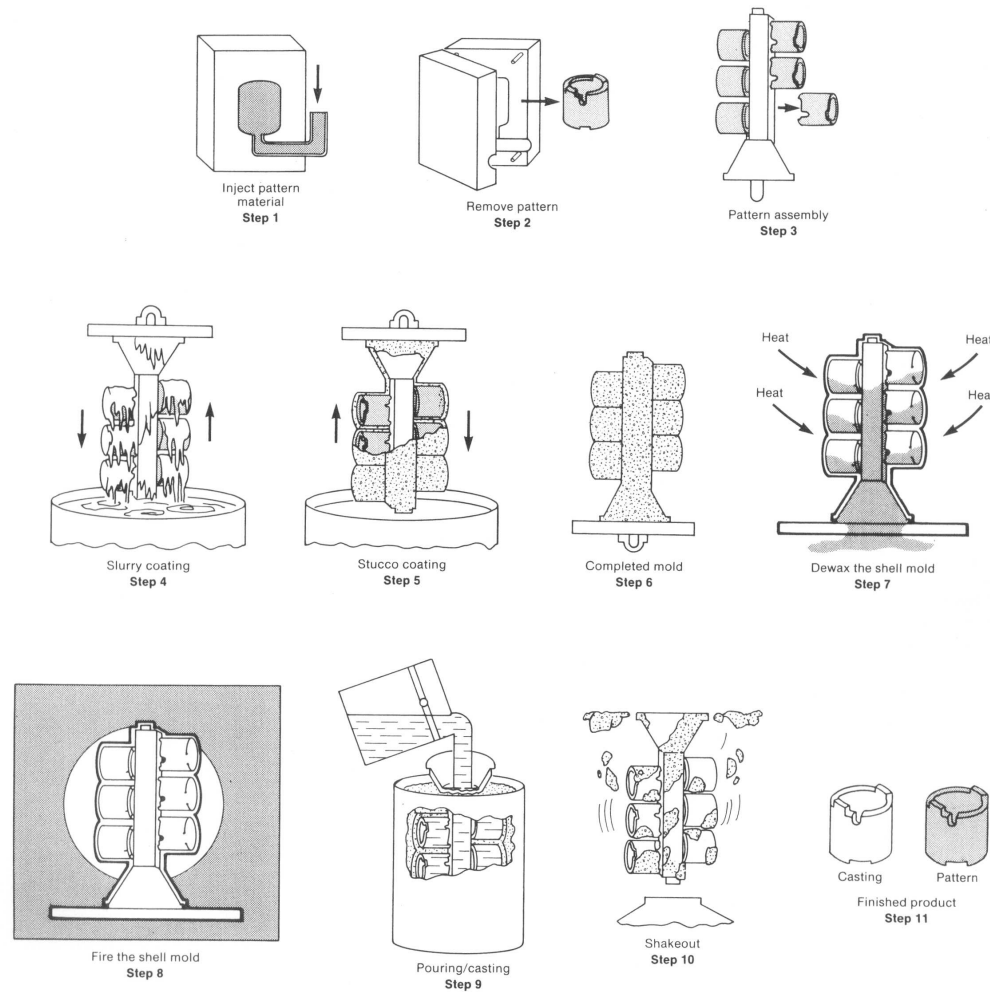
## Pouring

Cope and drag mold pieces are assembled, along with any necessary cores, and the casting is poured.

Step 8

**Fig. 1** Sequence of operations used in the Shaw all-ceramic mold process

# Cera perdida (Fundição de Precisão)



**Fig. 3** Basic steps involved in investment casting



# Cera perdida (Fundição de Precisão)

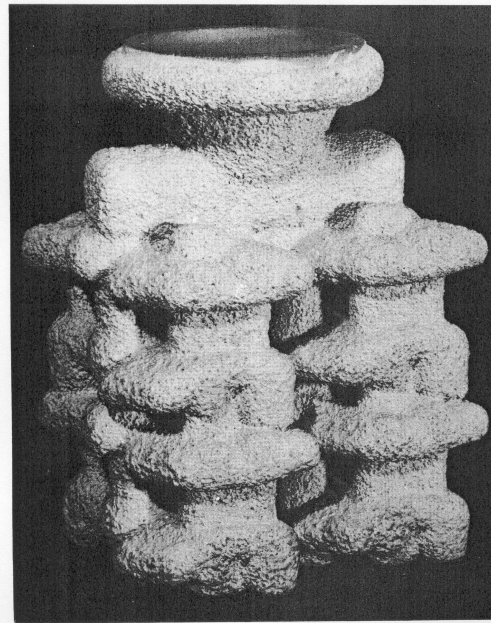
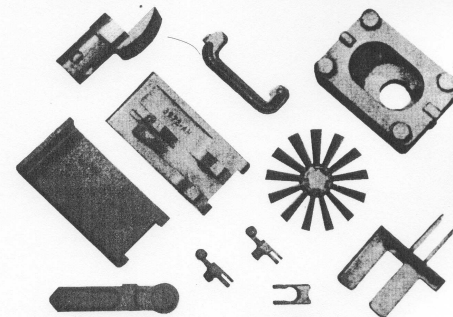


Fig. 6.13 Molde típico de uma fundição por cera perdida.





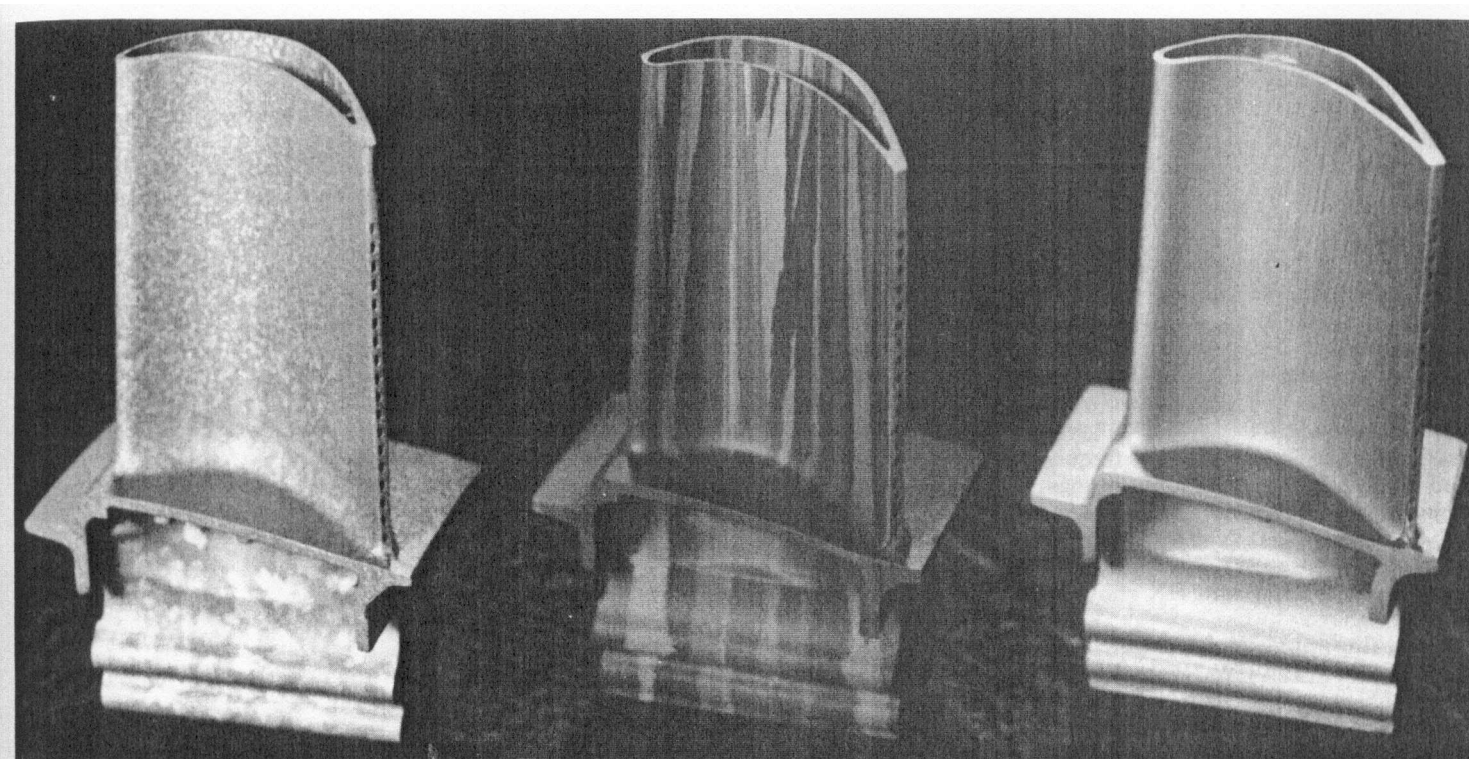
# Cera Perdida (filme)

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- [Parte 1](#)
- [Parte 2](#)
- [Parte 3](#)
- [Parte 4](#)
- [Parte 5](#)
- [Parte 6](#)

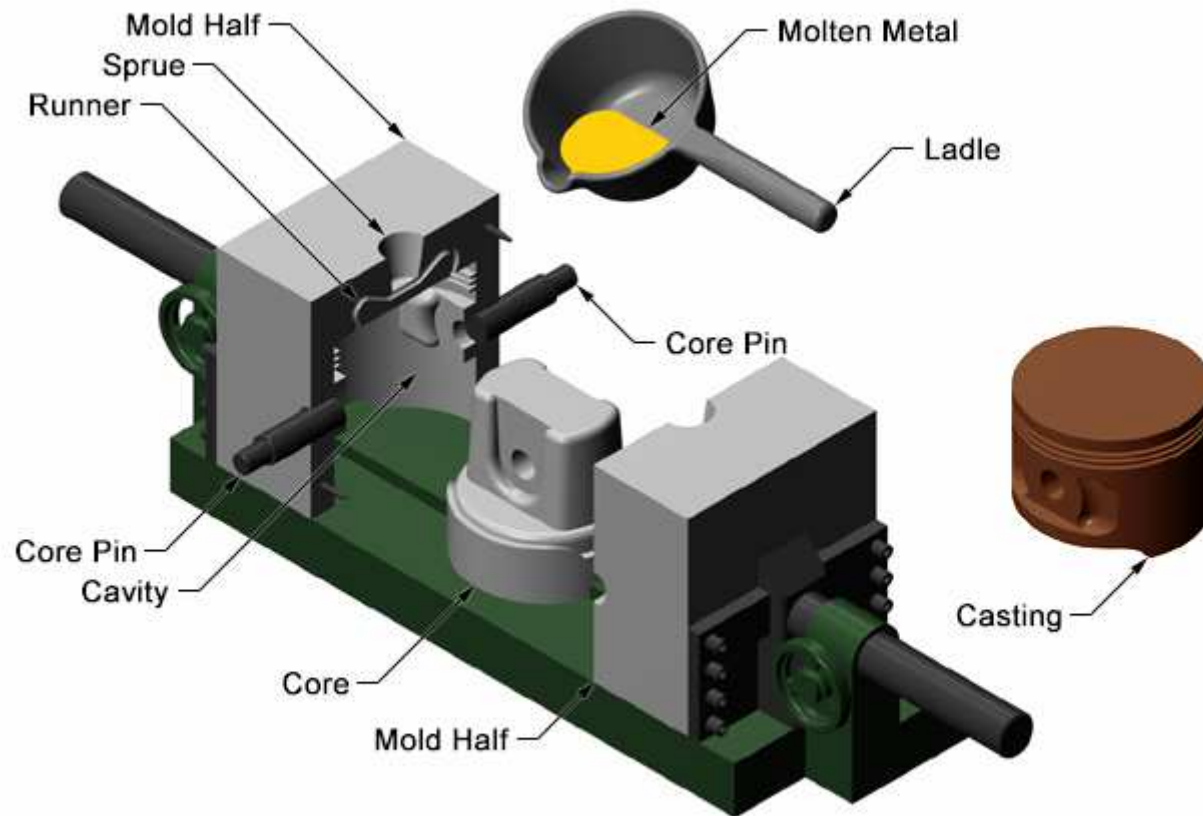
# Exemplo: Cera perdida

## Palheta de Turbina (Solid. Direcional)



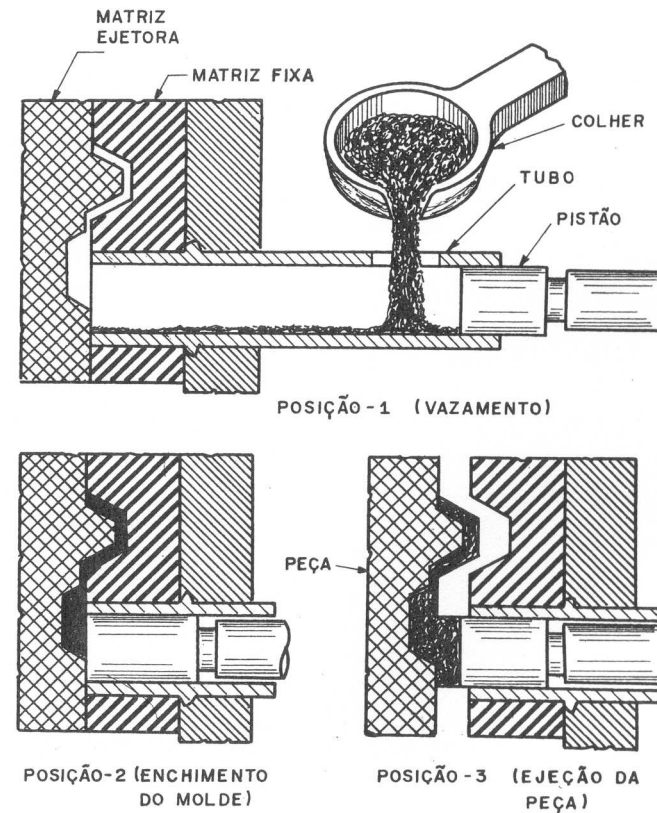
**Fig. 1** Comparison of equiaxed (left), directionally solidified (center), and single-crystal (right) nickel-base alloy turbine blades for an aircraft engine. Courtesy of Howmet Corporation, Whitehall Casting Division

# Fundição em Coquilha (Molde permanente) por gravidade

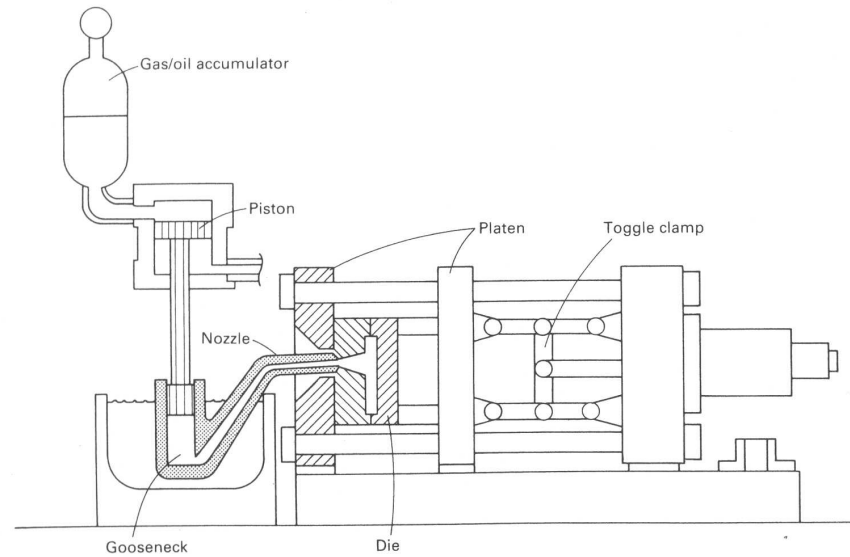


# Fundição sob pressão

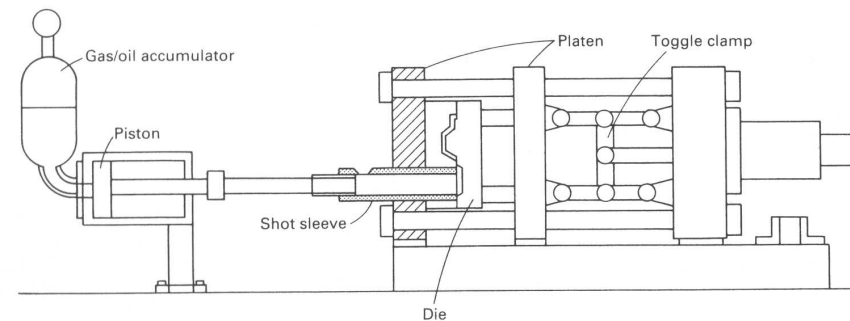
Fig. 6.19 Ciclo de operação de um equipamento de fundição de câmara fria horizontal em matriz.



# Fundição sob pressão



**Fig. 1** Schematic showing the principal components of a hot chamber die casting machine



**Fig. 2** Schematic showing the principal components of a cold chamber die casting machine



# Fundição sob pressão (filmes)

---

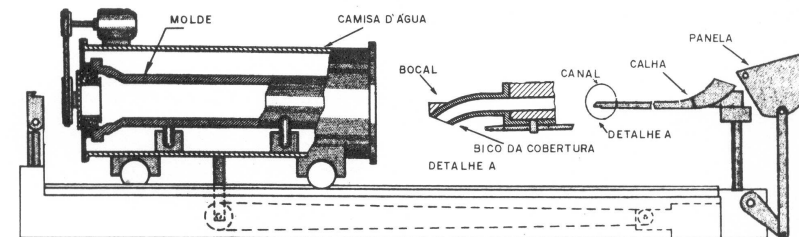
Link Filme 1

Link Filme 2

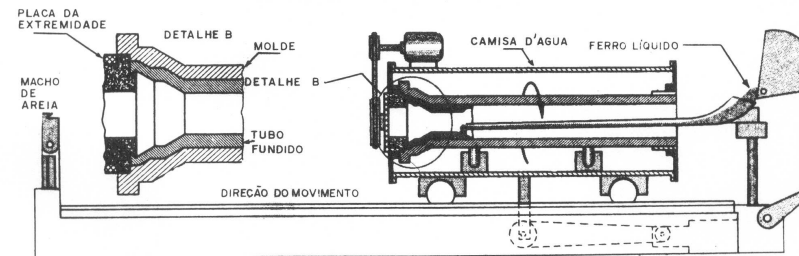
# Fundição Centrífuga (horizontal)

## 6.10 Fundição Centrífuga

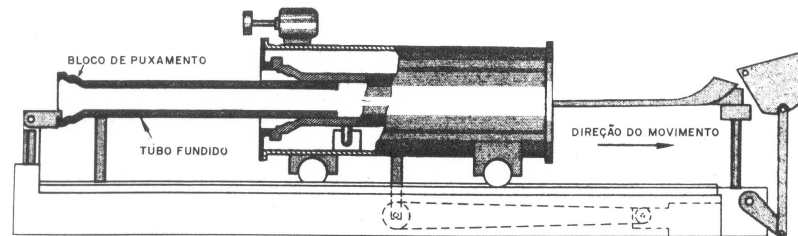
A fundição centrífuga envolve a solidificação de metal num molde rotativo. Sua maior aplicação é em moldes horizontais, que giram ao redor do seu eixo de simetria. O



EQUIPAMENTO DE FUNDIÇÃO CENTRÍFUGA



EQUIPAMENTO EM OPERAÇÃO

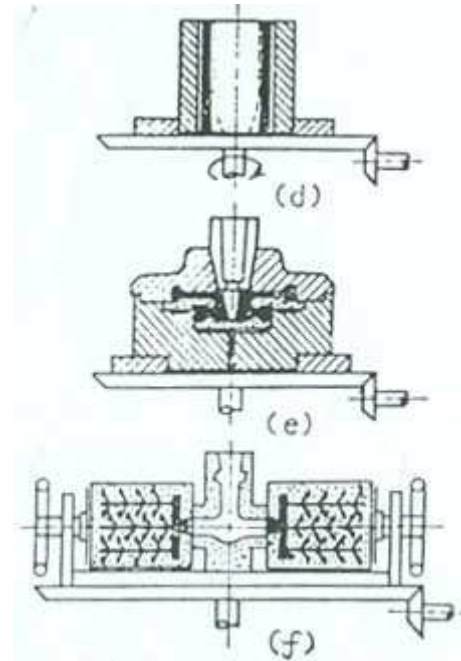
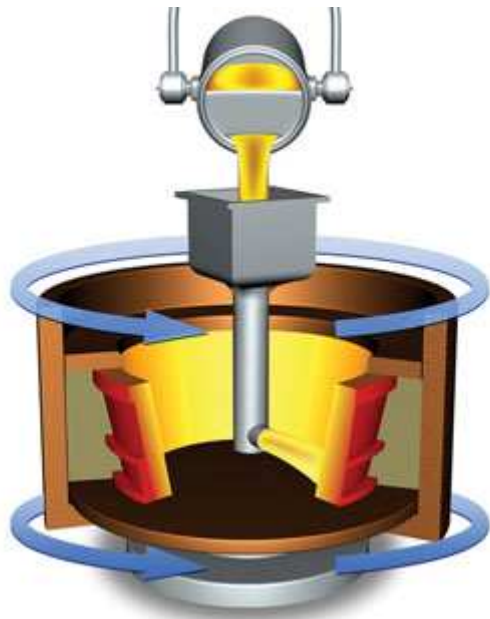


EQUIPAMENTO DURANTE A DESMOLDAGEM

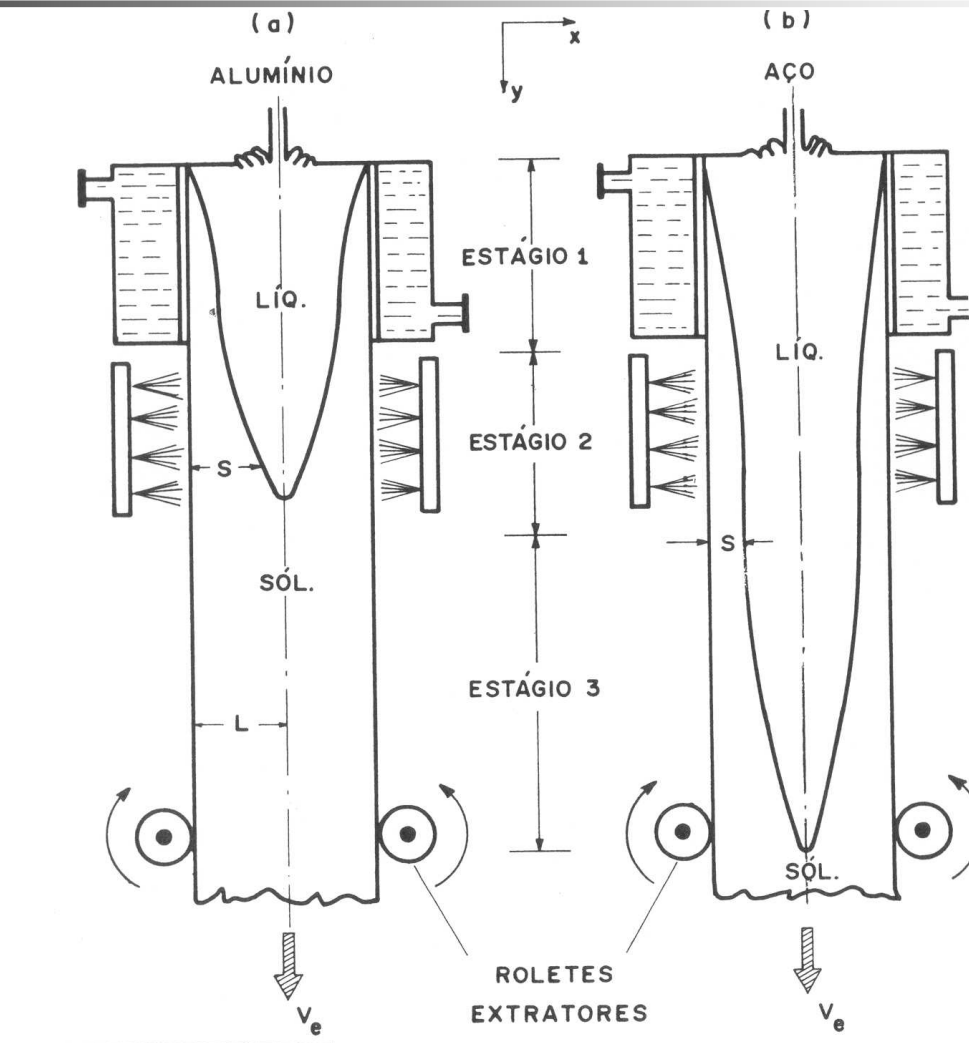
Fig. 6.21 Fundição centrífuga de um tubo de ferro fundido.



# Fundição centrífuga (vertical)



# Lingotamento Contínuo





# Lingotamento Contínuo (filme)

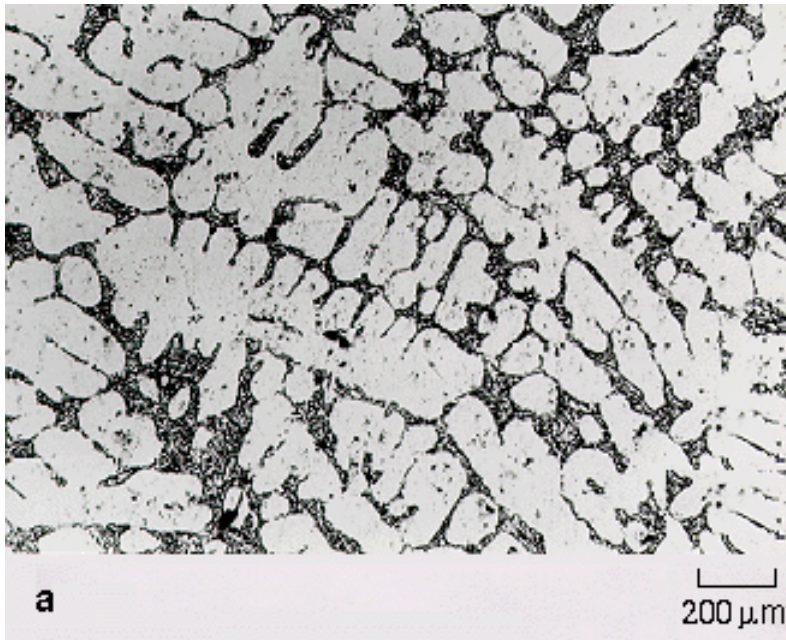
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Link

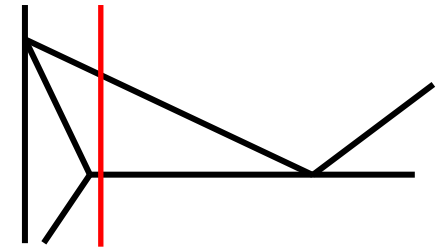
# Reofundição / Tixofundição



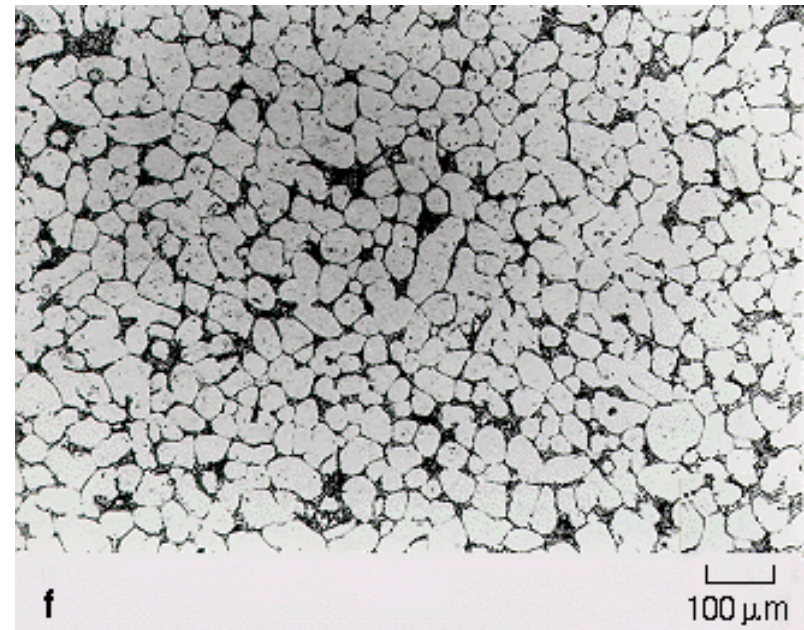
# Reofundição e Tixofundição



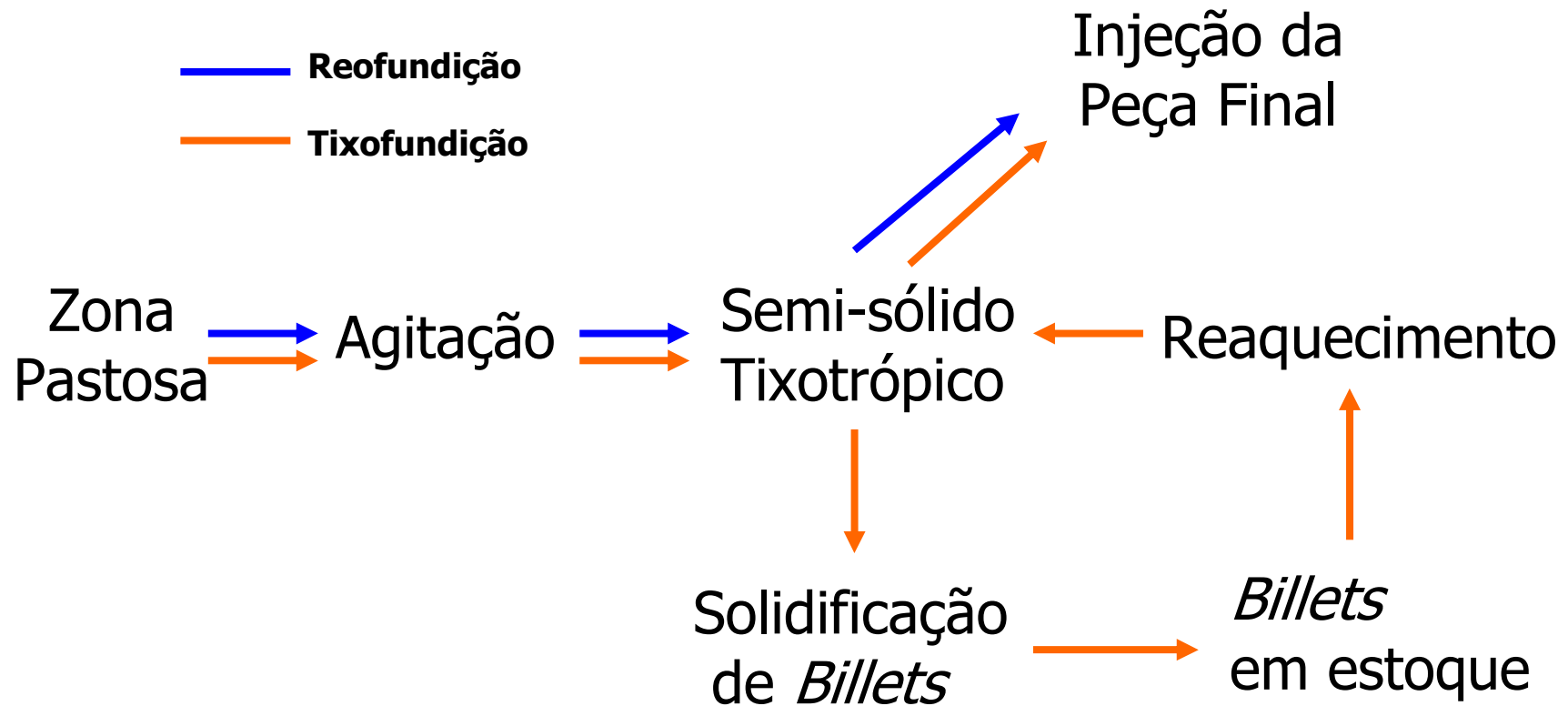
Liga com longo  
intervalo de  
Solidificação



Após agitação  
Comportamento Tixotrópico



# Reofundição $\neq$ Tixofundição

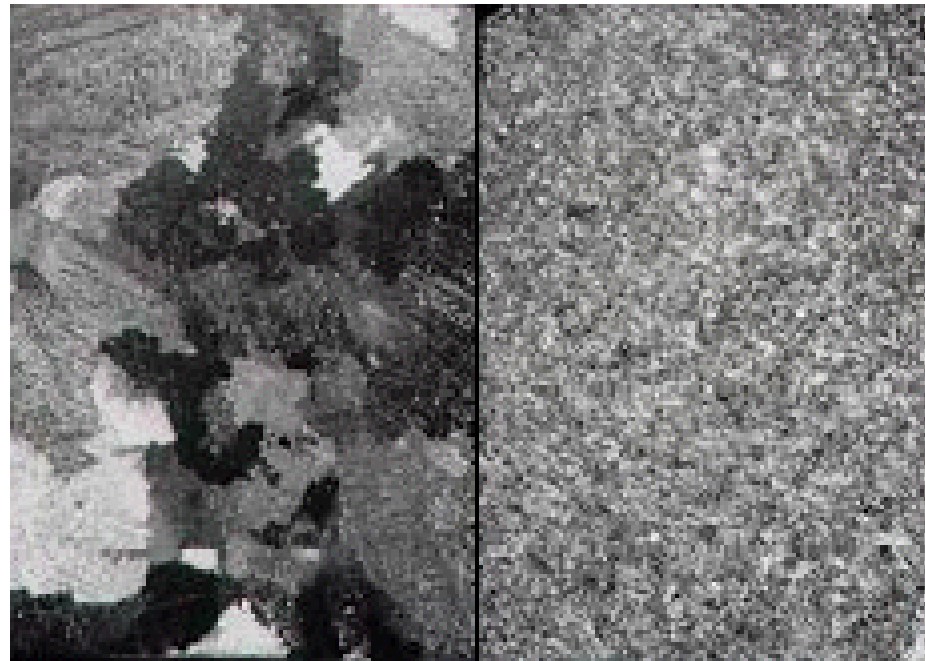


# Reofundição e Tixofundição



# Reofundição e Tixofundição

Usual



**a**

**b**

Reofundição  
e  
Tixofundição





# Reofundição e Tixofundição

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Filme

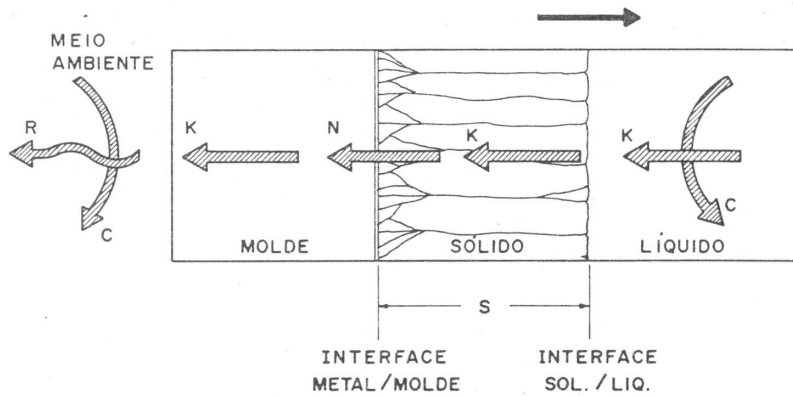


# Fundição

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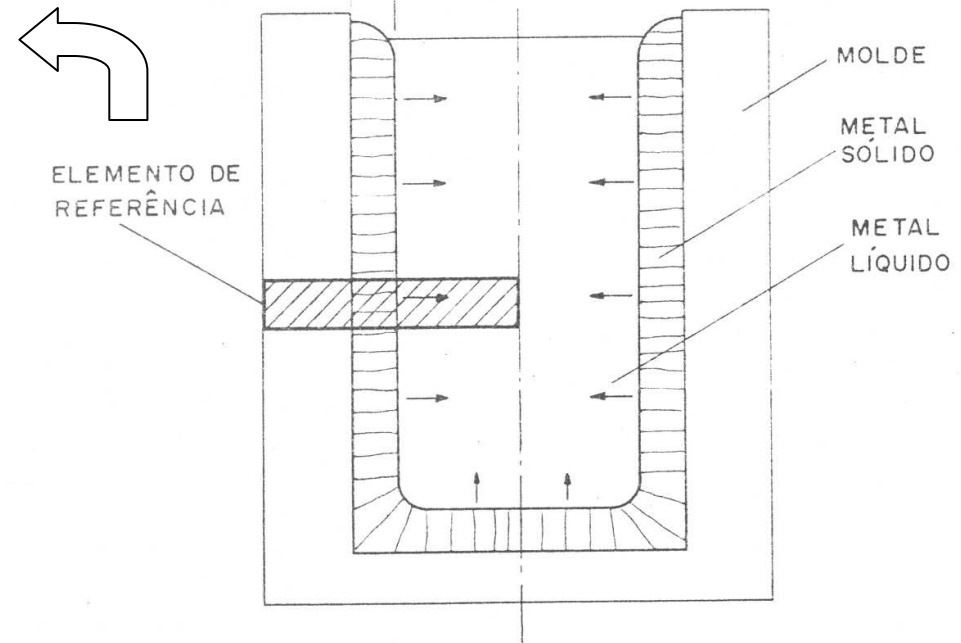
- Projetos de Moldes

# Fluxo de calor e direção de crescimento

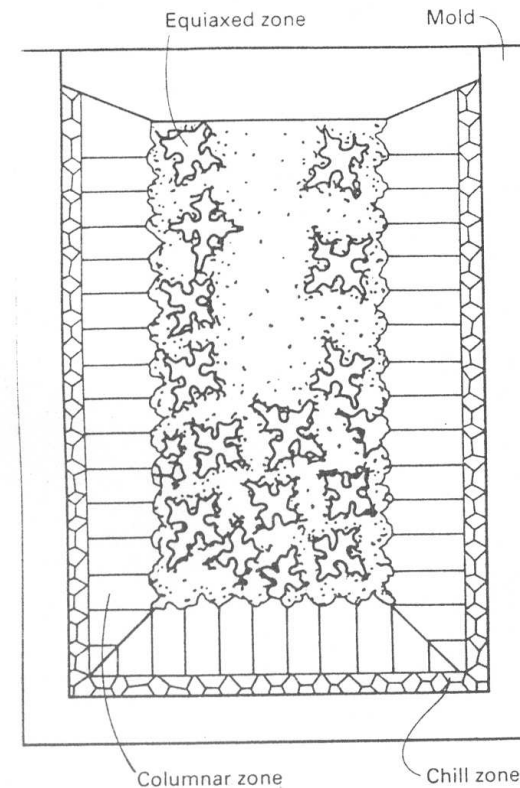
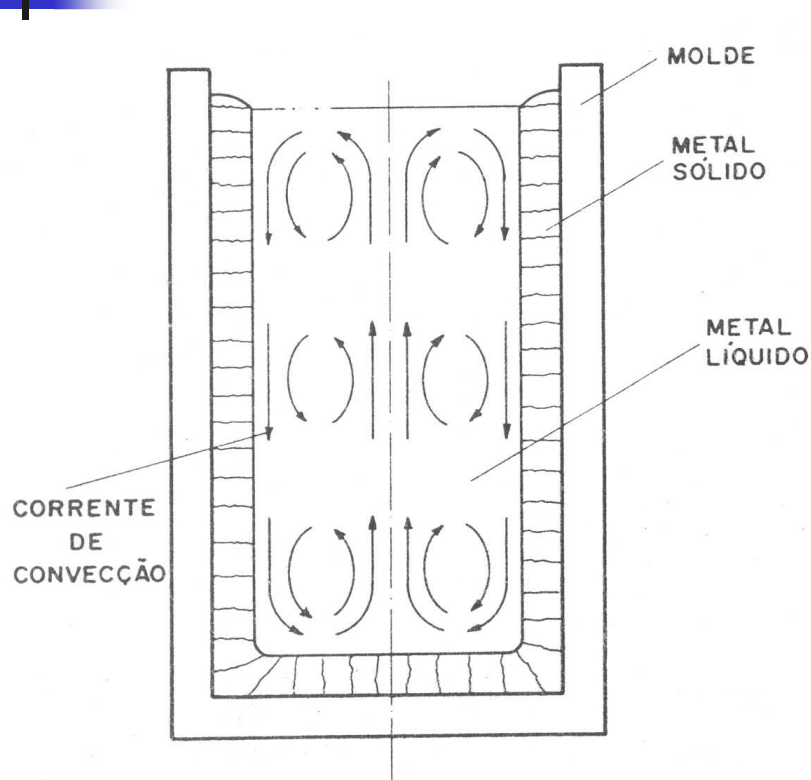


INTERFACE METAL/MOLDE      INTERFACE SOL./LIQ.

- K = CONDUÇÃO
- N = TRANSFERÊNCIA NEWTONIANA
- C = CONVECÇÃO
- R = RADIAÇÃO



# Formação da macroestrutura



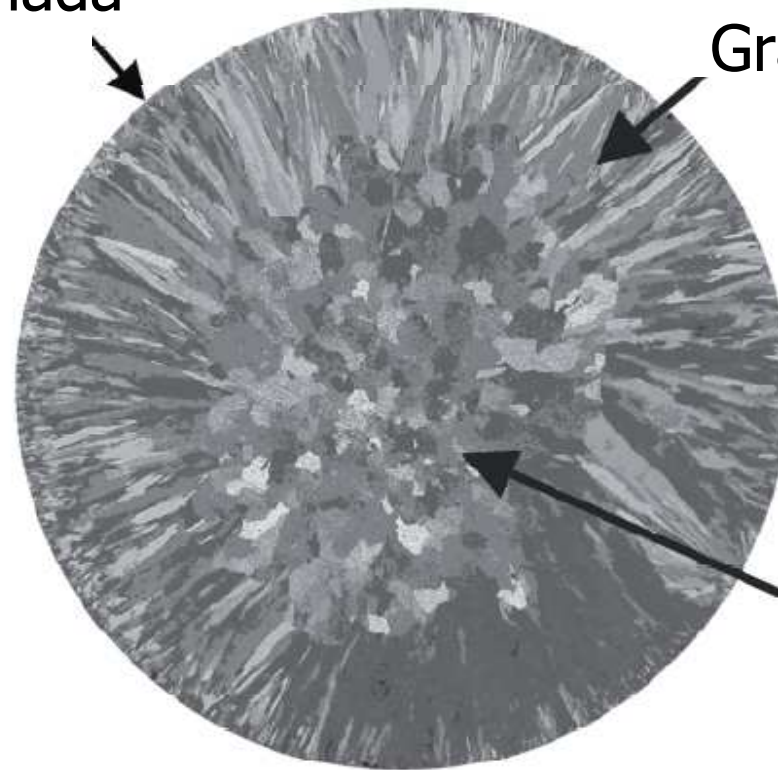
**Fig. 11** Schematic of microstructure zone formation in castings. Directional solidification conditions give rise to a columnar zone, while an equiaxed zone is formed at the center where the liquid is undercooled.

Filme

# Macroestrutura

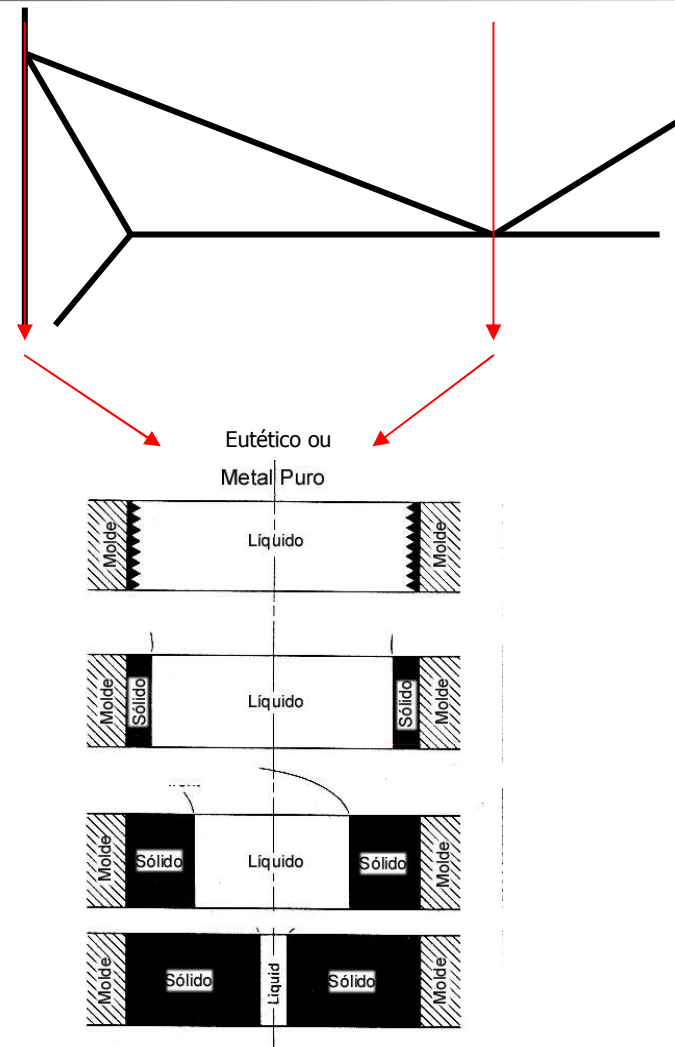
Zona Coquilhada

Grão Colunares

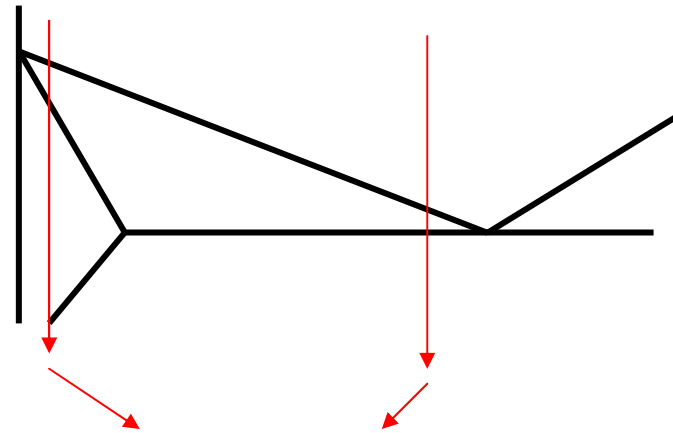


Grão Equiaxiais

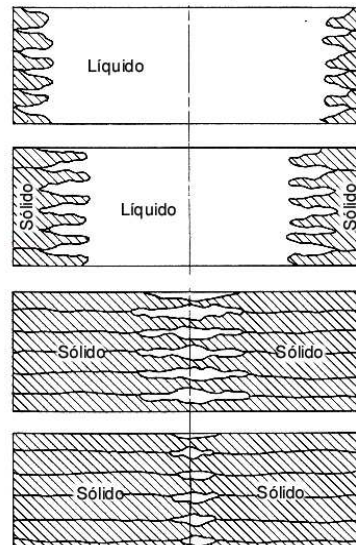
# Intervalo de Solidificação e a macroestrutura



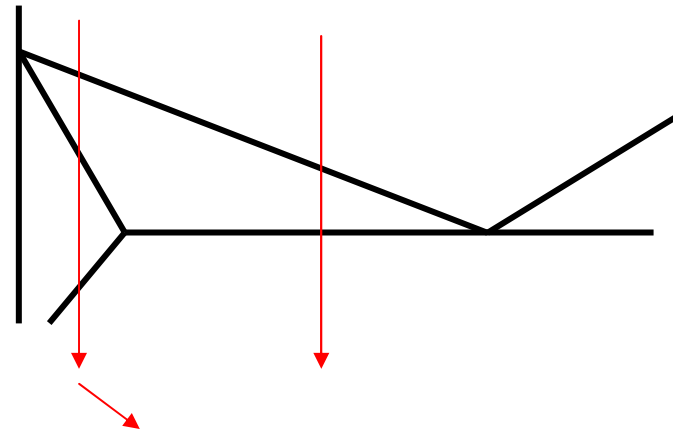
# Intervalo de Solidificação e a macroestrutura



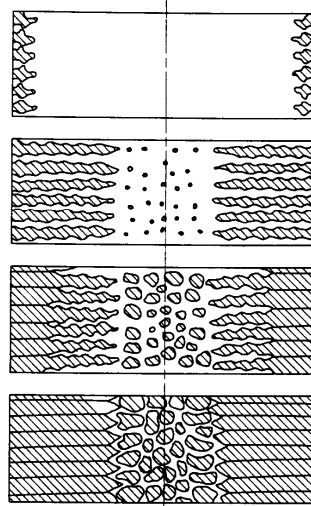
Liga com curto intervalo de solidificação



# Intervalo de Solidificação e a macroestrutura

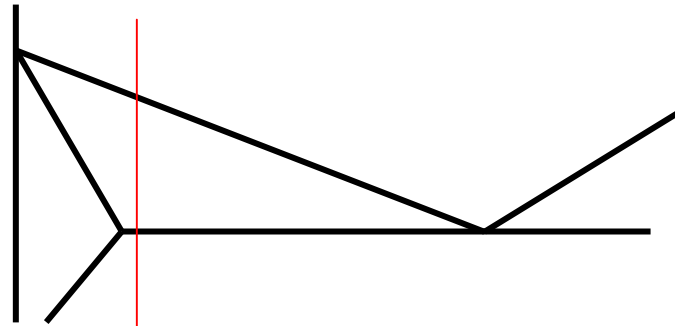


Liga com intervalo de solidificação intermediário

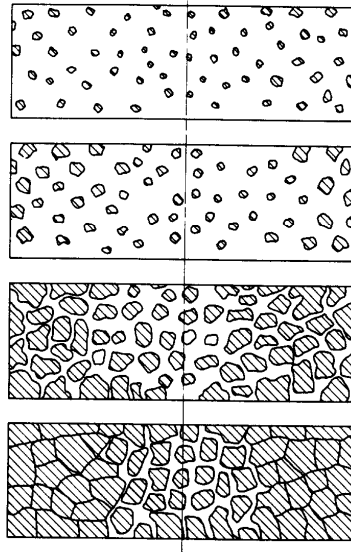




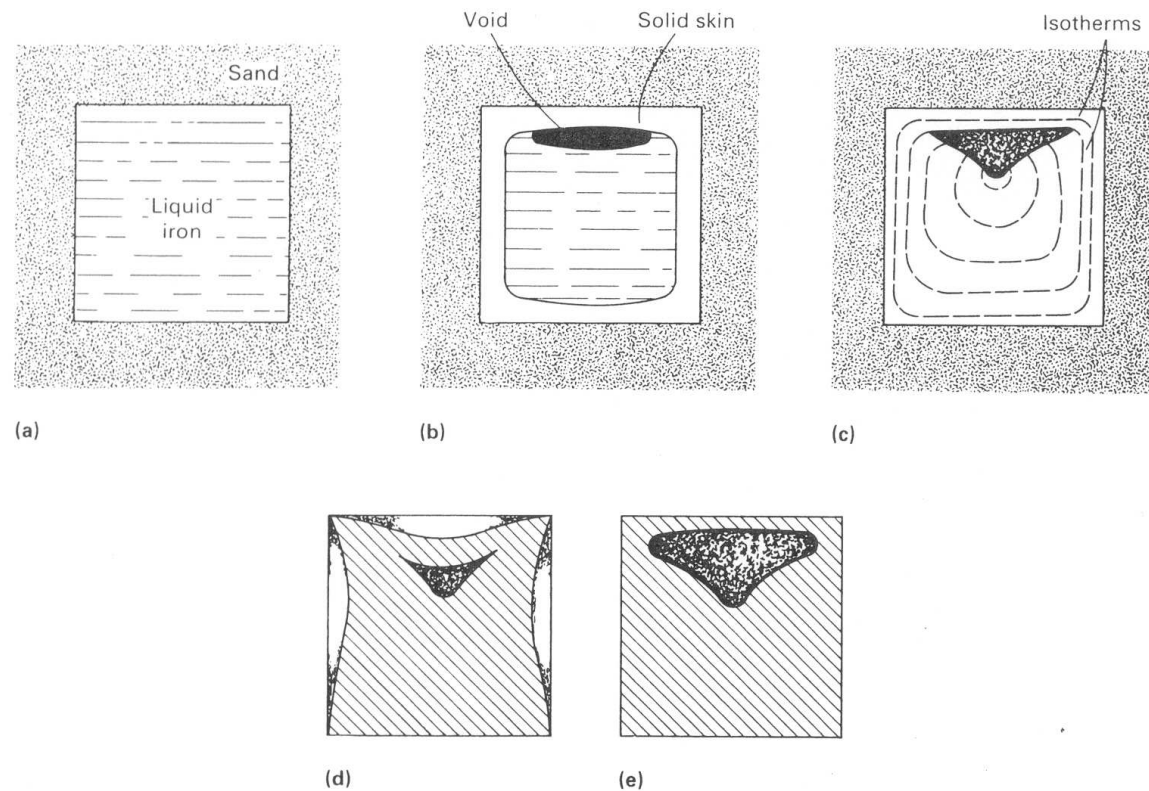
# Intervalo de Solidificação e a macroestrutura



Liga com longo  
intervalo de solidificação



# Contração na Solidificação



**Fig. 2** Schematic of sequence of solidification shrinkage in an iron cube. (a) Initial liquid metal. (b) Solid skin and formation of shrinkage void. (c) Internal shrinkage. (d) Internal shrinkage plus dishing. (e) Surface puncture



# Contração na solidificação

<i>Metal</i>	<i>Crystal structure</i>	<i>Melting point</i> °C	<i>Liquid density</i> (kg/m <sup>3</sup> )	<i>Solid density</i> (kg/m <sup>3</sup> )	<i>Volume change</i> (%)	<i>Ref.</i>
Al	fcc	660	2368	2550	7.14	1
Au	fcc	1063	17 380	18 280	5.47	1
Co	fcc	1495	7750	8180	5.26	1
Cu	fcc	1083	7938	8382	5.30	1
Ni	fcc	1453	7790	8210	5.11	1
Pb	fcc	327	10 665	11 020	3.22	1
Fe	bcc	1536	7035	7265	3.16	1
Li	bcc	181	528	–	2.74	4,5
Na	bcc	97	927	–	2.6	4,5
K	bcc	64	827	–	2.54	4,5
Rb	bcc	39	1437	–	2.3	4,5
Cs	bcc	29	1854	–	2.6	4,5
Tl	bcc	303	11 200	–	2.2	2
Cd	hcp	321	7998	–	4.00	2
Mg	hcp	651	1590	1655	4.10	3
Zn	hcp	420	6577	–	4.08	2
Ce	hcp	787	6668	6646	–0.33	1
In	fcc	156	7017	–	1.98	2
Sn	tetrag	232	6986	7166	2.51	1
Bi	rhomb	271	10 034	9701	–3.32	1
Sb	rhomb	631	6493	6535	0.64	1
Si	diam	1410	2525	–	–2.9	2

References: 1, Wray (1976); 2, Lucas (quoted by Wray, 1976); 3, This book; 4, Iida and Guthrie (1988); 5, Brandes (1983).



# O módulo de resfriamento

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- Módulo de Resfriamento

$$MR = \frac{Volume}{Superfície}$$

- Tempo de Solidificação

$$TS = c.(MR)^n \quad \blacksquare \quad 1,5 < n < 2$$

- Exemplos:
  - Calcular p/ Esfera, Chapa, Cubo, Cilindro
  - Como maximizar MR p/ Cilindro?
  - Comparar
  - MR em geometrias mais complexas

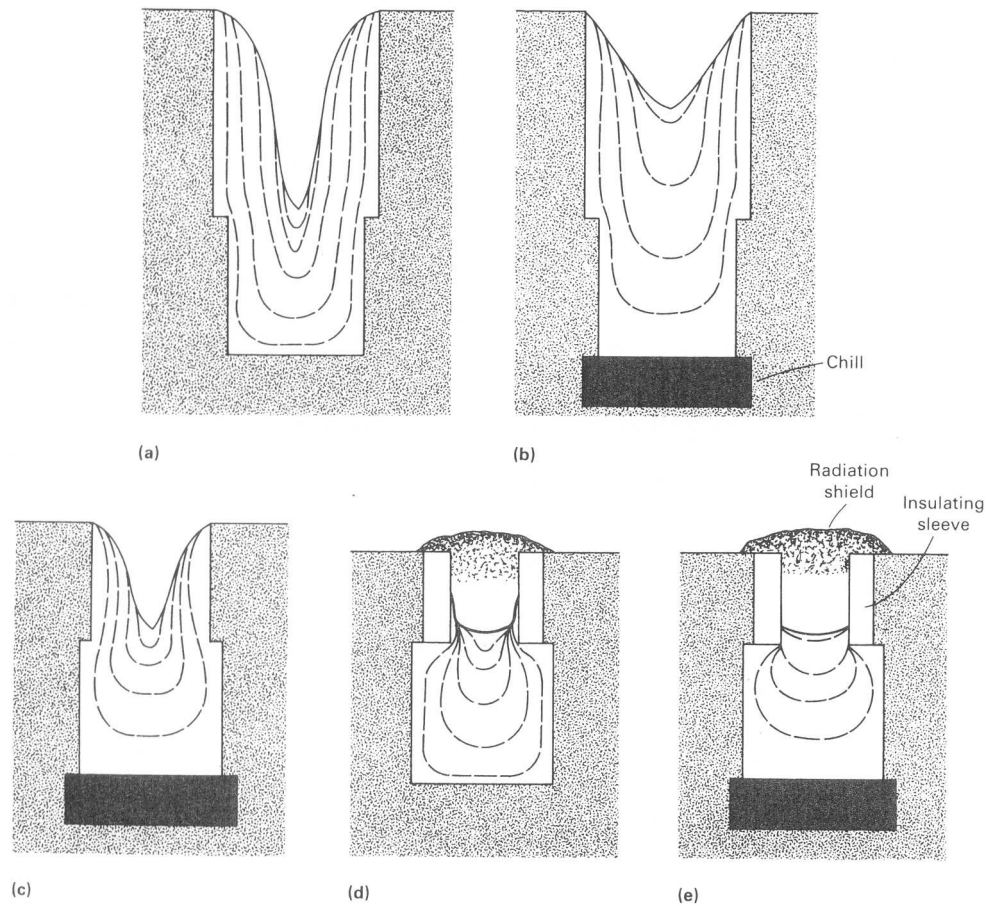


# Massalotes

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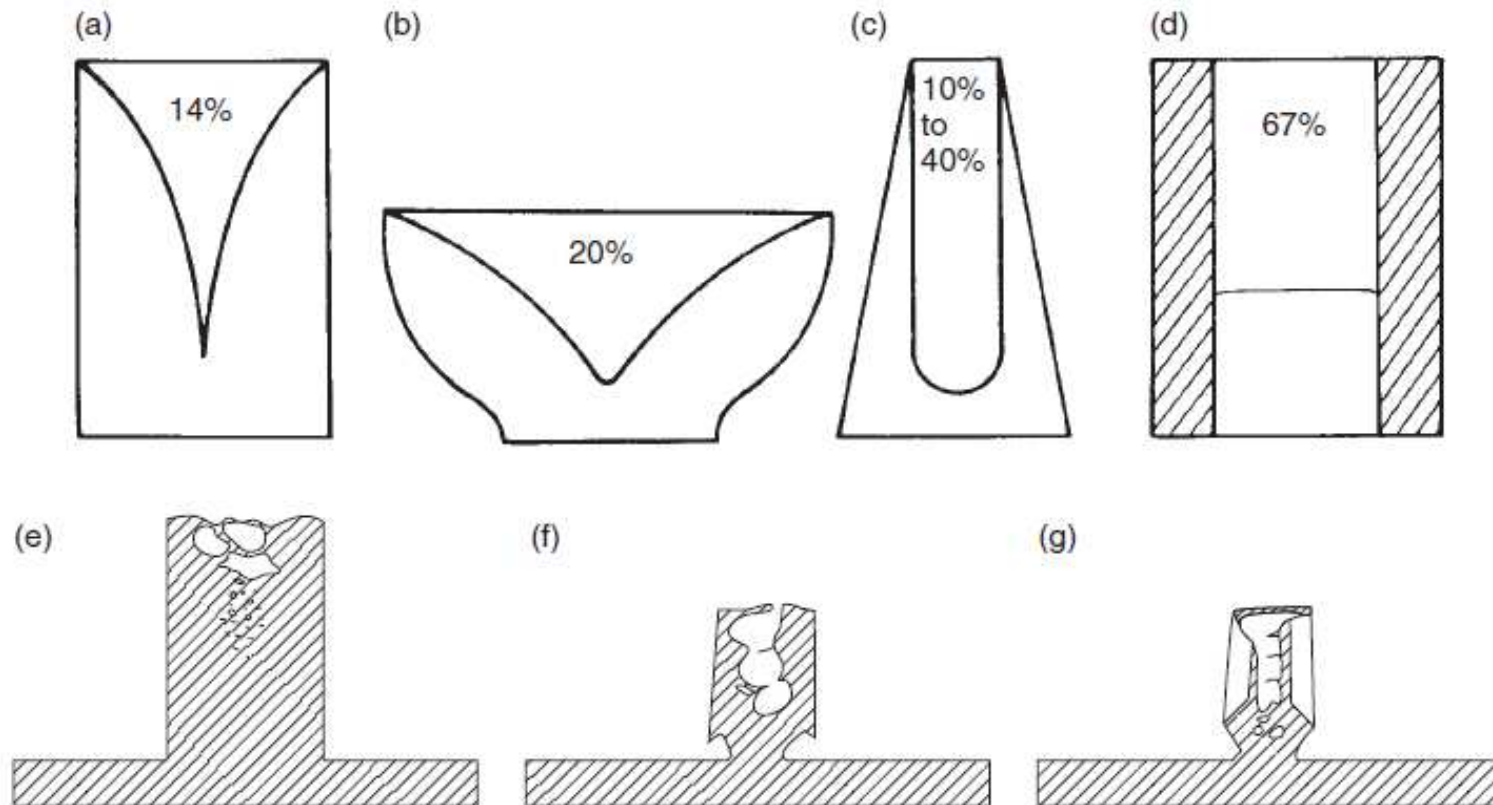
- Usados em fundidos, ou parte de fundidos, com MR elevado
- Geralmente desnecessários para fundidos de paredes finas ( $< 6 \text{ mm}$ )
- $MR_m > 1,2.MR_f$

# Massalotes



**Fig. 3** Methods of controlling shrinkage in an iron cube to reduce riser size. (a) Open-top riser. (b) Open-top riser plus chill. (c) Small open-top riser plus chill. (d) Insulated riser. (e) Insulated riser plus chill

# Eficiência de massalotes



**Figure 6.5** Metal utilization of feeders of various forms moulded in sand. The (a) cylindrical and (b) hemispherical heads have been treated with normal feeding compounds; (c) efficiency of the reverse taper heads depends on detailed geometry (Heine, 1982, 1983); (d) exothermic sleeve (Beeley, 1972). Metal utilization for ductile iron plates with (e) cylindrical sand feeder; (f) insulating feeder; and (g) cruciform exothermic feeder (after Foseco 1988).



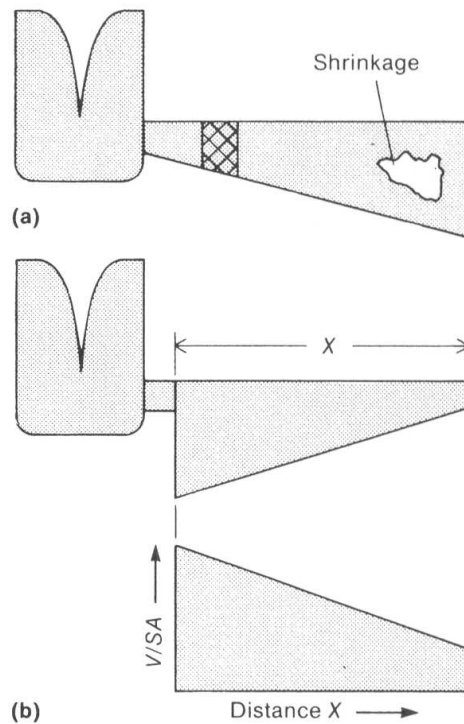
# Volume do Massalote

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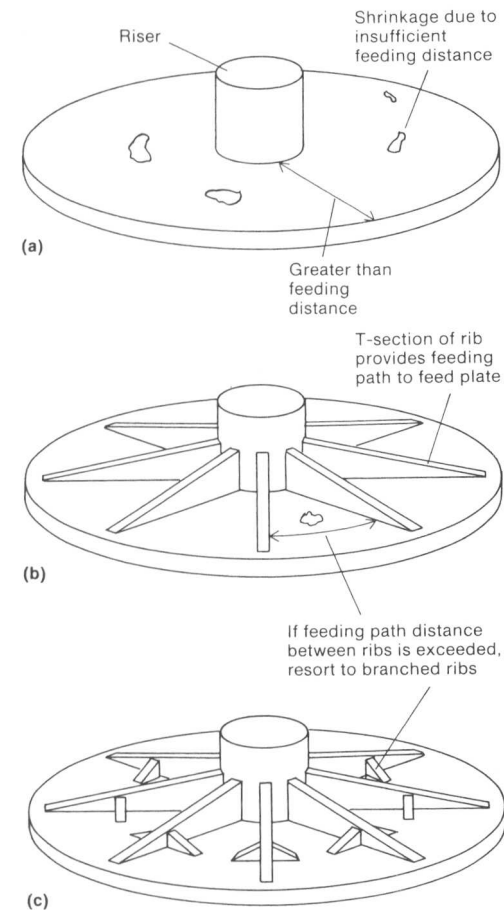
- $V_m = \alpha \cdot V_p / (e - \alpha)$
- Exemplos para massalote cilíndrico com  $H = 1,5D$  ( $e = 14\%$ ):
  - Ligas de Al:  $V_m = V_p$
  - Aços:  $V_m = 0,4 V_p$



# Posicionamento de massalotes

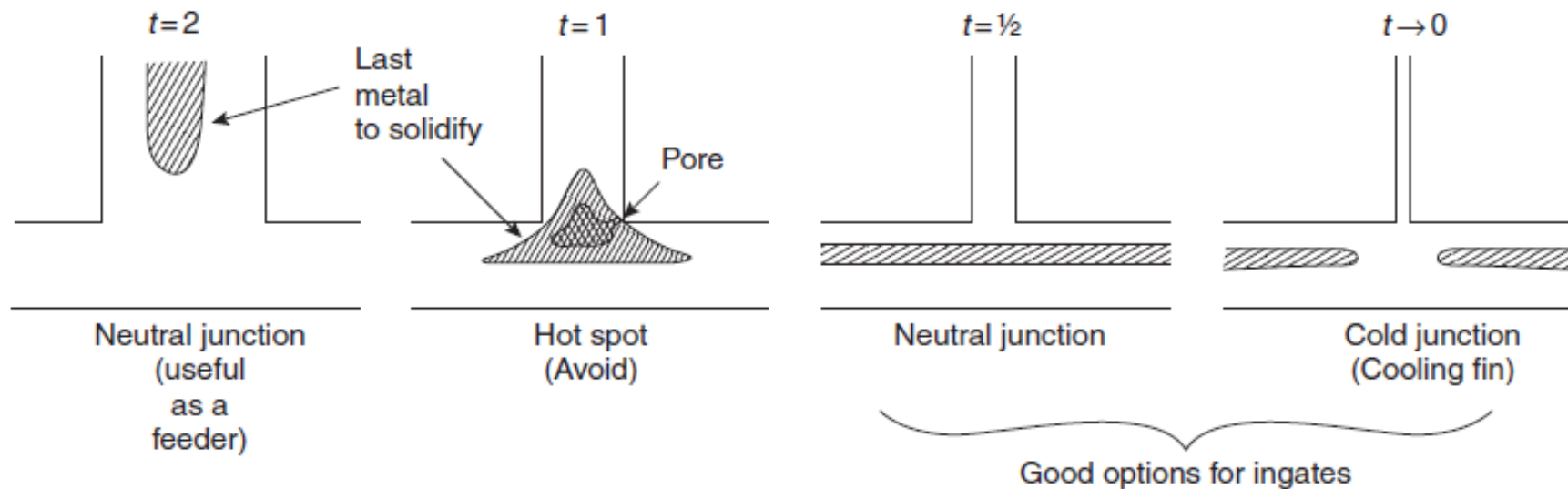


**Fig. 3** Casting design and solidification of a simple wedge. (a) Riser placed at narrow end of wedge; shrinkage occurs at wide end. The crosshatched region represents the approximate area of the casting where solidification is first complete, thus cutting off the feeding path of the casting. (b) Correct riser placement.  $V/SA$  is the volume-to-surface-area ratio (casting modulus).



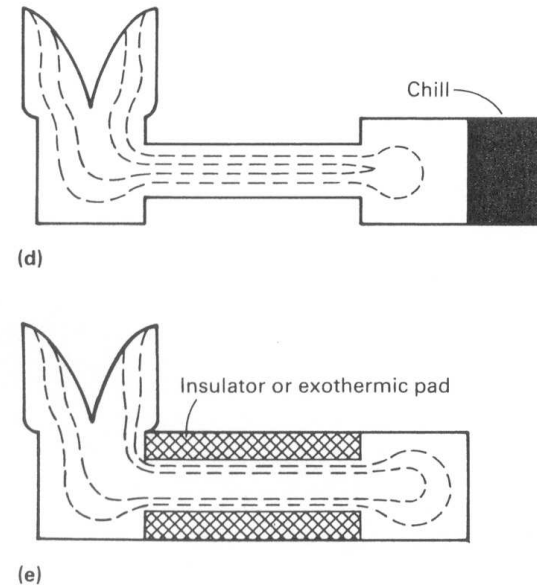
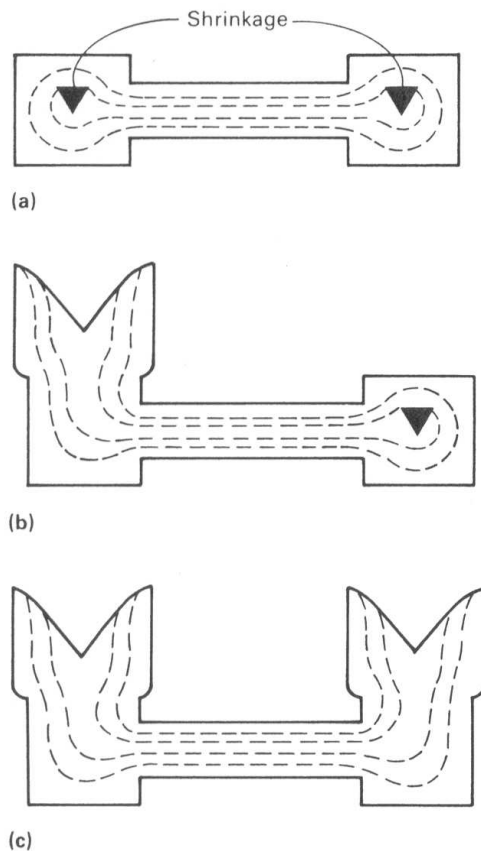
**Fig. 16** Feeding path design considerations. (a) Circular flat plate with a single riser. (b) Addition of wedge-shaped ribs to ensure proper solidification. (c) Branched ribs to overcome feeding problems at the circumference of the plate

# Ligação do massalote à peça



$t$  = razão entre as espessuras

# Posicionamento de Massalotes (direcionando a solidificação)



**Fig. 16** Risering of isolated heavy sections joined by a thinner section to minimize shrinkage and number of risers. (a) Workpiece with no risers. (b) Riser added to one side. (c) Risers located on both ends. (d) Chill applied to one end and riser to other end. (e) Riser used on one end and insulator or exothermic pad on opposite end

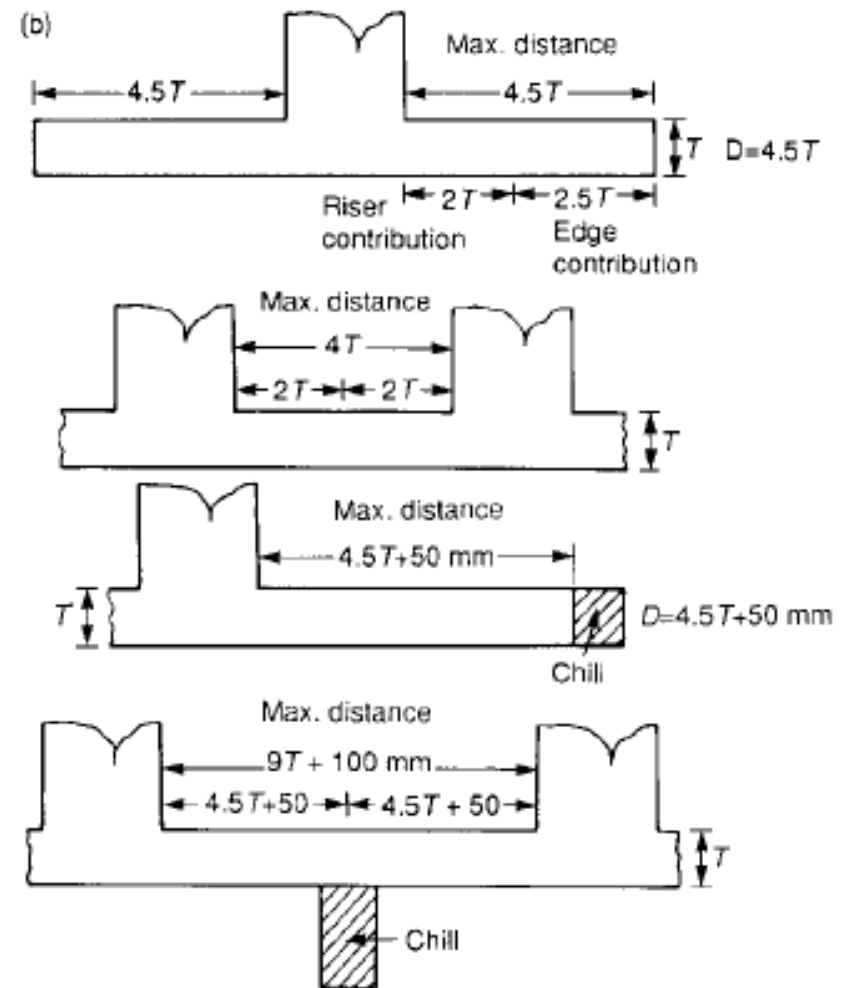
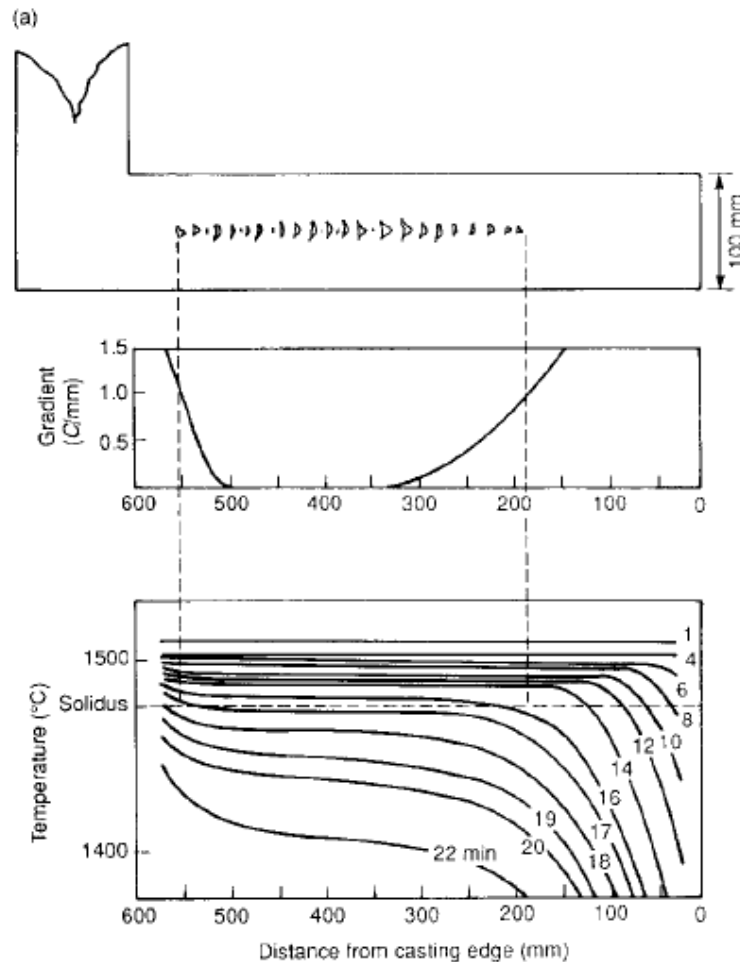


# Exemplos

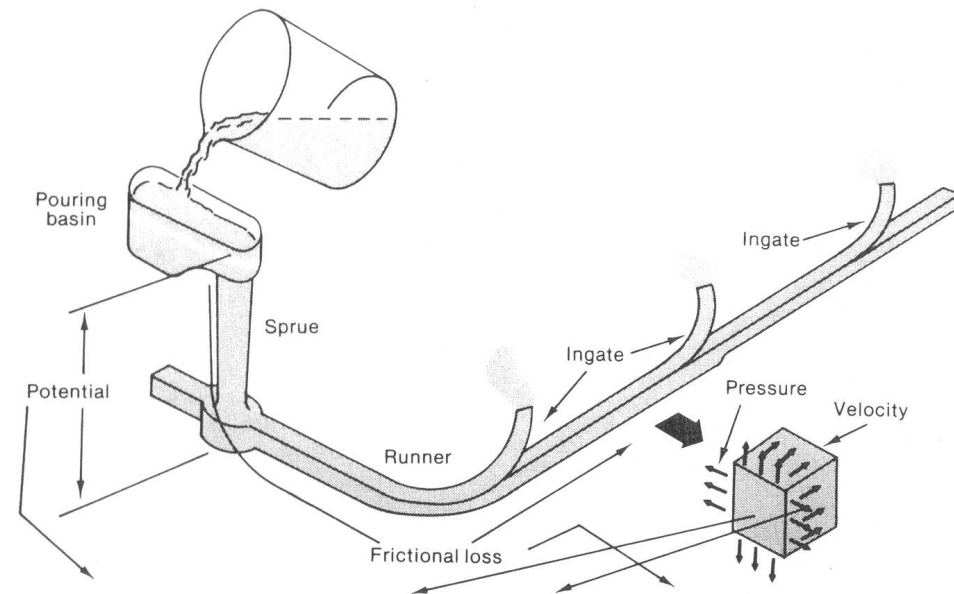
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- Simulações em Excel

# Mais de um massalote



# Sistema de preenchimento



Potential head ( $wZ$ ) + Pressure head ( $wPv$ ) + Velocity head ( $wV^2/2g$ ) + Frictional loss of head ( $wF$ ) = Constant ( $K$ )

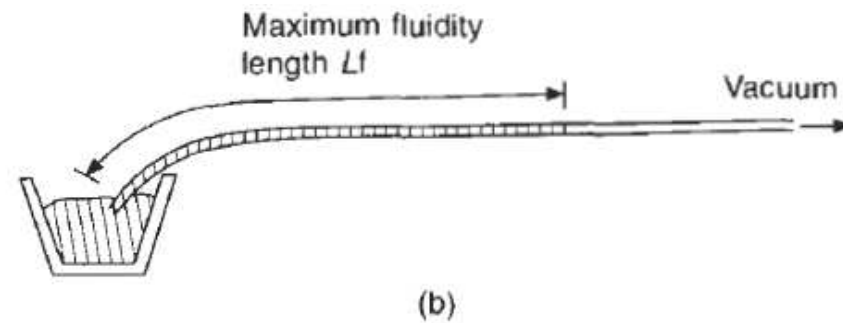
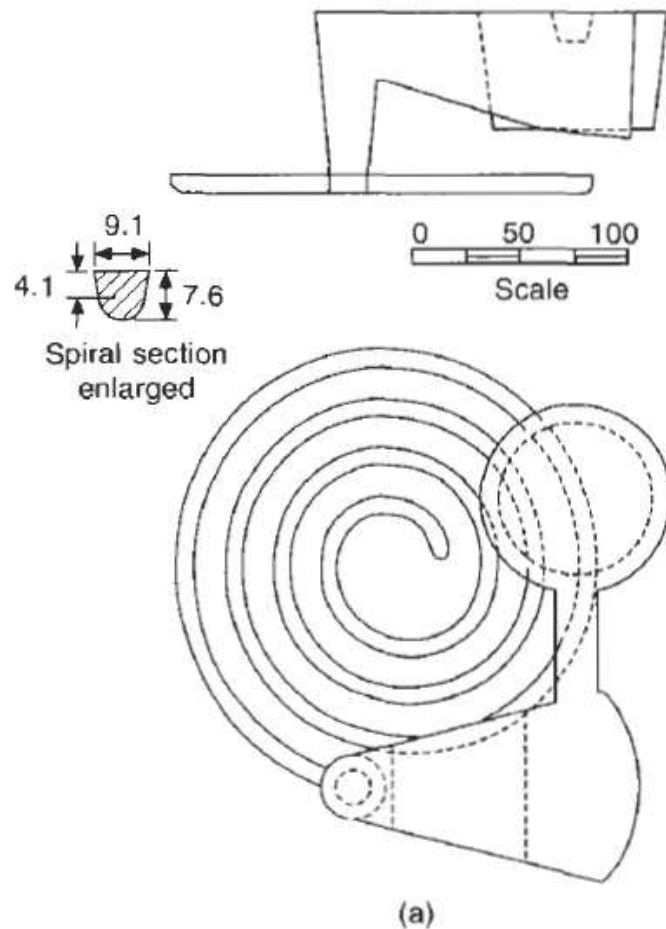
**Fig. 2** Schematic illustrating the application of Bernoulli's theorem to a gating system. Source: Ref 1

## Principal função:

### •Evitar turbulência superficial

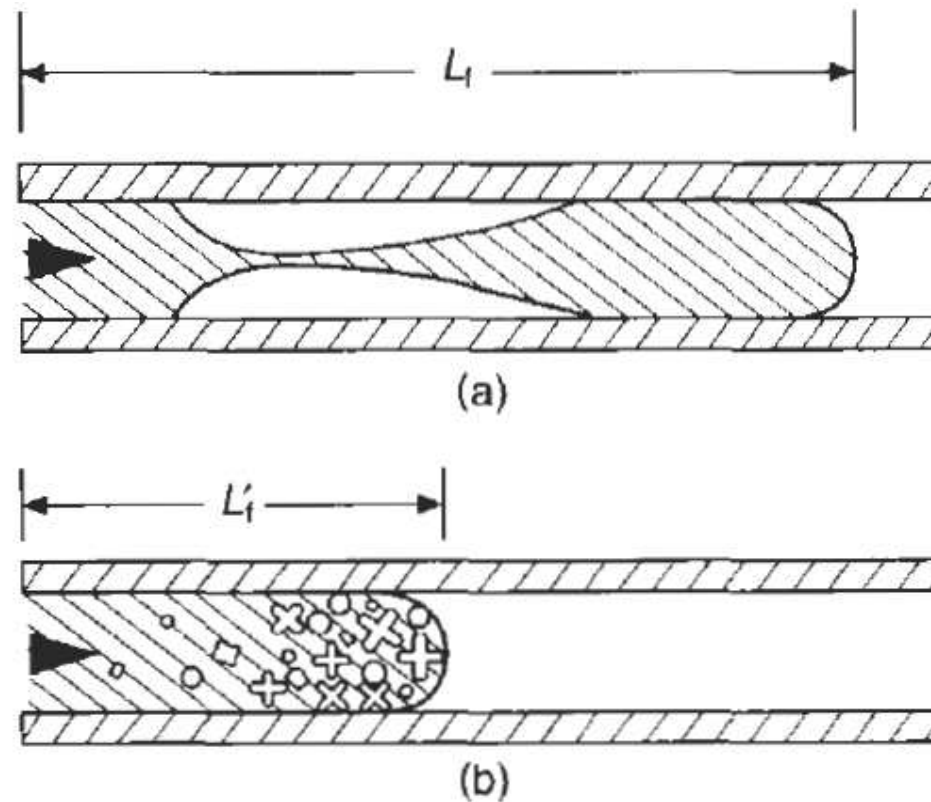
- Manter avanço contínuo da superfície líquida
- Evitar efeito "cascata" e a incorporação de bolhas
- Controlar a velocidade e evitar projeção de metal

# Medidas de fluidez



**Figure 3.2** Typical fluidity tests for (a) foundry and (b) laboratory use.

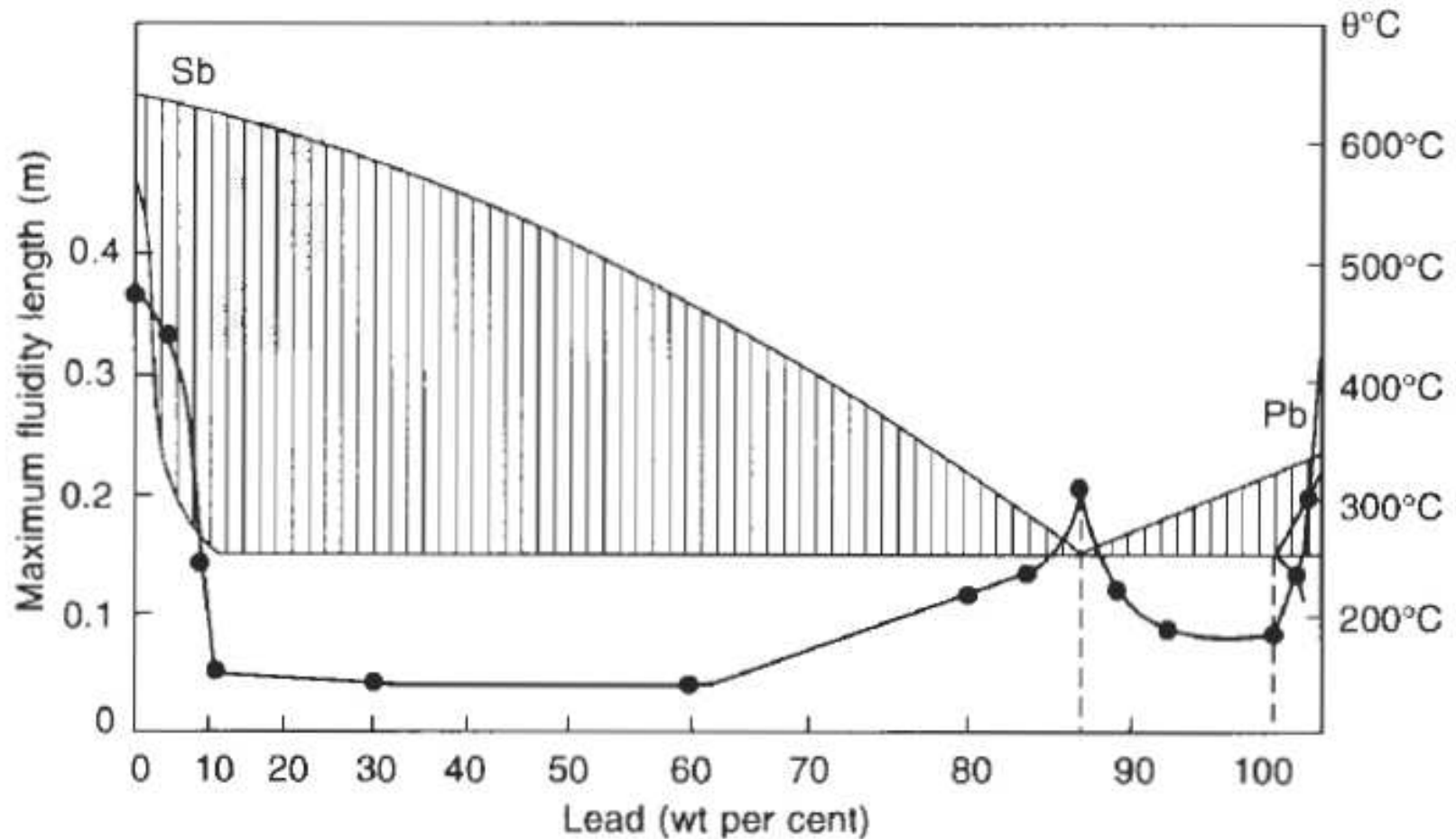
# Influência do tipo de liga na fluidez do metal



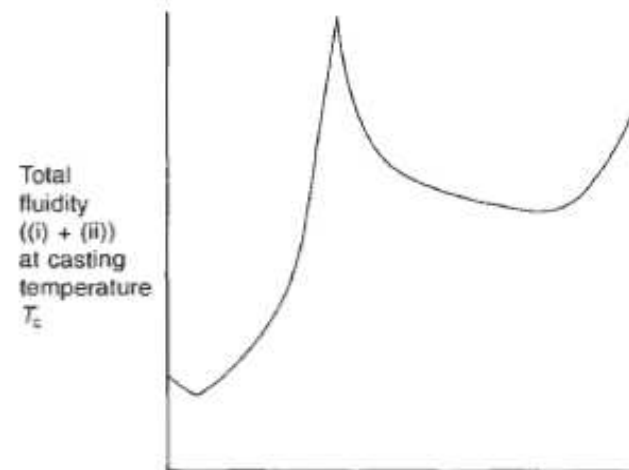
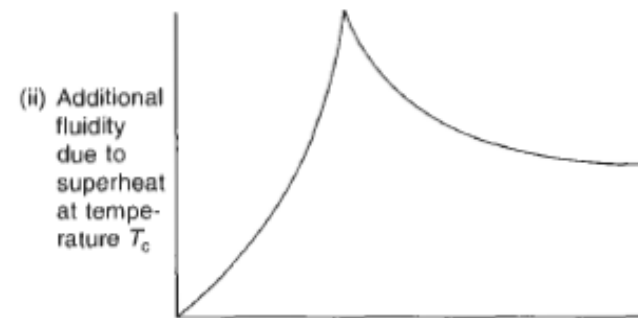
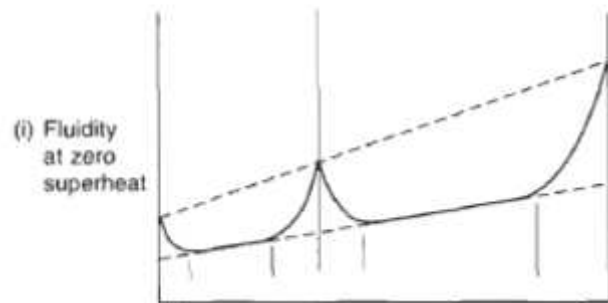
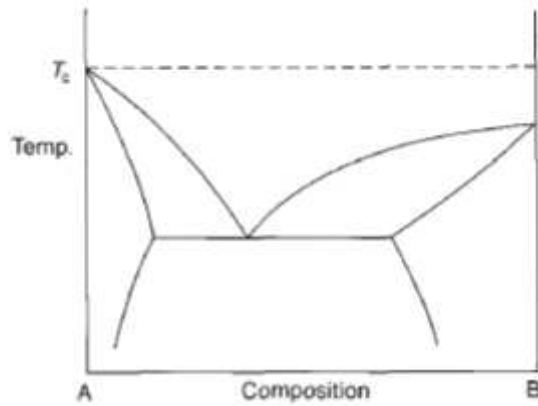
**Figure 3.3** Flow arrest: (a) in pure metals by complete solidification; and (b) in long-freezing-range alloys by partial solidification.



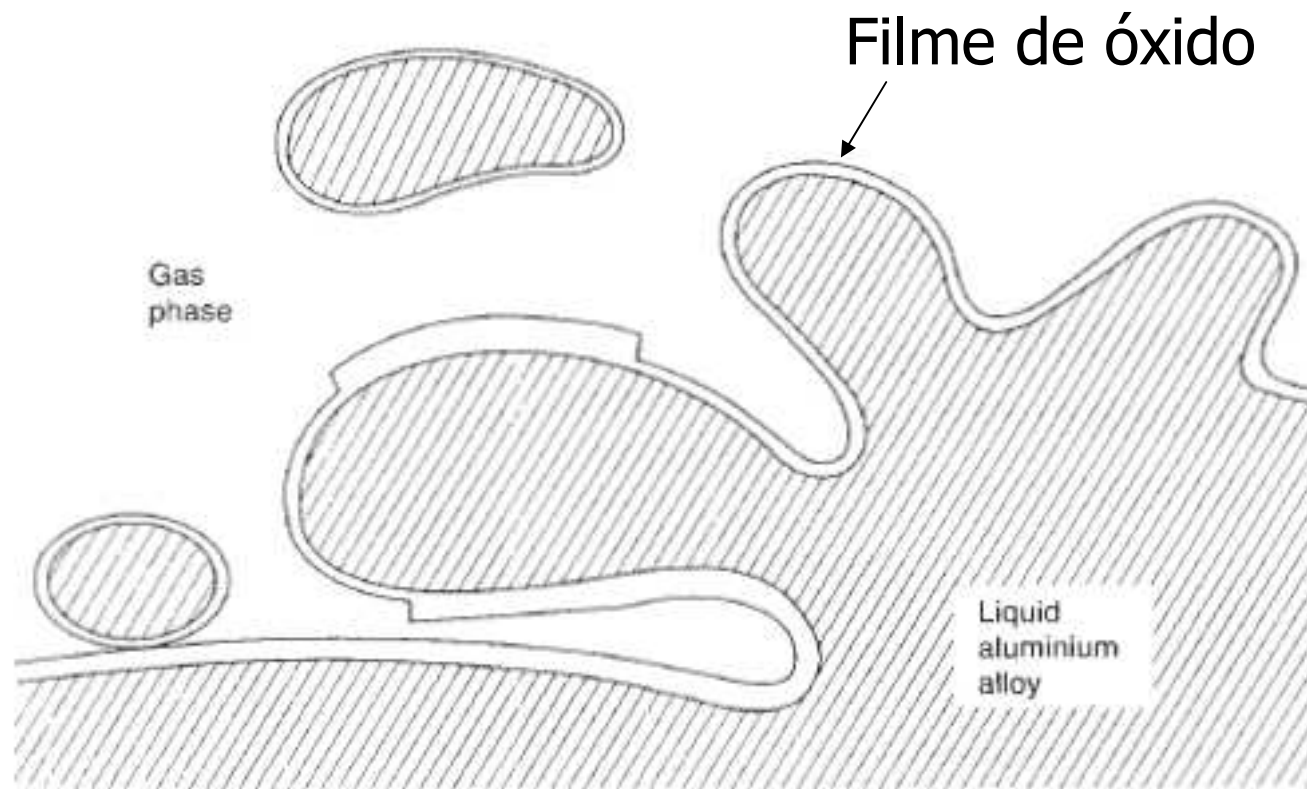
# Fluidez de acordo com o intervalo de solidificação



# Influência do super-aquecimento

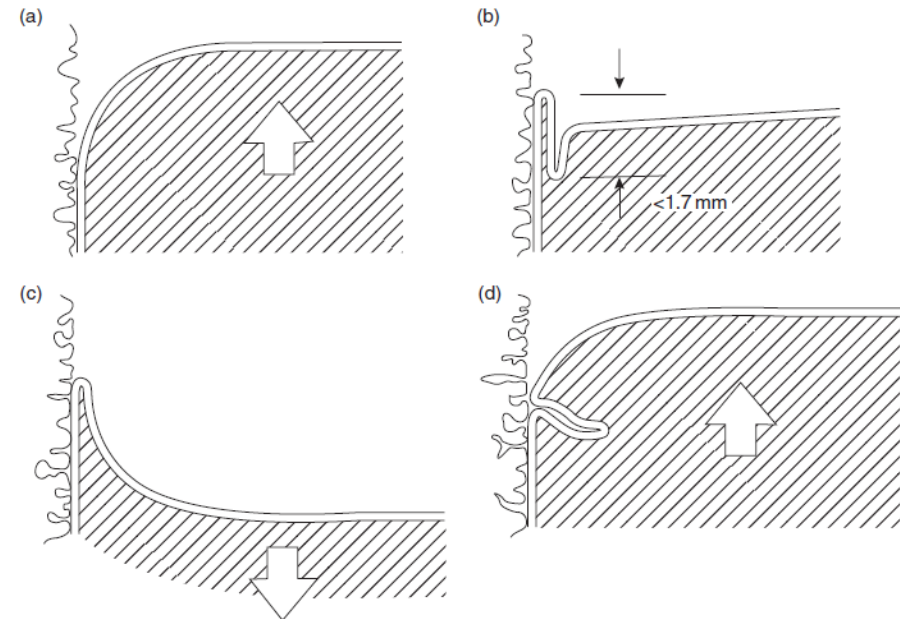
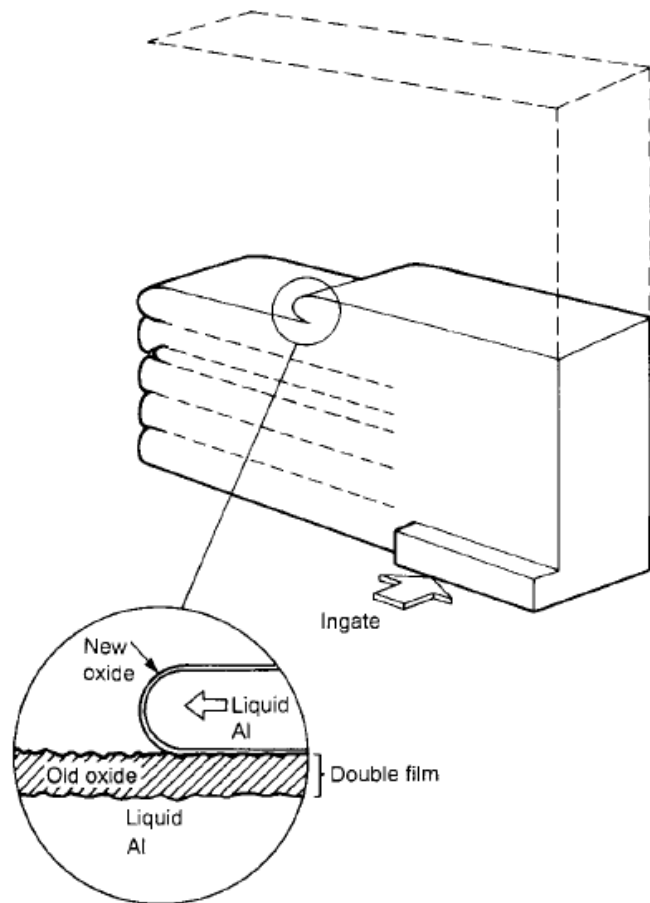


# Efeito de um avanço turbulento na superfície do metal líquido



**Figure 2.1** Sketch of a surface entrainment event.

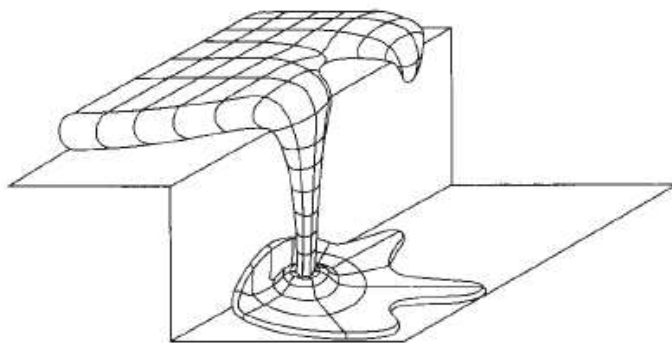
# Efeitos de alimentação intermitente



**Figure 3.6** The creation of a bifilm crack by the reversal of the front, causing the meniscus to flatten and enfold in the excess surface area. Surface cracks of the order of a millimetre depth can be formed in this way.

# Efeito "cascata" e projeção de metal líquido

Oxide flow tube defect from a fall



## Projeção

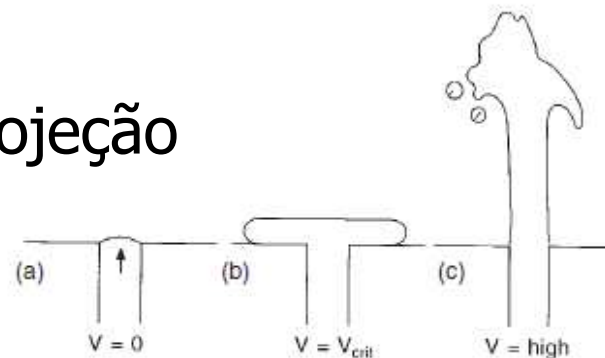
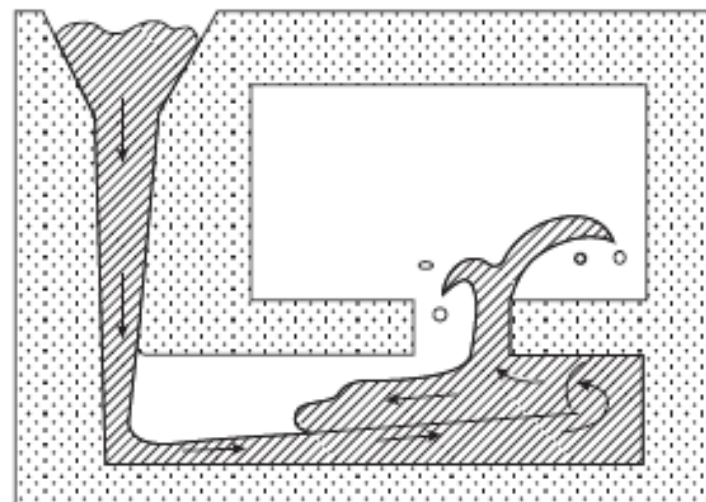
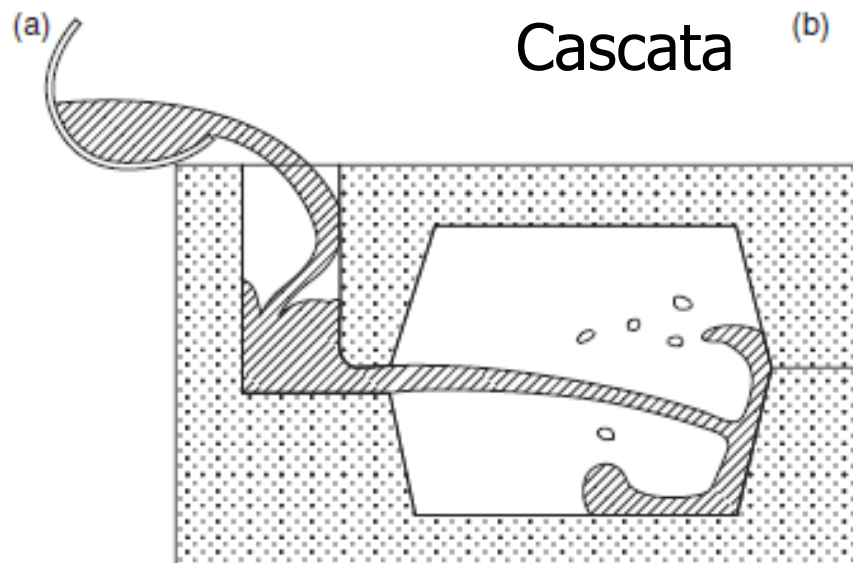
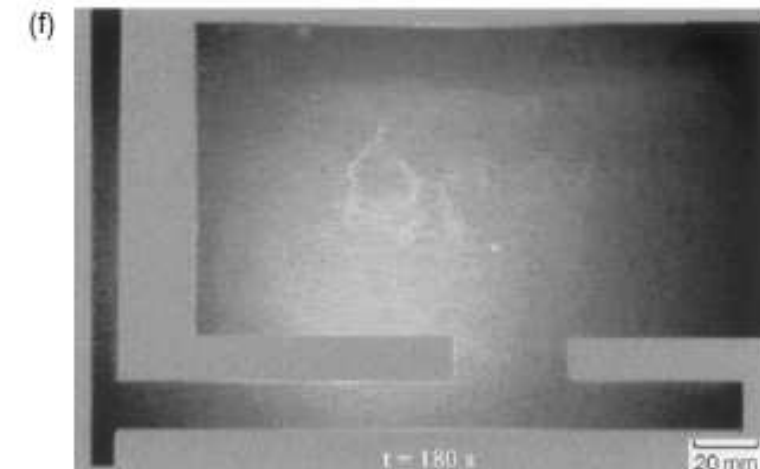
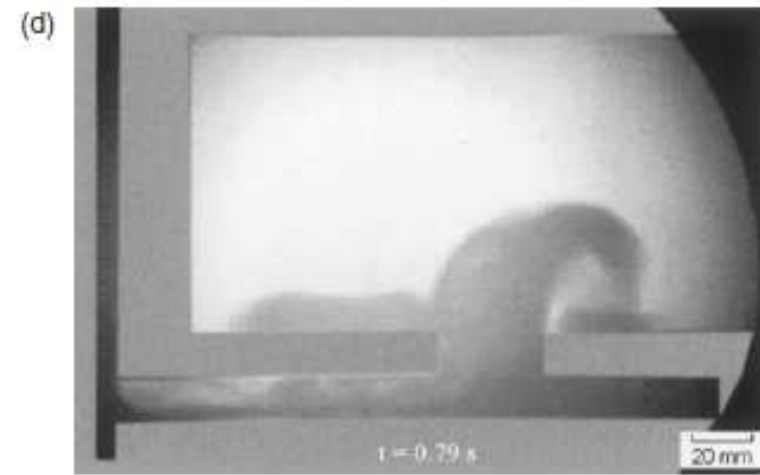


Figure 2.1 The extremes of velocity entering the mould from the gate; zero, critical and high.

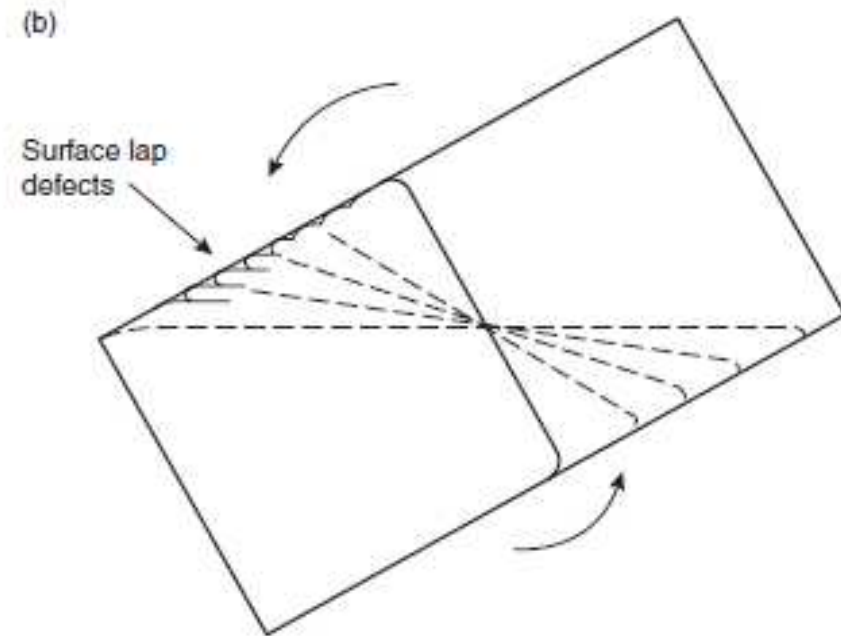
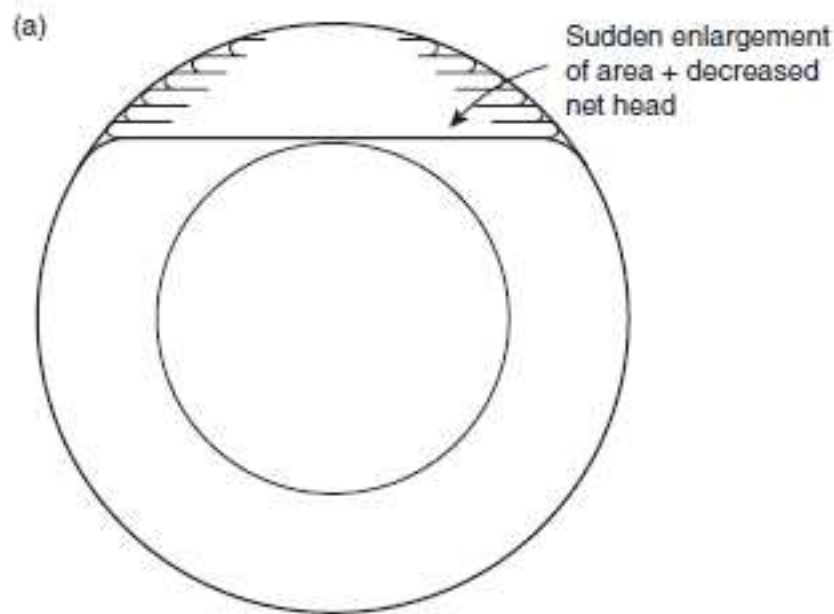
$V_{crit} \approx 0,5 \text{ m/s}$  p/ a maioria dos metais



# Efeito da projeção de metal líquido

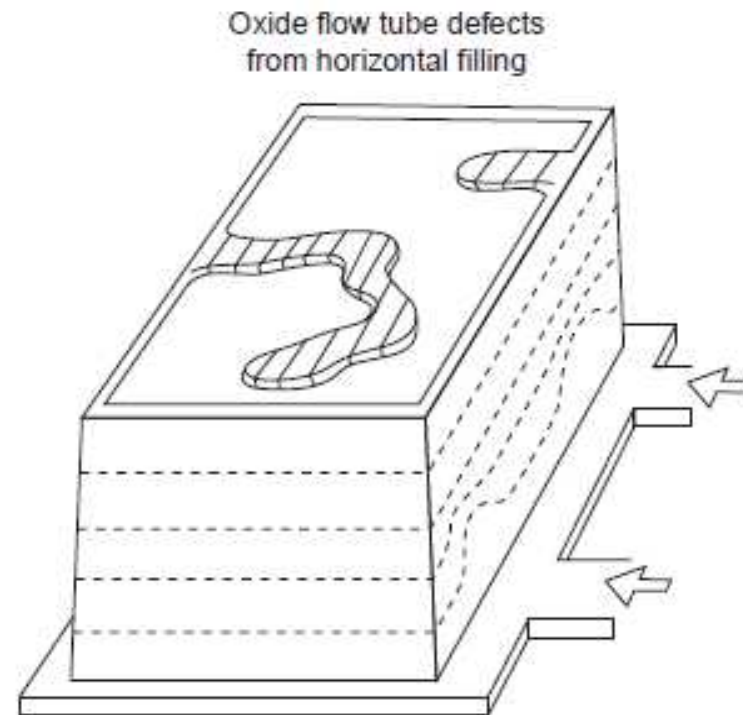


# Efeito de mudanças bruscas de área durante o preenchimento



**Figure 2.60** Common lap problems at low rates of rise of liquid surface in the mould (a) in a horizontal pipe or cylinder; (b) on the cope surface of a tilt casting.

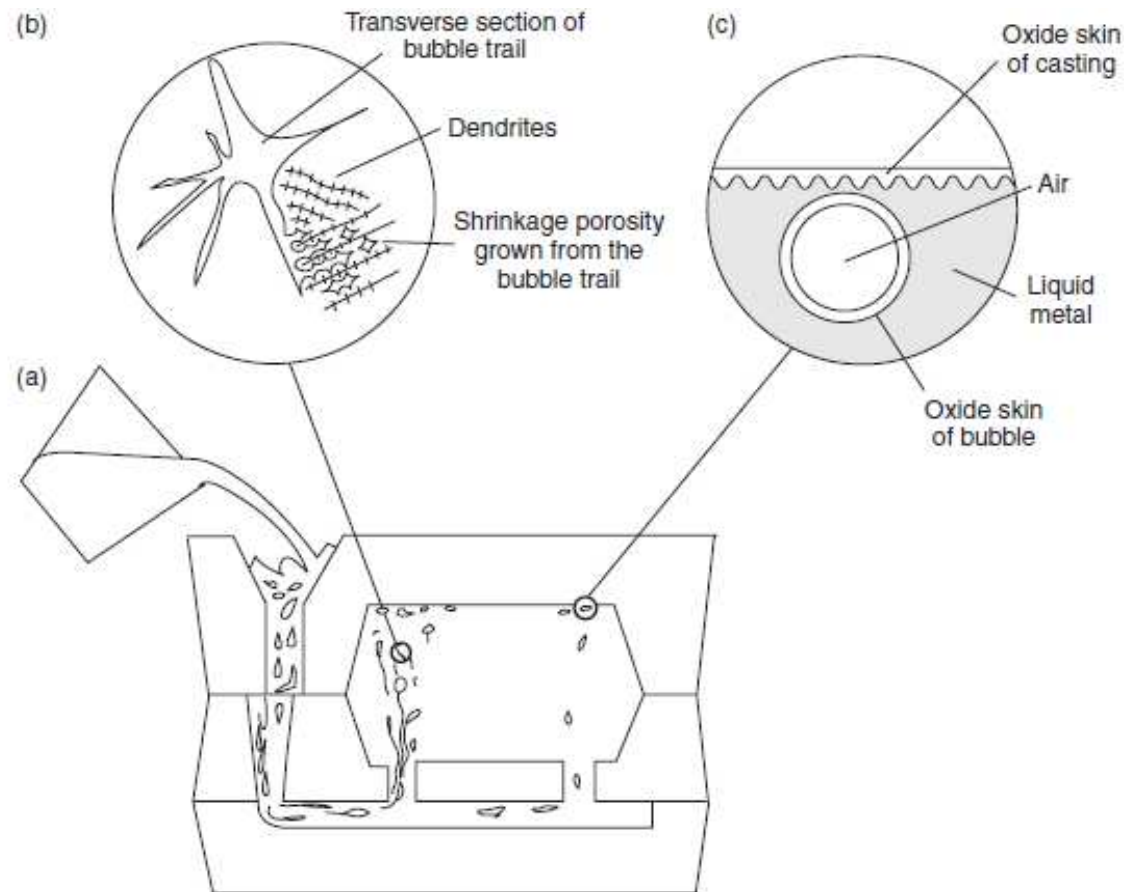
# Efeito de mudanças bruscas de área durante o preenchimento



**Figure 3.4** *The filling of a rectangular box type casting, illustrating the progressive advance of the front that characterizes the filling of vertical walls. The horizontal top, however, fills unpredictable meanders of river-like flows, leading to horizontal oxide flow tubes.*

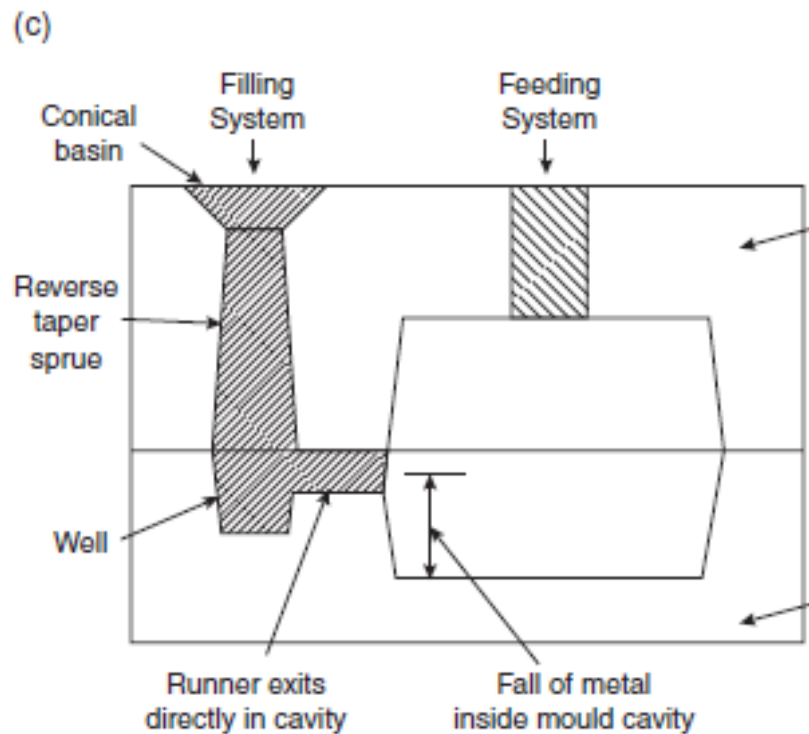


# Inclusão de bolhas devido a sistema de alimentação incorreto

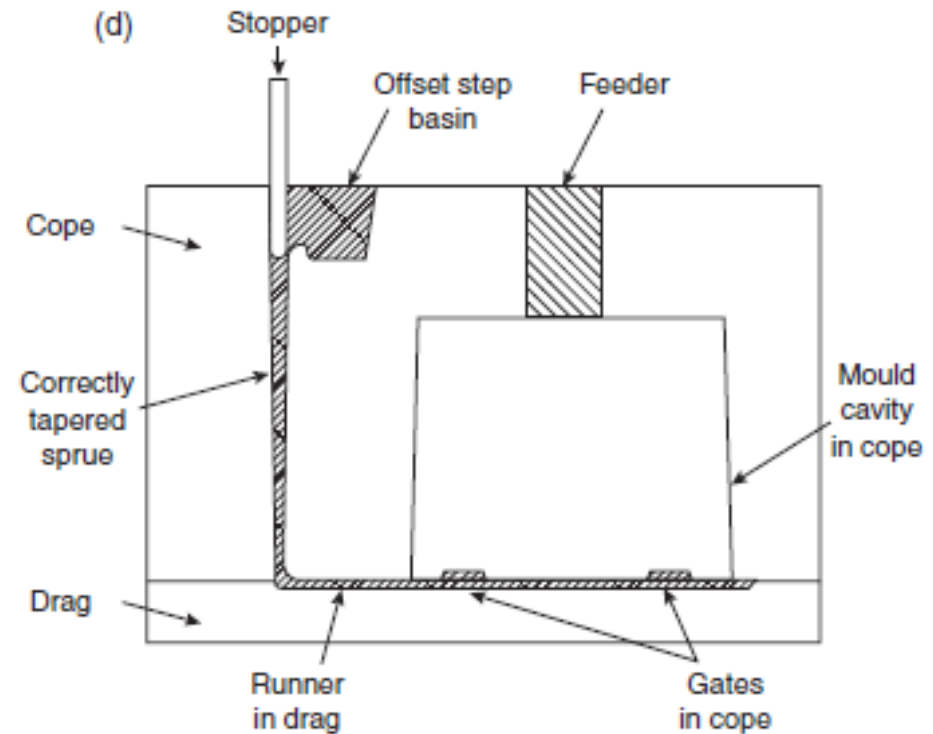


**Figure 4.1** (a) Pattern of bubble damage in a casting; (b) trails invisible in radiography are usually visible on transverse sections; (c) small entrained air bubbles do not have sufficient buoyancy to break the double oxide barrier to escape to the atmosphere.

# Exemplo

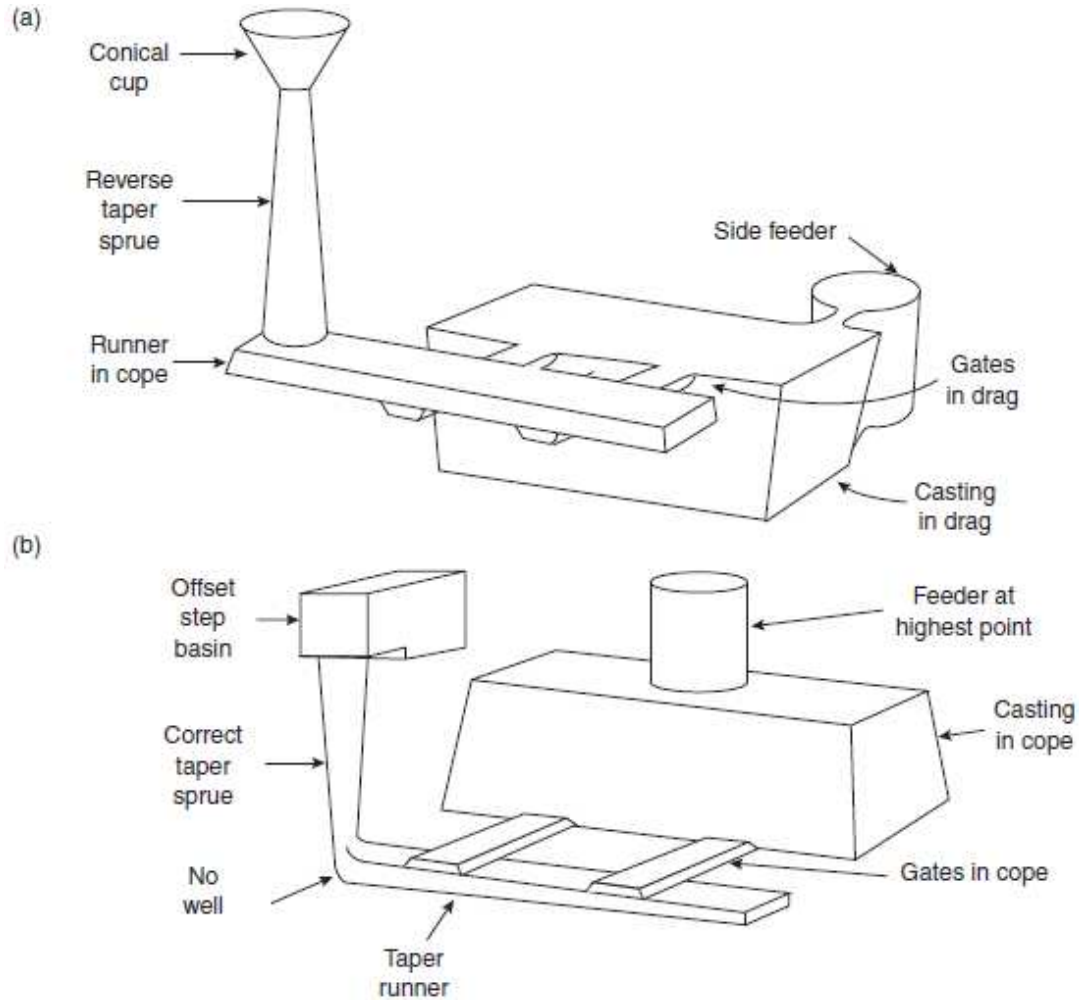


**Ruim**



**Bom**

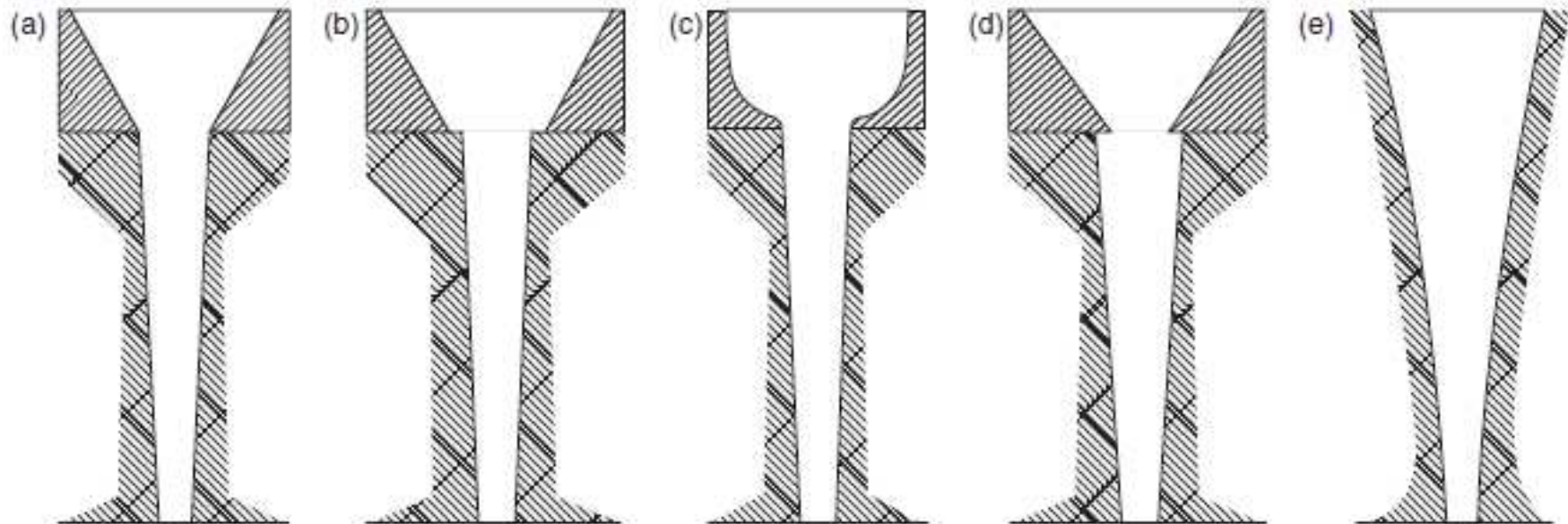
# Exemplo



**Ruim**

**Bom**

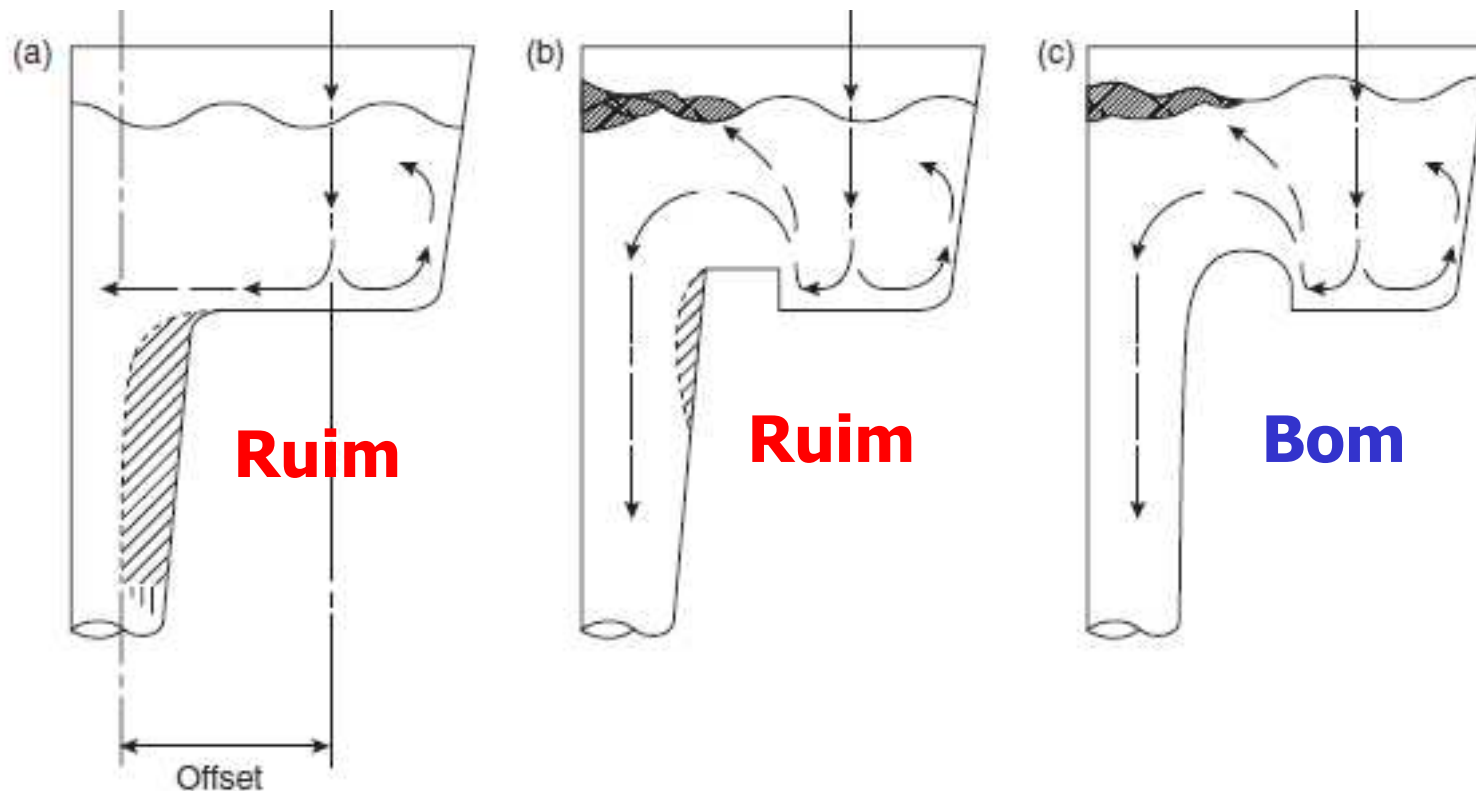
# Bacia de vazamento



**Figure 2.8** A rogues gallery of non-recommended scrap generating systems. Conical basin and sprue combinations showing (a) perhaps least damaging; (b) basin too large; (c) cup form; (d) basin too small; (e) enlarged sprue to act as a combined basin and sprue.

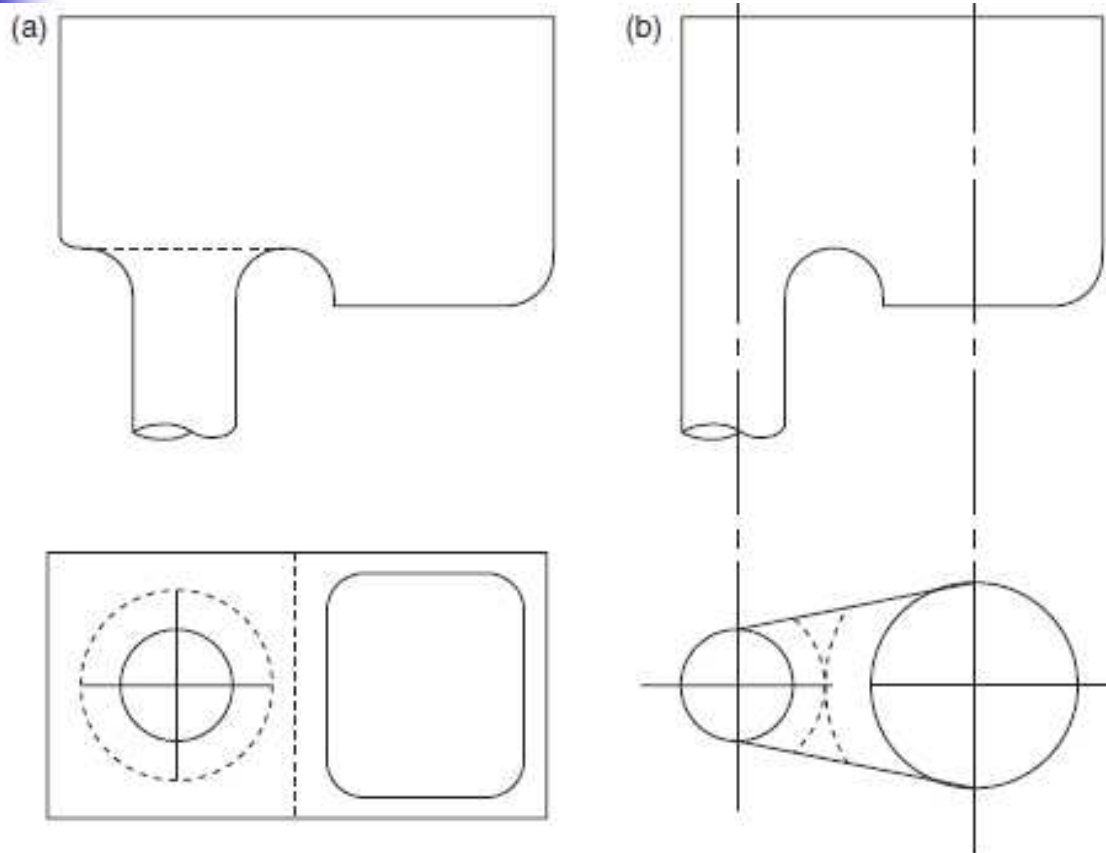
**TODOS OS CASOS ACIMA NÃO SÃO RECOMENDADOS**

# Bacia de vazamento



**Figure 2.9** Offset pouring basins (a) without step (definitely not recommended); (b) sharp step (not recommended); (c) radiused step (recommended).

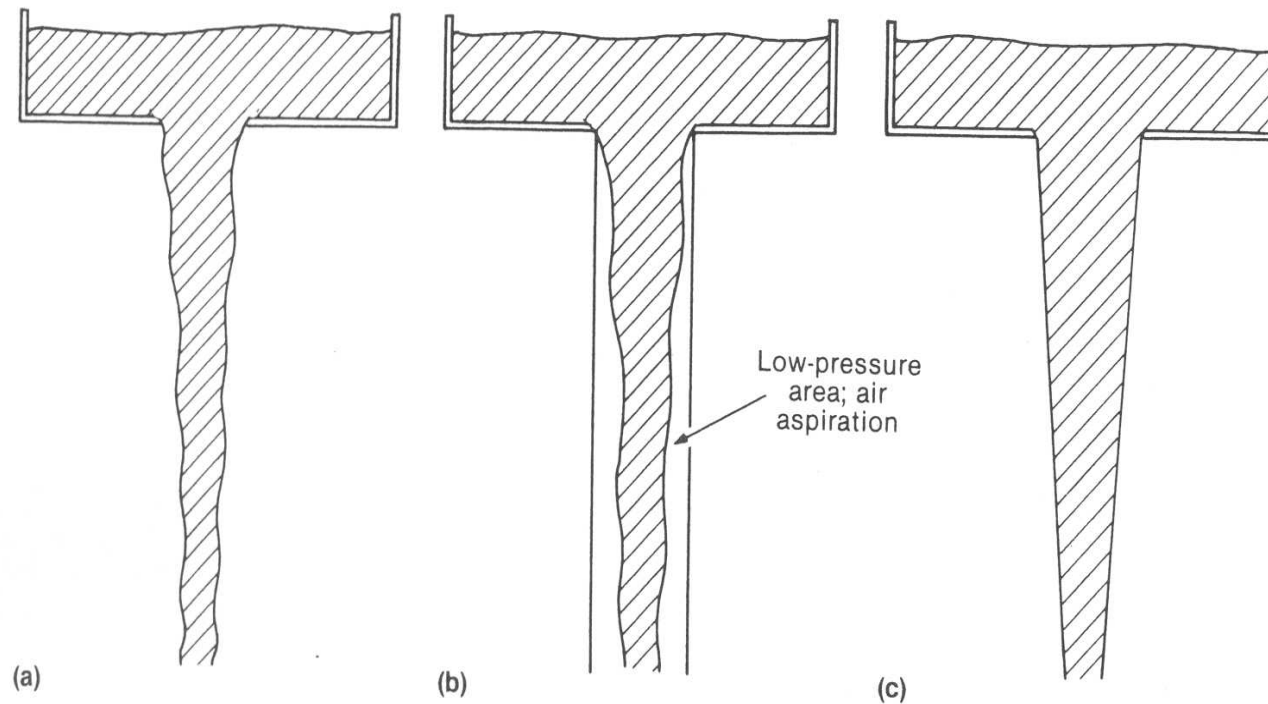
# Bacia de vazamento



**Figure 2.11** Side and plan views of offset basins (a) conventional rectangular; (b) slimmed shape to streamline flow and improve metal yield.

**Melhor**

# Canal de descida



**Fig. 3** Schematic showing the advantages of a tapered sprue over a straight-sided sprue. (a) Natural flow of a free-falling liquid. (b) Air aspiration induced by liquid flow in a straight-sided sprue. (c) Liquid flow in a tapered sprue

# Canal de descida

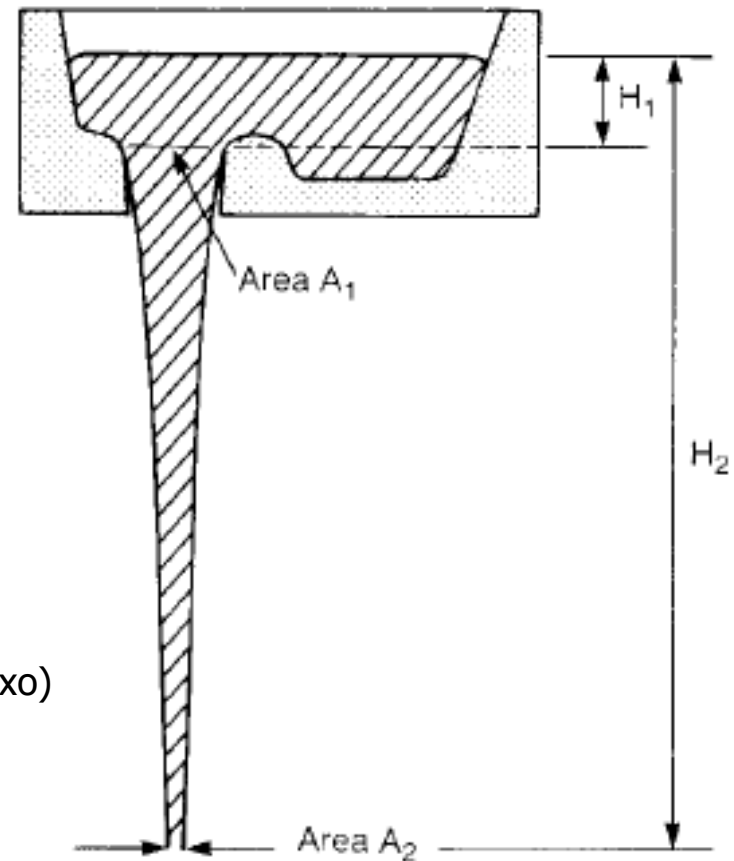
$$\frac{A_1}{A_2} = \sqrt{\frac{H_2}{H_1}}$$

$$t = \frac{V}{A_2 \cdot C \cdot \sqrt{2gH_2}}$$

t – tempo de preenchimento estimado (alimentação por baixo)

V – volume de metal

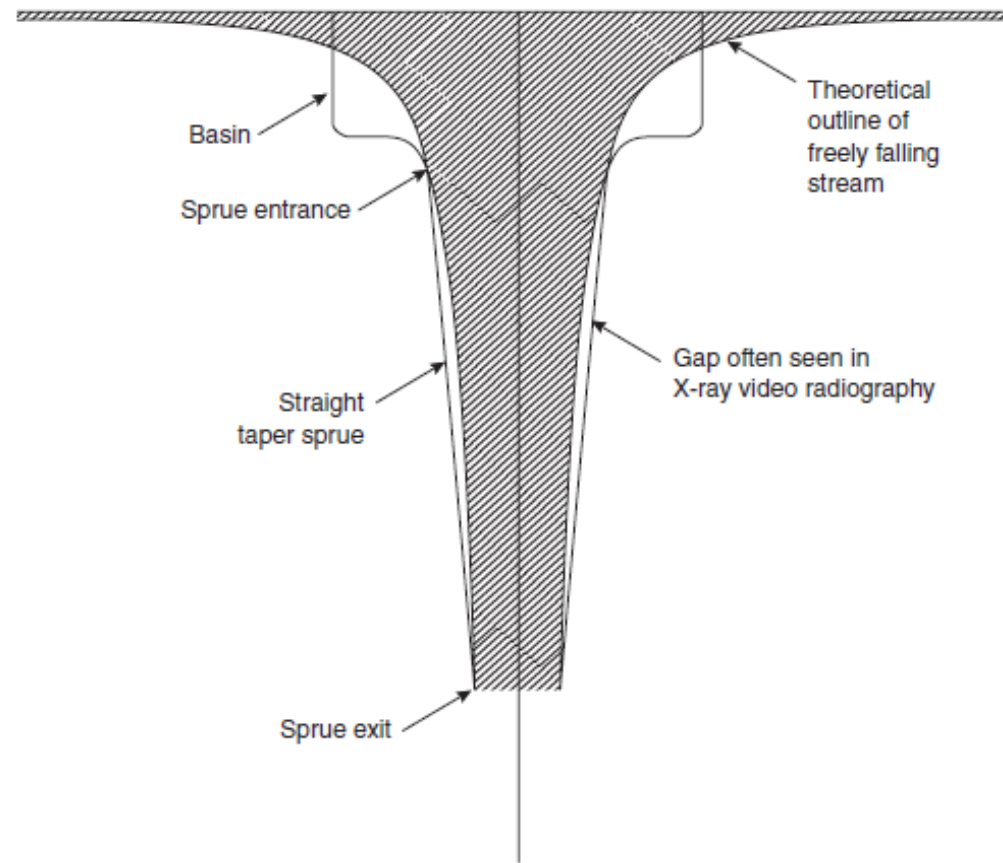
C – eficiência do canal (C=1 p/ atrito zero)



**Figure 2.13** *The geometry of the stream falling freely from a basin.*

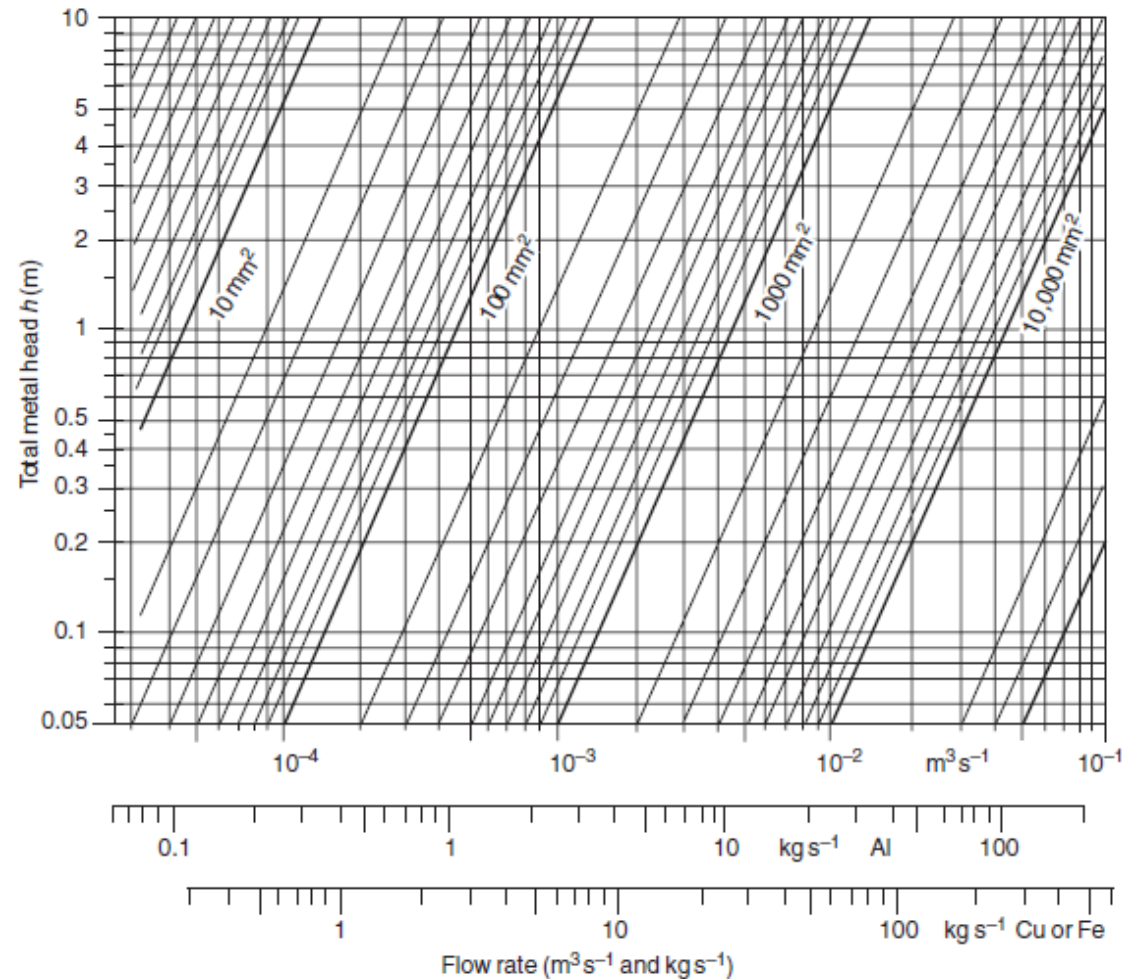


# O canal de descida e a curva do filete de metal líquido



**Figure 2.15** The theoretical hyperbola shape of the falling stream, illustrating the complicating effects of the basin and sprue entrance.

# Diagrama de áreas para canais de descida



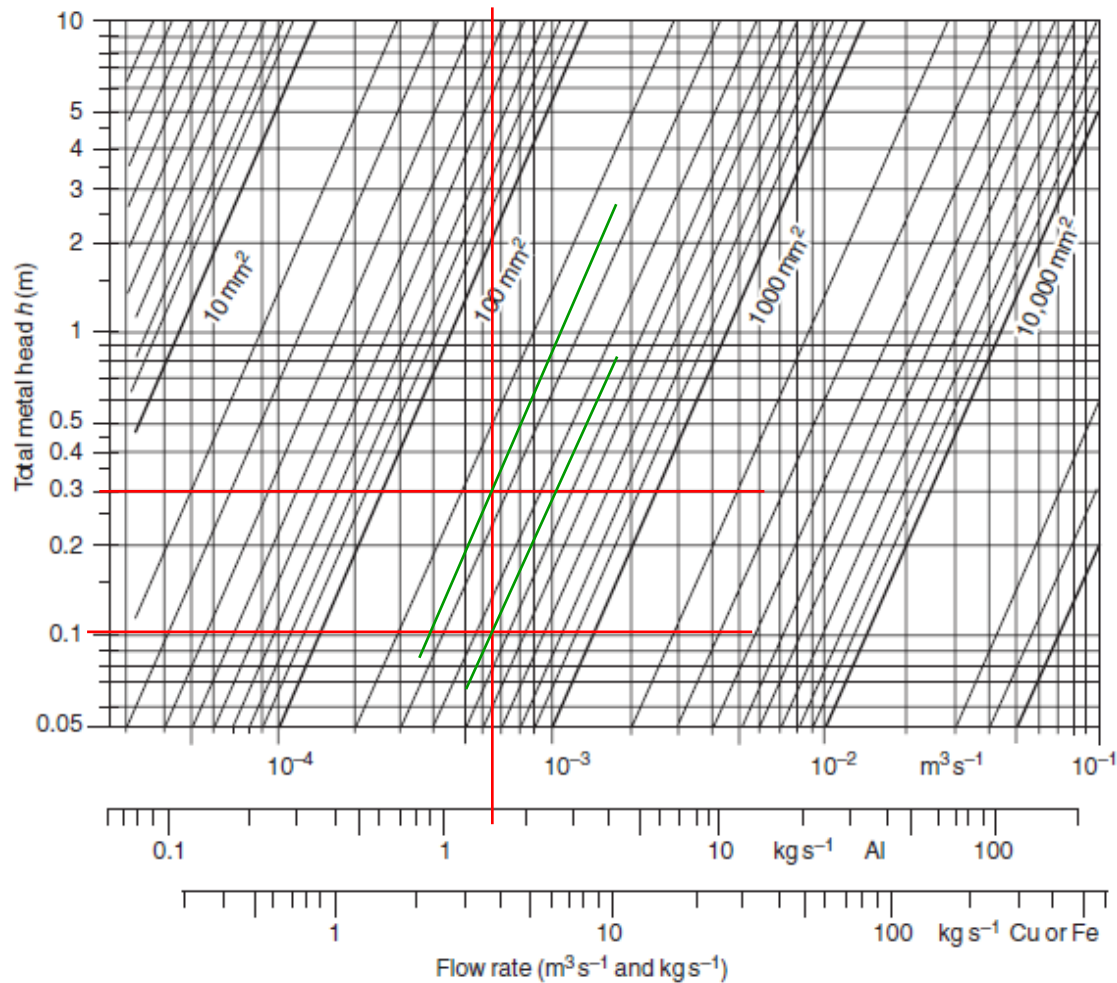


# Exemplo de uso

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- Liga de Al
- Taxa de alimentação média: 1,0 Kg/s
- Usar taxa inicial 1,5x maior: 1,5 Kg/s
- $H1 = 100 \text{ mm}$
- $H2 = 300 \text{ mm}$

# Exemplo de uso

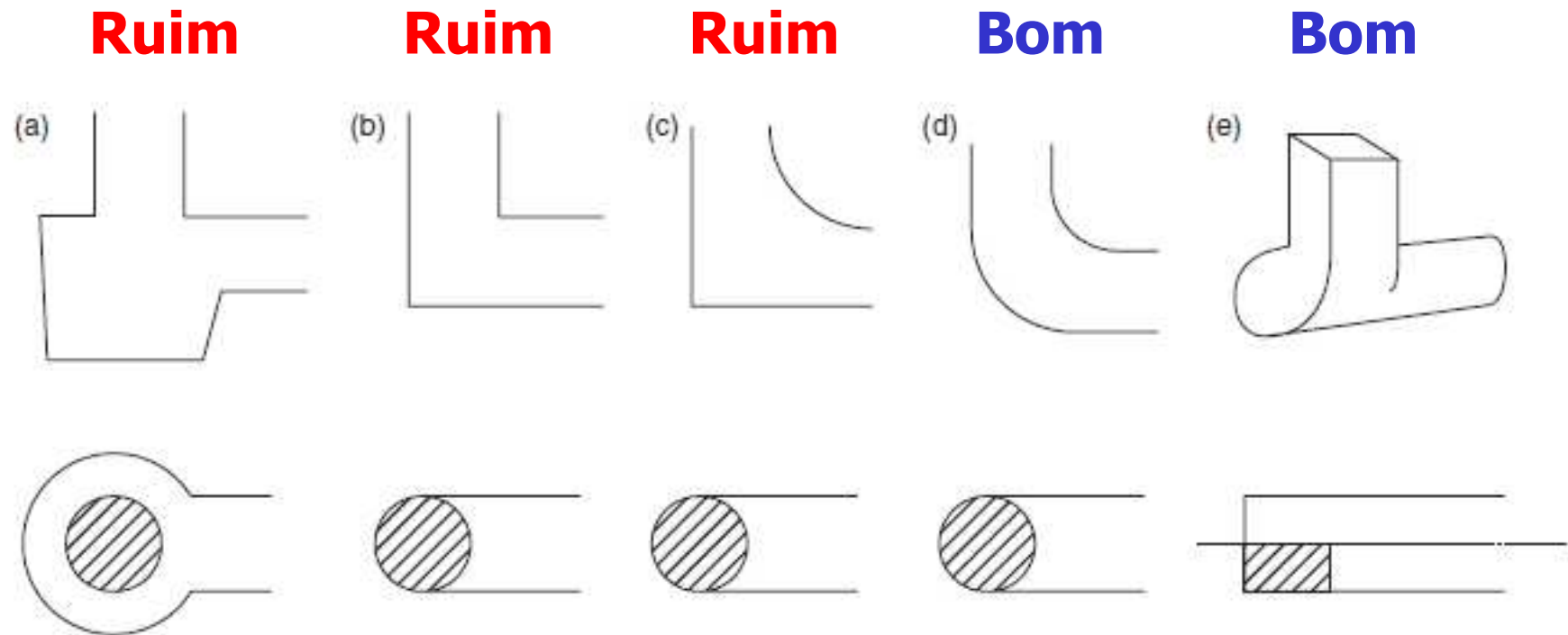


$A1 \approx 450 \text{ mm}^2$   
 $A2 \approx 250 \text{ mm}^2$

Usar 1,2.A1  
para compensar  
erro da geometria

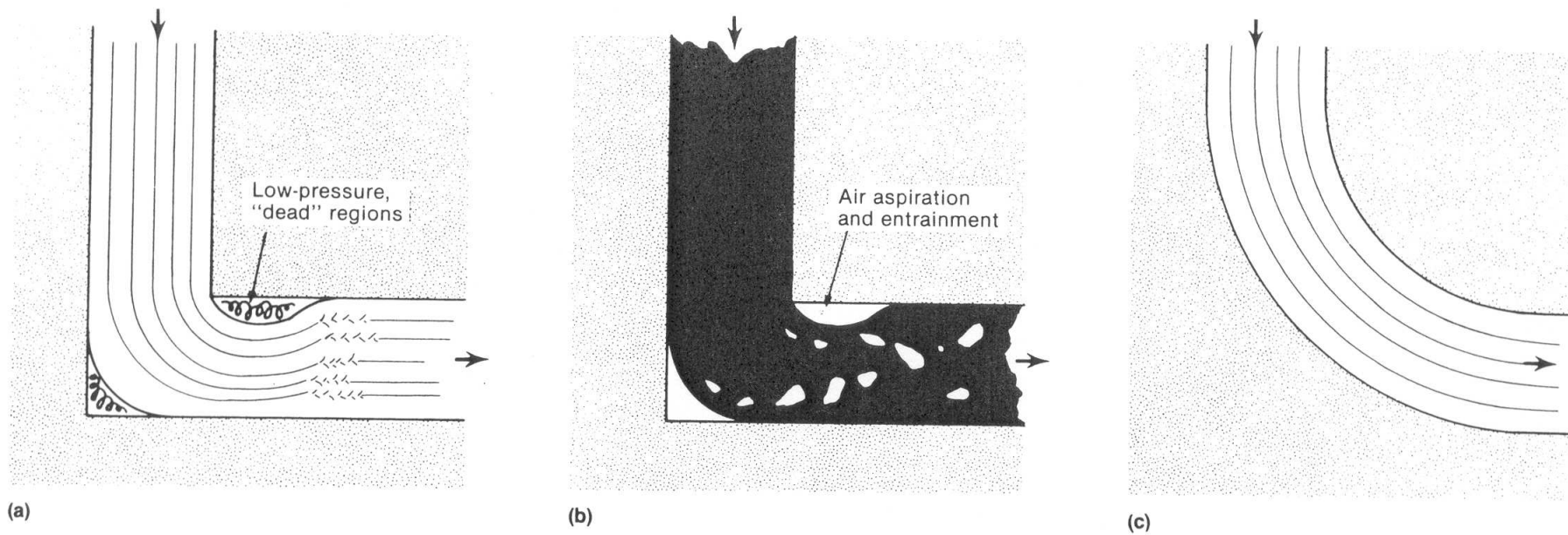
Portanto:  
 $A1 \approx 540 \text{ mm}^2$

# Base do canal de descida



**Figure 2.19** A variety of spruelrunner junctions in side and plan views from poorest (a) to best (d). The offset junction at (e) forms a vortex flow along the cylindrical runner.

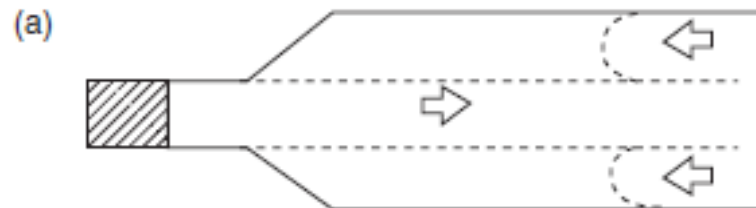
# Base do canal de descida



**Fig. 7** Schematic illustrating fluid flow around right-angle and curved bends in a gating system. (a) Turbulence resulting from a sharp corner. (b) Metal damage resulting from a sharp corner. (c) Streamlined corner that minimizes turbulence and metal damage

# Base do canal de descida

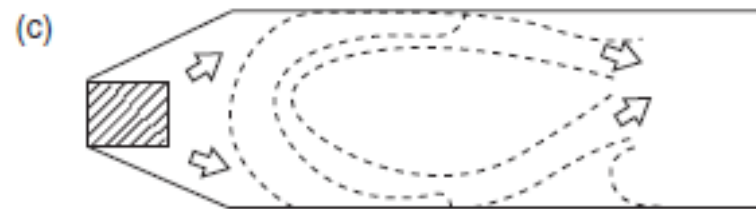
**Ruim**



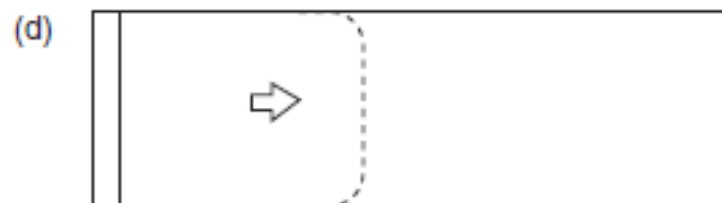
**Ruim**



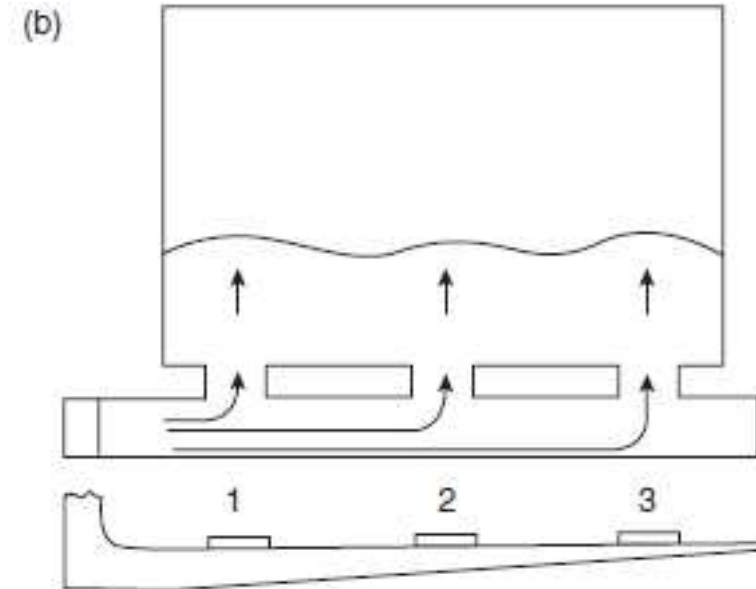
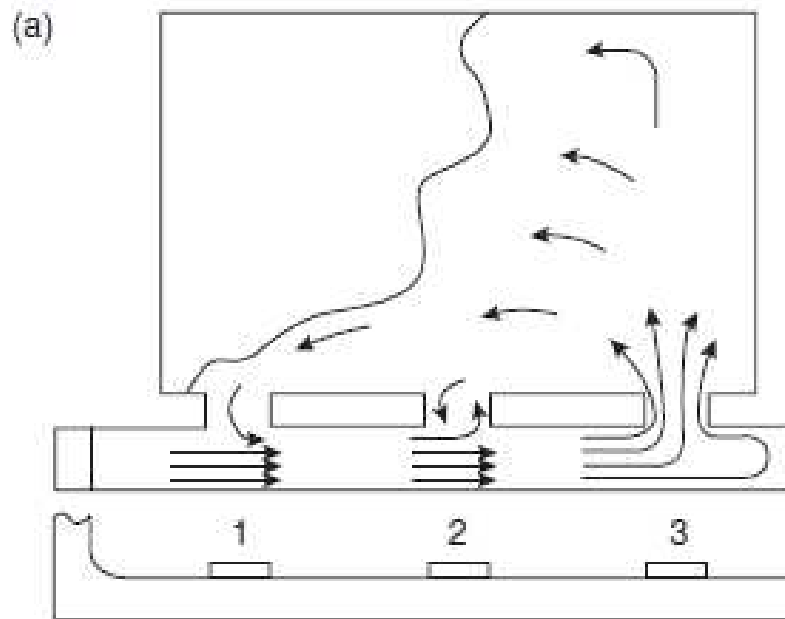
**Ruim**



**Bom**



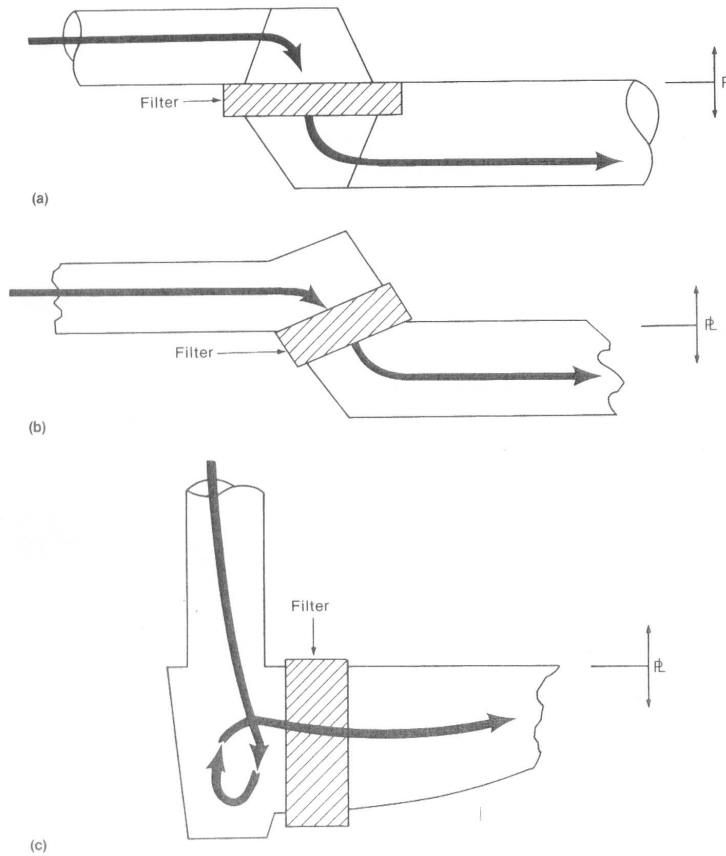
# Canais de distribuição



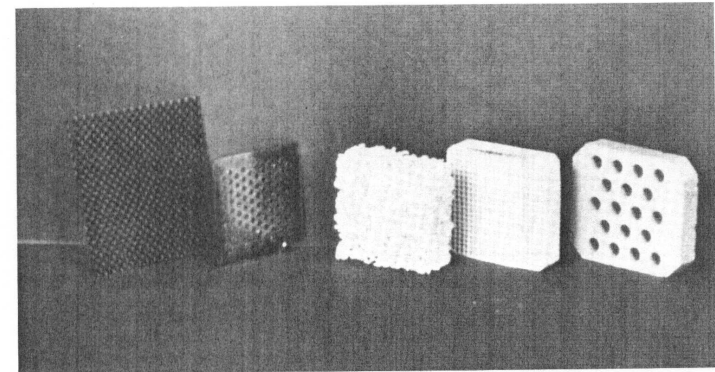
**Figure 2.26** (a) *An unbalanced delivery of melt into the mould as a result of an incorrect runner design;* (b) *a tolerably balanced system.*



# Uso de filtros

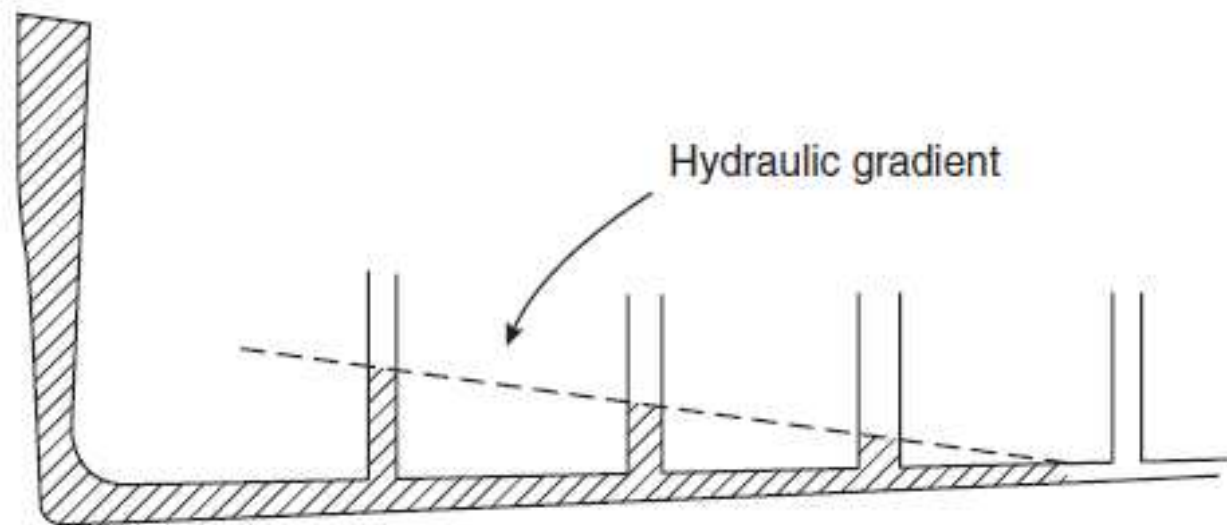


**Fig. 16** Common methods of filter placement in horizontally parted molds. (a) Parallel to parting line. (b) Between 0 and 90° to parting line. (c) 90° to parting line. Arrows indicate the direction of metal flow.



**Fig. 14** Several common filtration and flow modification devices (from left to right): strainer core, extruded ceramic filter, ceramic foam filter, mica screen, and woven fabric screen. The two types of ceramic filters are by far the most widely used.

# Canais de ataque



**Figure 2.29** *The partial filling of vertical ingates along the length of a runner.*

# Canais de ataque

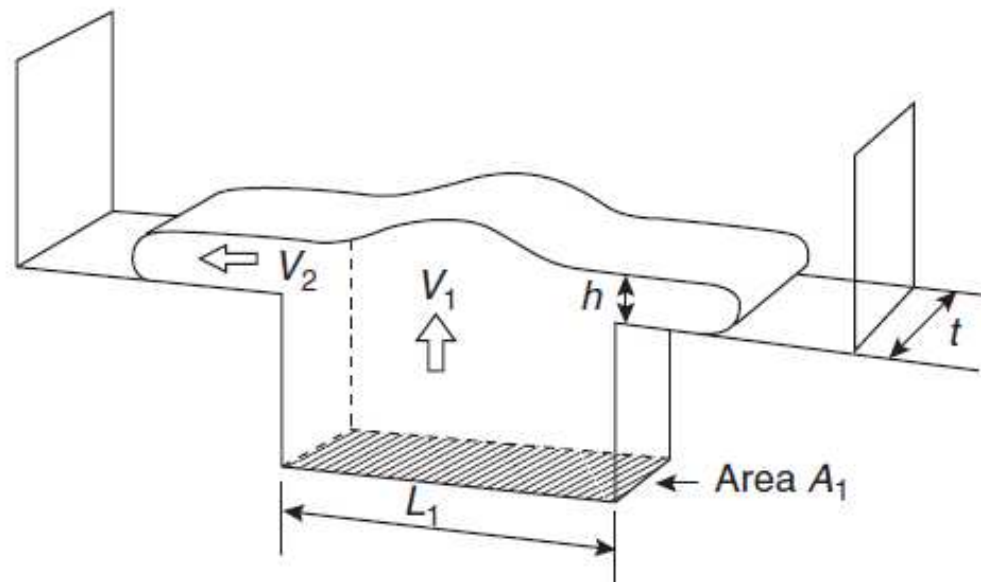


Figure 2.30 Sideways flow inside mould cavity.

$$L_1 \leq 2h$$

$$p/Alh = 13 \text{ mm}$$

p/ferrosos

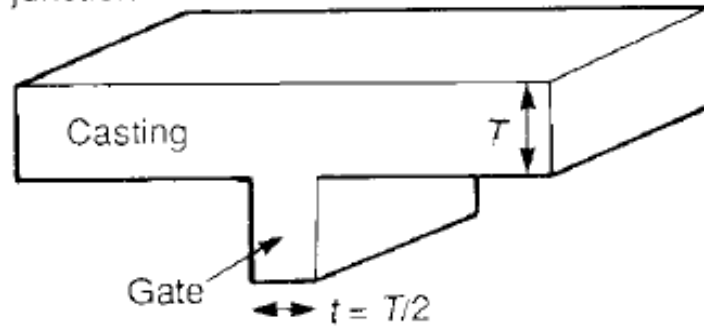
$$h = 10 \text{ mm}$$

Quando  $L_1$  precisa ser maior então usar vários:

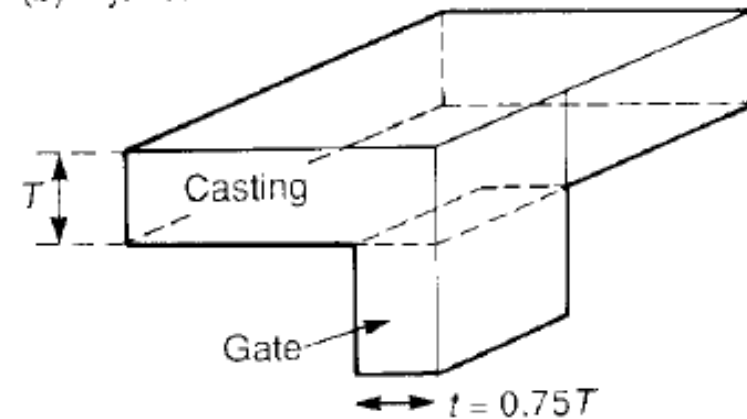
$$N \geq L_1/2h$$

# Canais de ataque

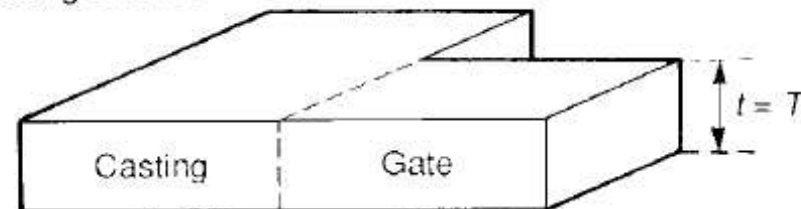
(a) T-junction



(b) L-junction

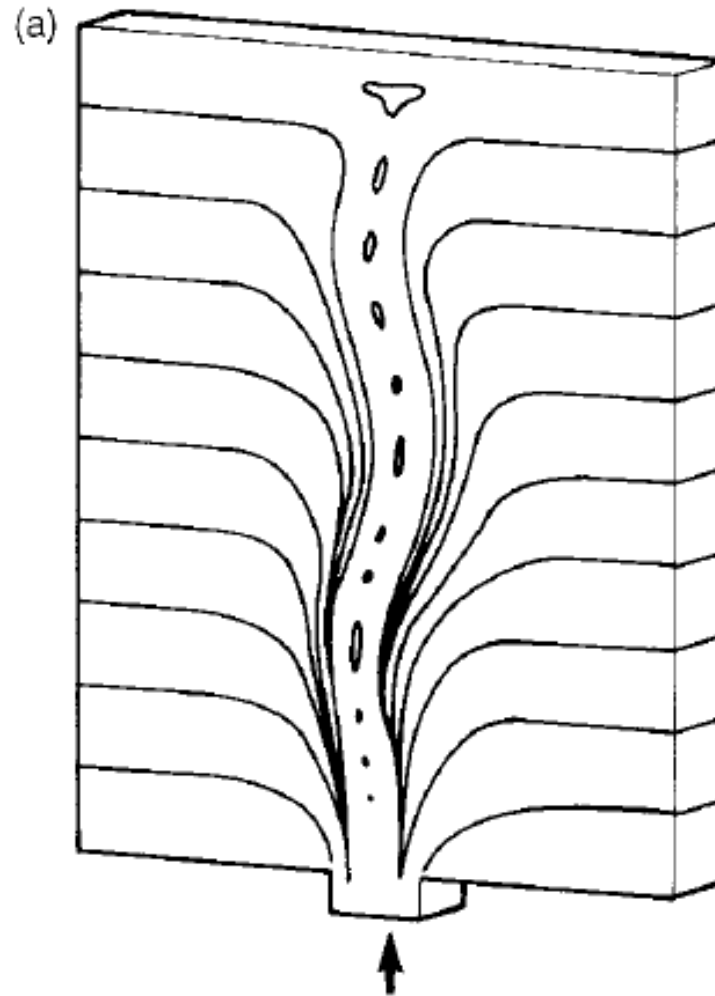


(c) Casting extension



**Figure 2.31** Maximum allowable gate thickness to avoid a hot spot at the junction with the casting.

# Efeito do canal de ataque em placas



# Alimentação indireta para placas

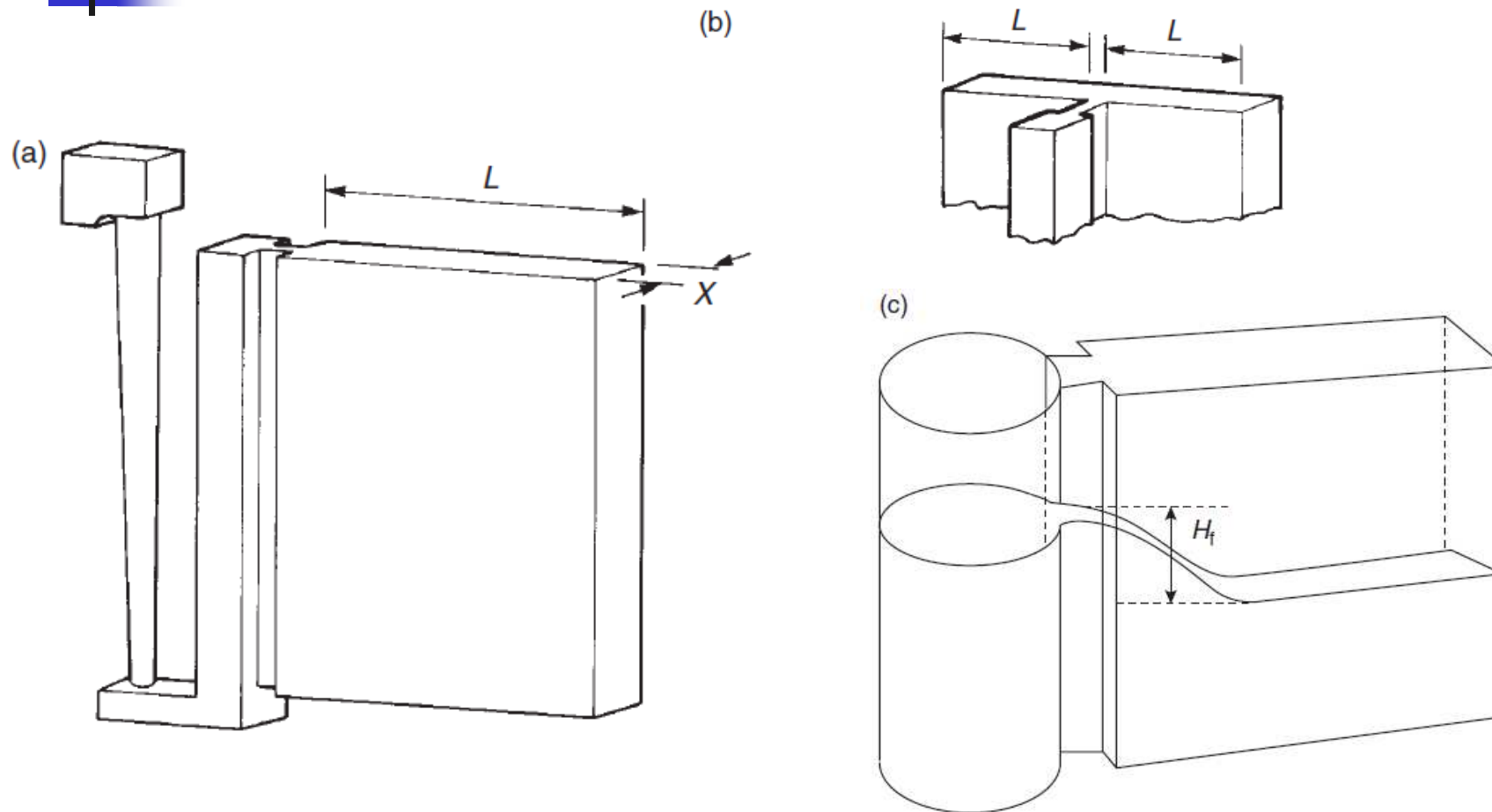
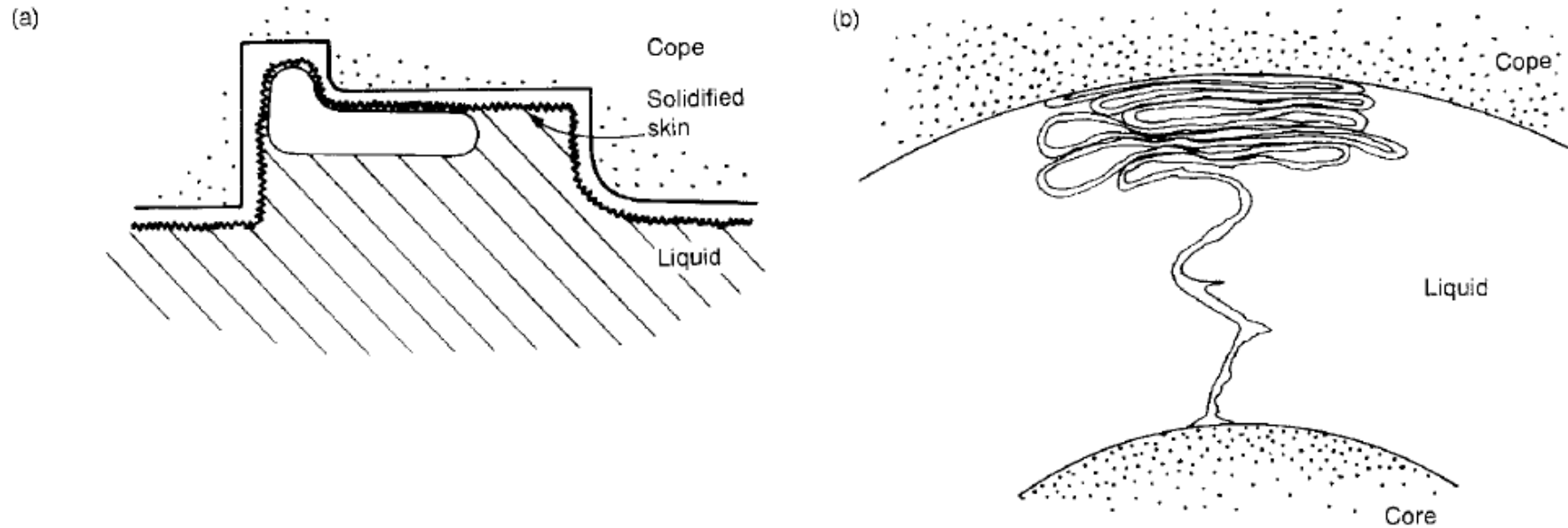


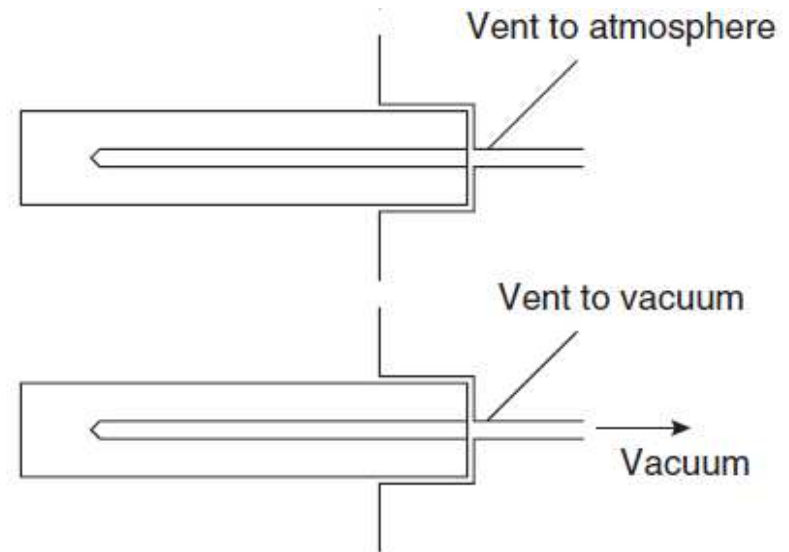
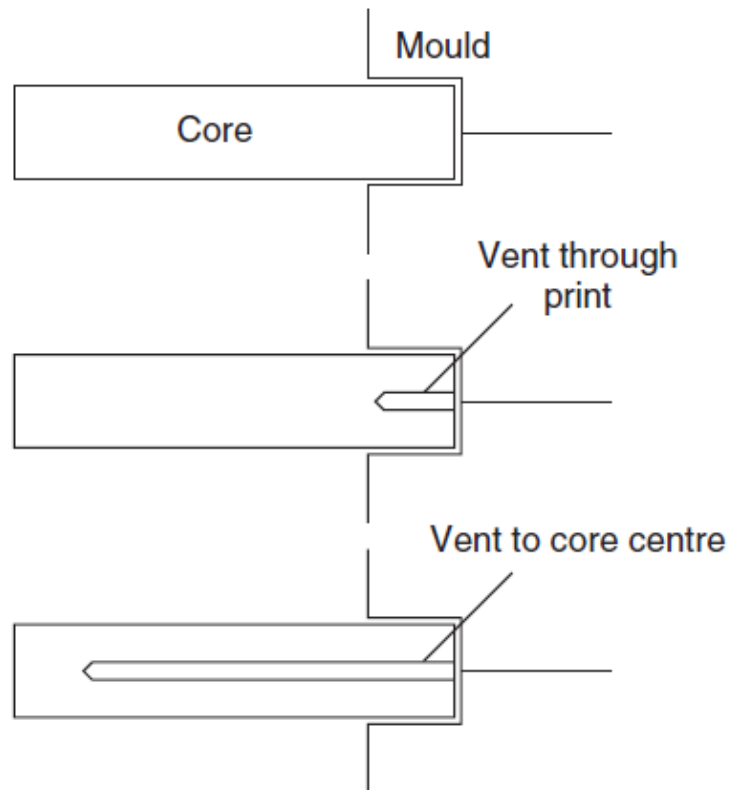
Figure 2.39 Riser and slot gate to both gate and feed a vertical plate from (a) its side, or (b) its centre.

# Efeito de sopro do macho



**Figure 5.1** (a) A core blow—a trapped bubble containing core gases evolved after some solidification; (b) an exfoliated dross defect produced by copious gas from a core blow prior to solidification.

# Prevenindo o sopro do macho



**Figure 5.4** *Venting of a core, illustrating progressively improved techniques.*



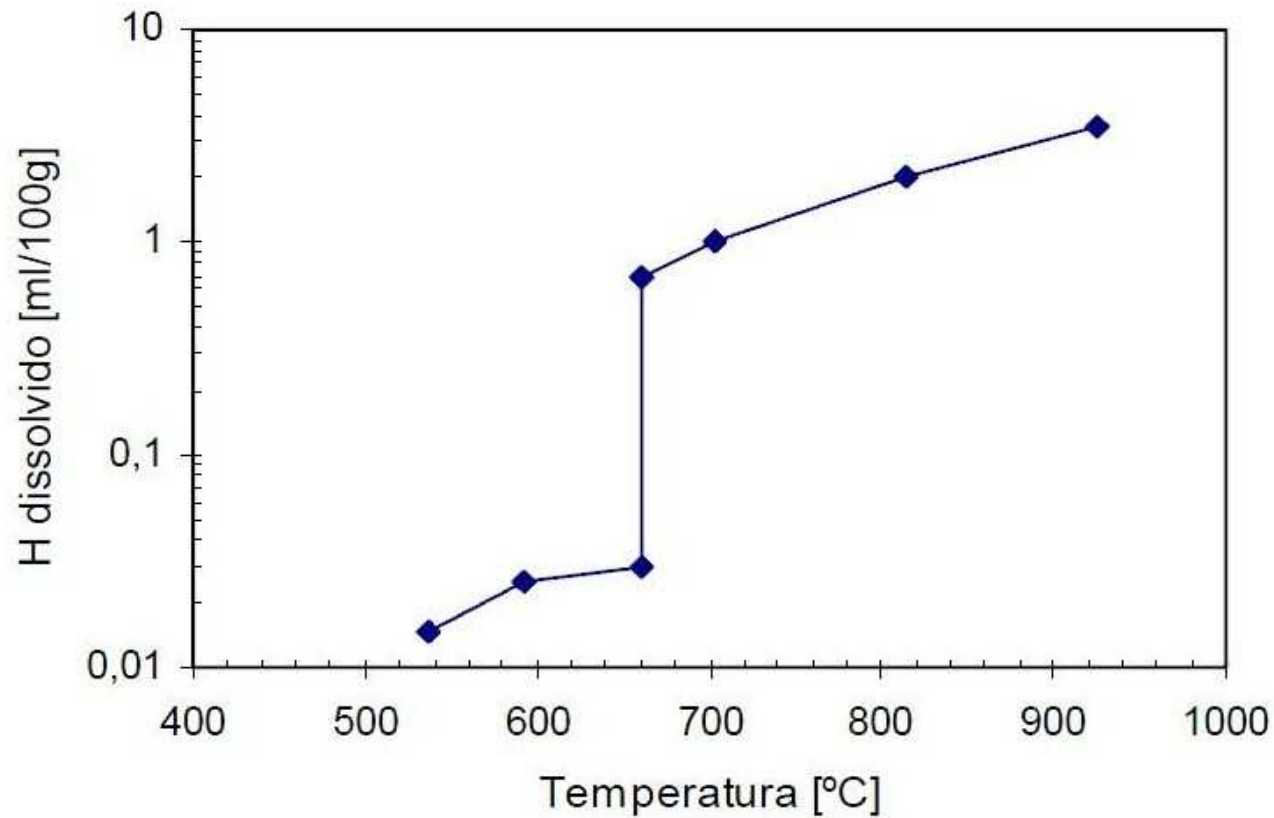


# Importante: Metal líquido de qualidade

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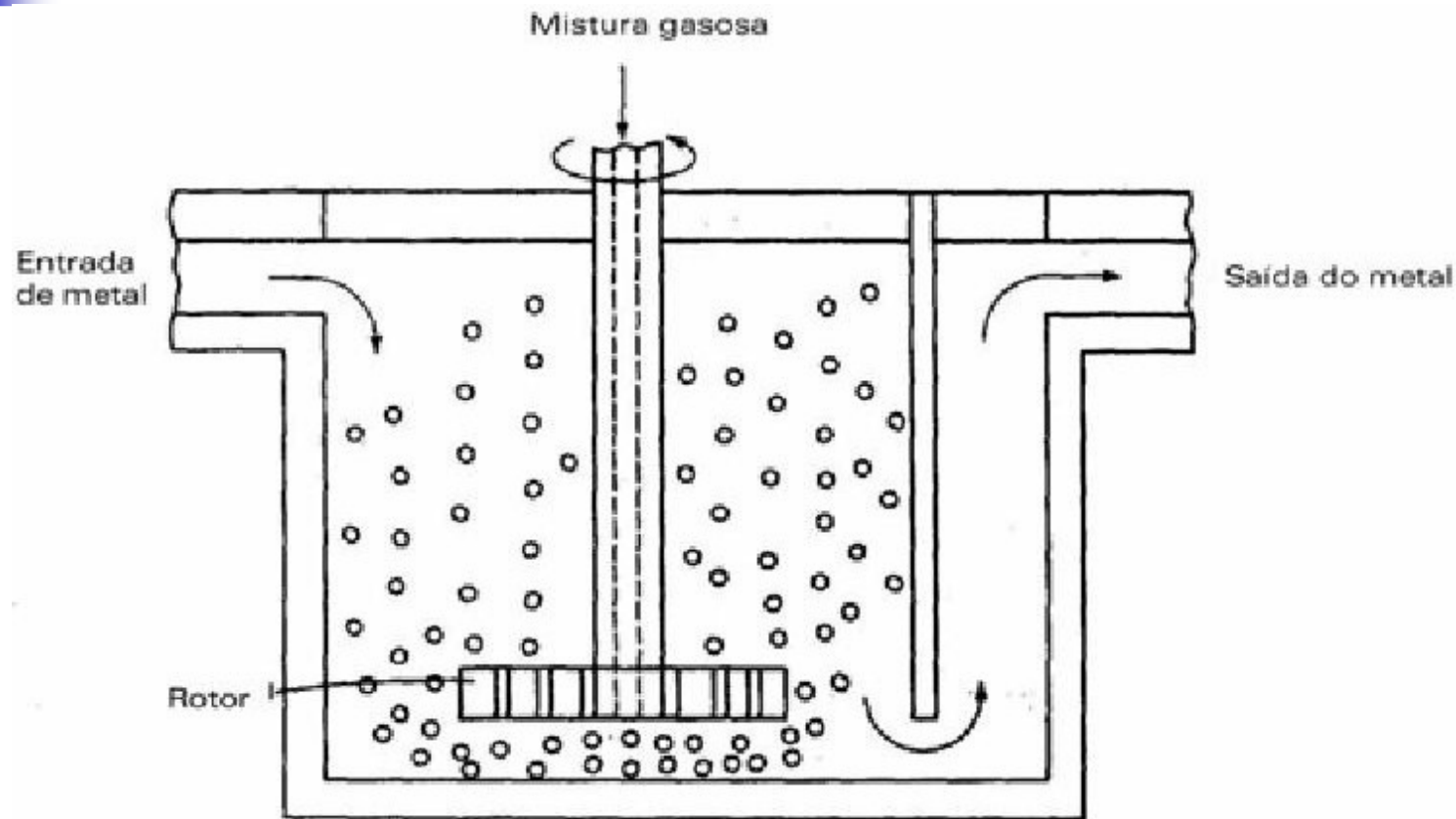
- Livre de gases
- Livre de inclusões de escória
- Na composição química correta

# Exemplo: desgaseificação de Al



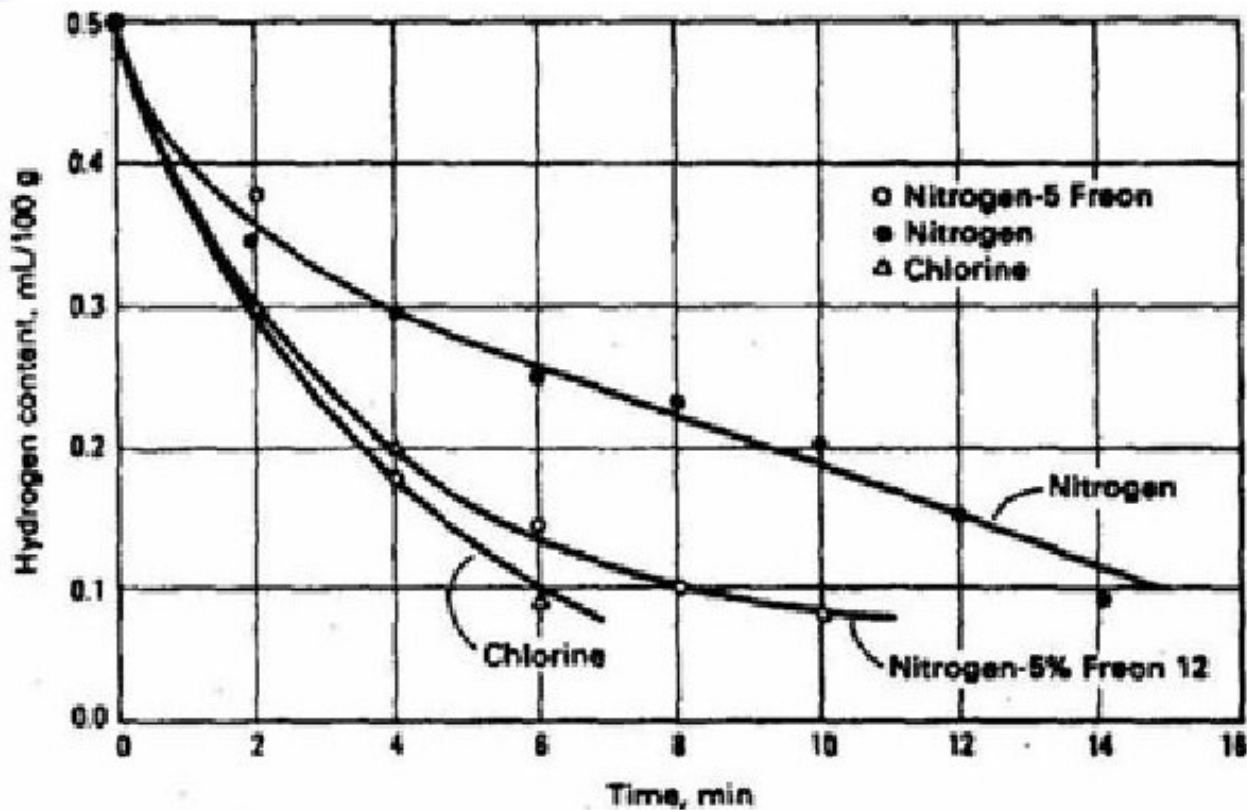
Solubilidade do H no Al

# Exemplo: desgaseificação de Al



Esquema de uma unidade de desgaseificação contínua (rotor).

# Exemplo: desgaseificação de Al



Redução do teor de H dissolvido no banho com o tempo de desgaseificação.



# Bibliografia das Aulas

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- GARCIA, Amauri, Solidificação – fundamentos e aplicações, UNICAMP, 2a ed., 2007
- CAMPOS FILHO, Mauricio Prates de e DAVIES, Graeme John. Solidificação e fundição de metais e suas ligas, Rio de Janeiro: Livros Técnicos e Científicos, 1978.
- American Society for Metals. ASM Handbook Committee. Metals Handbook (Casting), 9a ed., vol. 15, Ohio, 1988.
- KIMINAMI, Claudio S.; CASTRO, Walman B. e OLIVEIRA, Marcelo F. Introdução aos processos de fabricação de produtos metálicos, Blucher, São Paulo, 2013.
- KALPAKJIAN, Serope e SCHMID, Steven. Manufacturing processes for engineering materials, 5a ed., Pearson Education, New Jersey, 2007.
- CAMPBELL, John, Castings, Elsevier, Oxford, 2ª ed., 2004.
- CAMPBELL, John, Castings practice – the 10 rules of castings, Elsevier, Oxford, 2004.