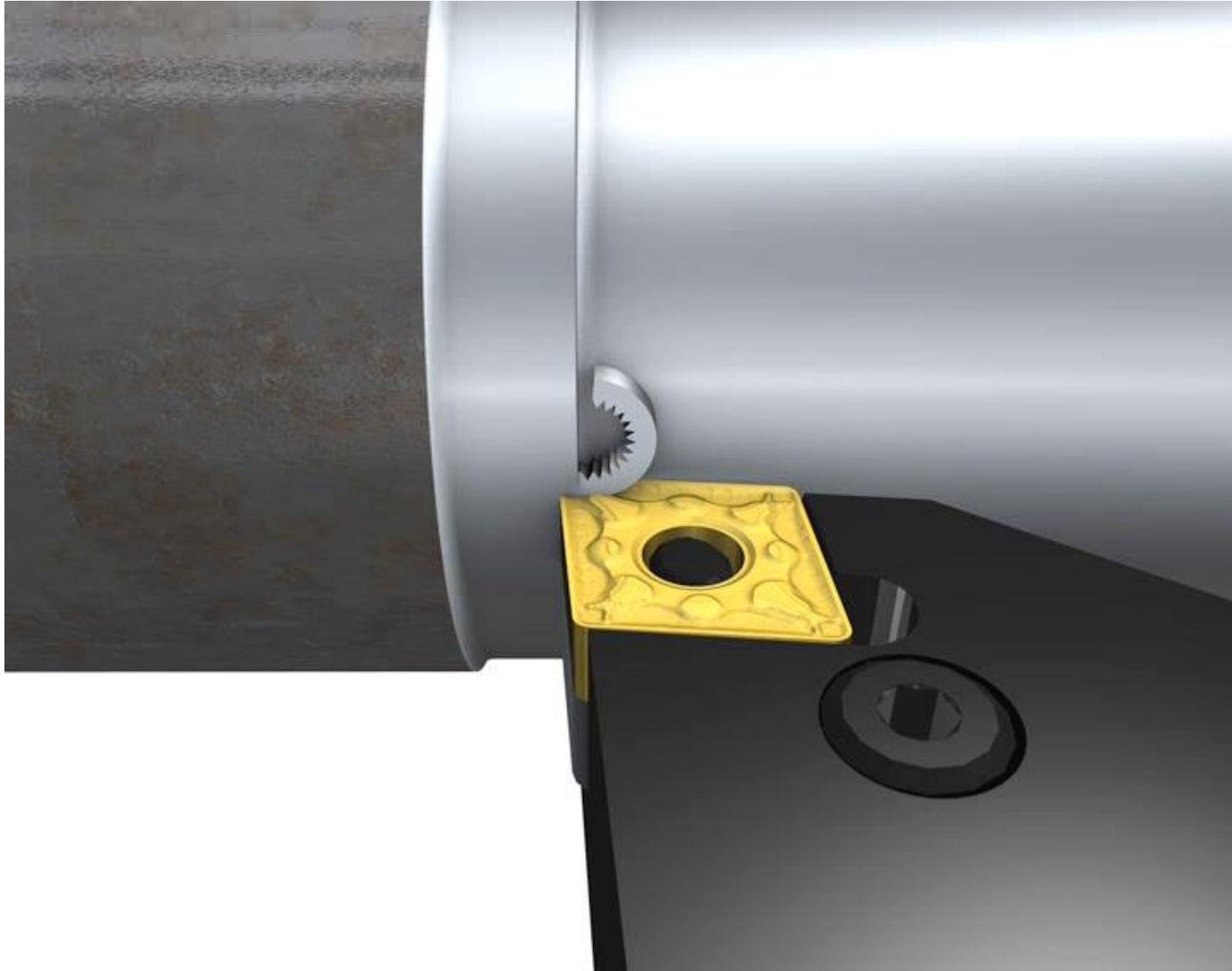
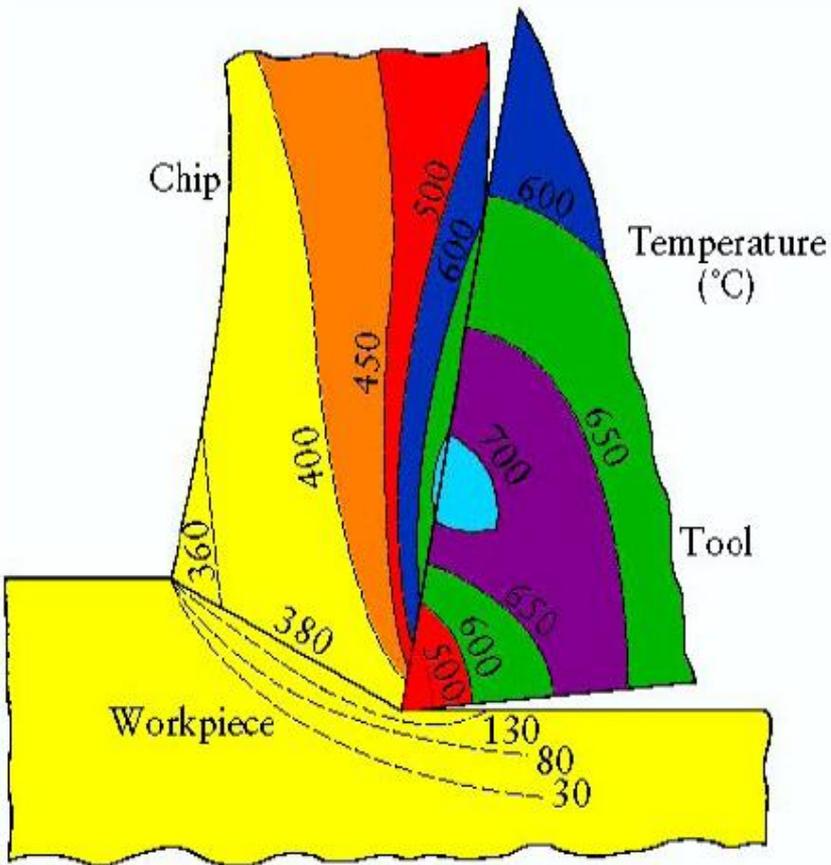


# Temperatura em usinagem de metais

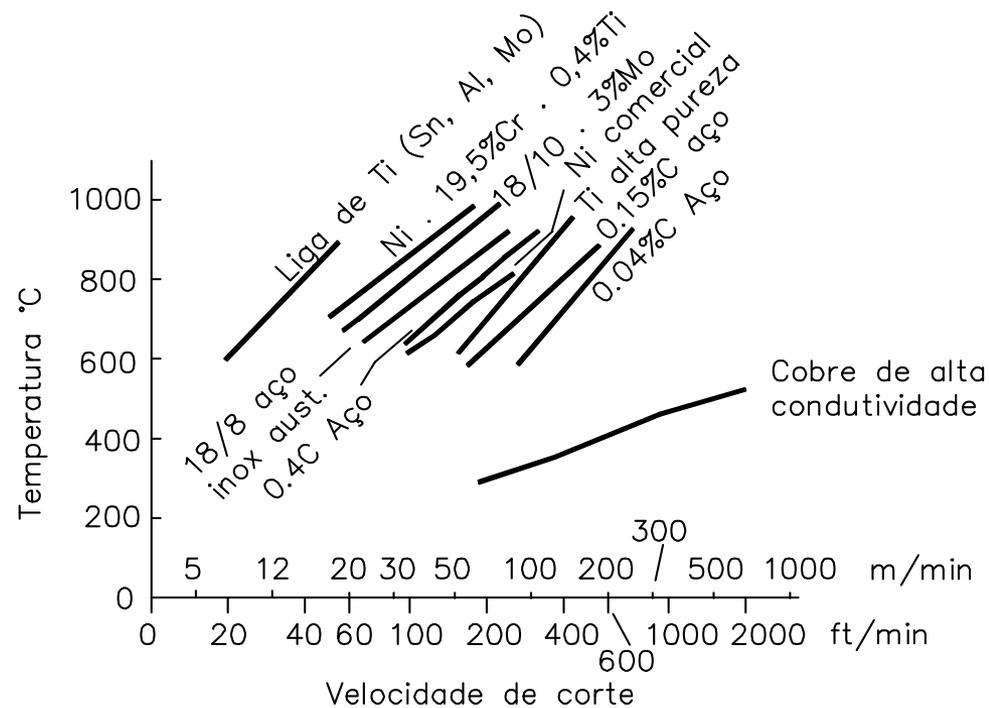
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# Temperatura em usinagem de metais

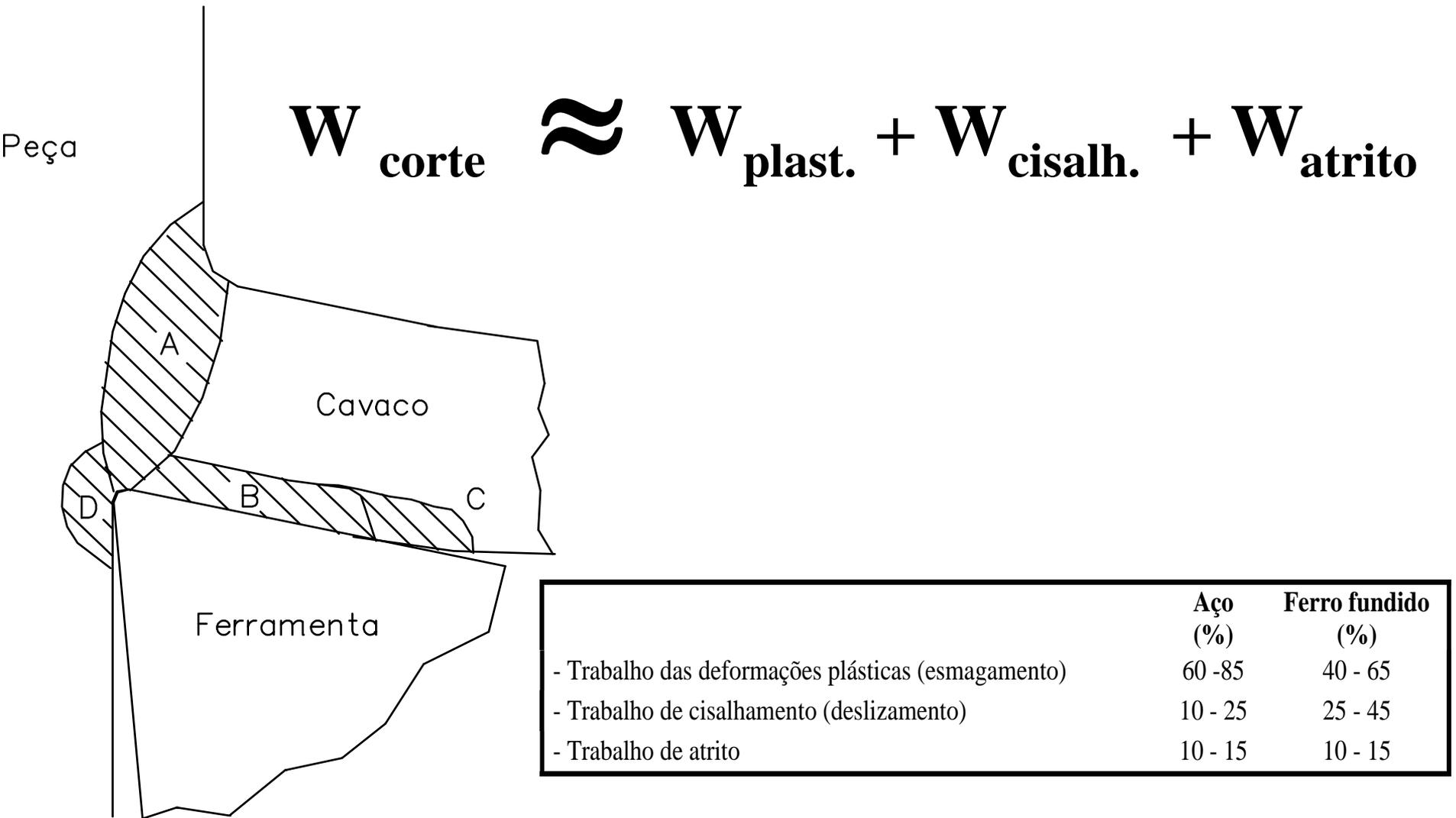


$$\theta = C \cdot v_c^n$$



$$T \cdot \theta^n = K$$

# Temperatura em usinagem de metais





# Temperatura em usinagem de metais

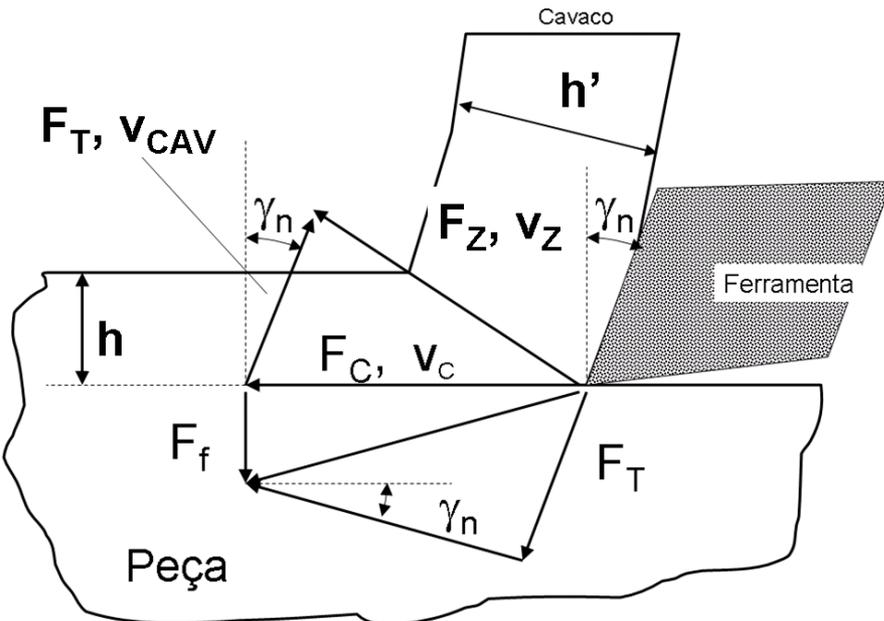
## TEMPERATURA NA FORMAÇÃO DE CAVACOS – Modelo de Trigger e Chao (unidades SI)

$$q = q_z + q_f$$

$q$ : Calor total;

$q_z$ : Calor devido ao cisalhamento;

$q_f$ : Calor devido ao atrito;



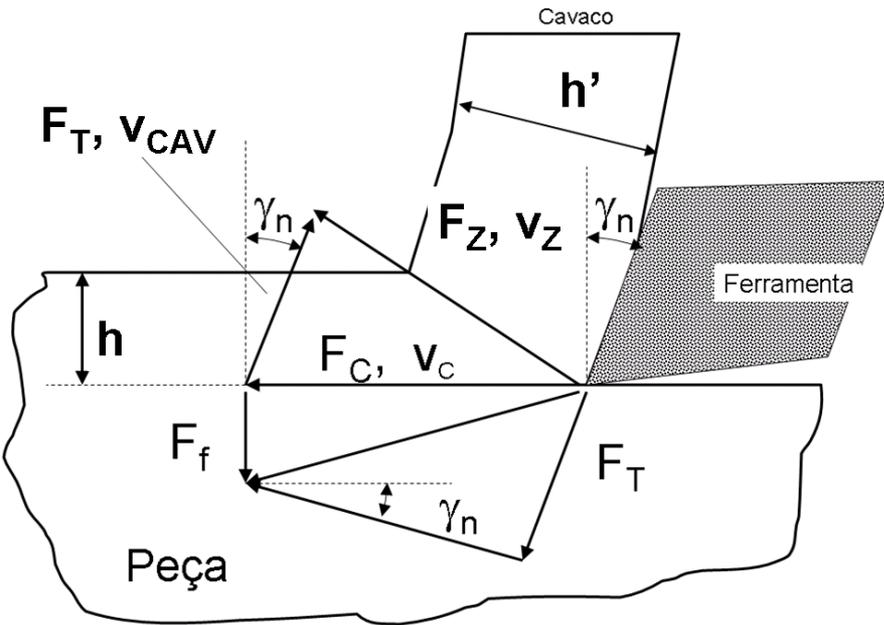
$$q_z = \frac{F_z \cdot v_z}{S_z}$$

$$S_z = \frac{w \cdot t_1}{\text{sen } \phi} = w \cdot t_1 \cdot \text{csc } \phi$$

$$v_z = \frac{v_c}{\text{cos } \phi}$$

$$F_z = \frac{F_C v_C - F_T v_{cav}}{v_z}$$

# Temperatura em usinagem de metais



$$F_T = F_f \cos \gamma_n + F_c \sin \gamma_n$$

$$v_{cav} = v_c \frac{h}{h'}$$

$$\Delta T_z = \frac{A_1 [F_c \cdot v_c \cdot (1 - B_1) - F_t \cdot v_{cav}]}{C \cdot \rho \cdot v_c \cdot f \cdot l_c}$$

$$\Delta T_f = \frac{B_2}{9 \cdot (5\pi)^{1/2}} \frac{F_T}{k \cdot m} \left[ \frac{K \cdot v_{cav}}{l_c} \right]$$

# Temperatura em usinagem de metais

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## Temperatura na Formação de Cavacos – Modelo de Loewen e Shaw

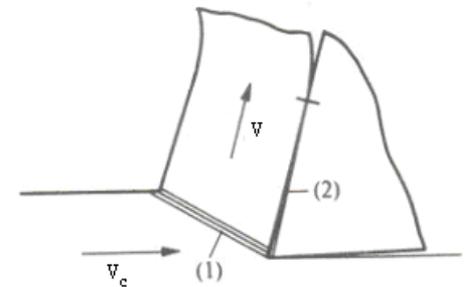
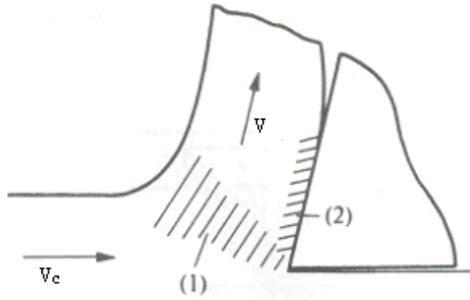
$$dQ - dW = dE \qquad dQ = k \cdot dA \cdot \frac{d\theta}{dx}$$

$$dE = c \cdot d\theta \cdot \rho \cdot dV$$

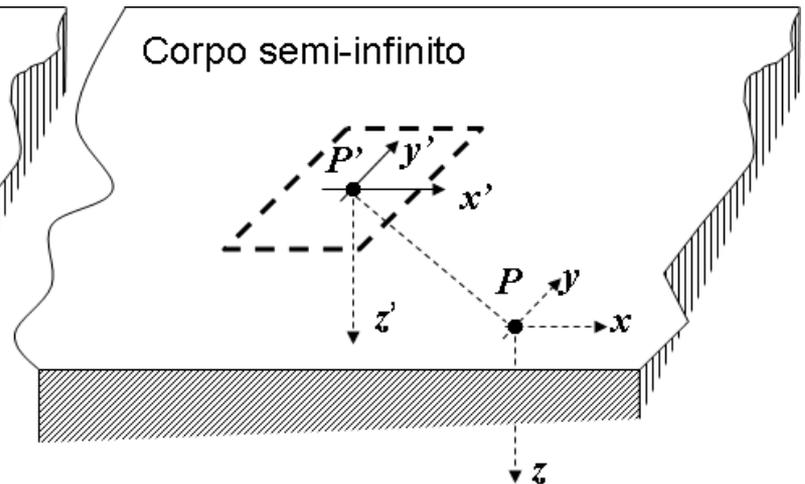
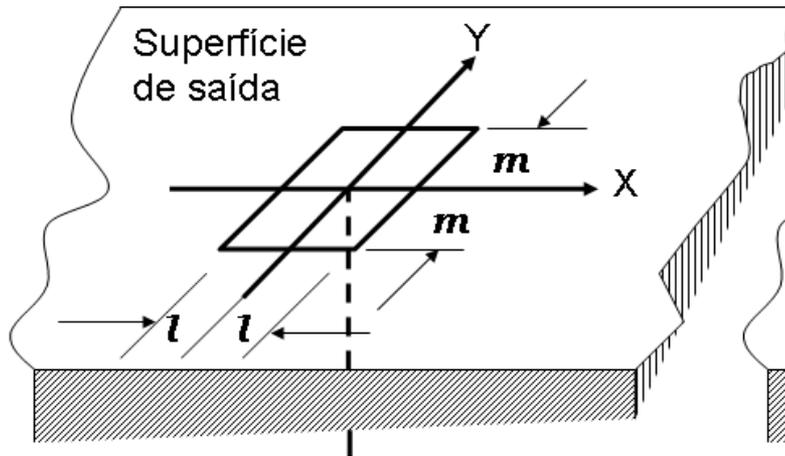
$$\frac{d\theta}{dt} = \frac{q}{\rho \cdot c} + \frac{k}{\rho \cdot c} \left( \frac{\partial^2 \theta}{\partial x^2} + \frac{\partial^2 \theta}{\partial y^2} + \frac{\partial^2 \theta}{\partial z^2} \right)$$

# Temperatura em usinagem de metais

## TEORIA GERAL



Calor fluindo para a ferramenta



$$\theta(x, y, z, t) = \left[ \frac{QK}{8k(\pi Kt)^{3/2}} \right] e^{-r^2 / 4Kt}$$

$$r^2 = (x - x')^2 + (y - y')^2 + (z - z')^2$$

# Temperatura em usinagem de metais

## TEORIA GERAL

$$\theta(x, y, z) = \frac{q_e}{2\pi k} \int_{-l}^l dx' \int_{-m}^m \frac{dy'}{\left[ (x-x')^2 + (y-y')^2 + z^2 \right]^{1/2}}$$

Integrando-se

$$\begin{aligned} \theta(x, y) = & \frac{q_e}{2\pi k} \left[ |x+l| \left\{ \sinh^{-1} \left( \frac{y+m}{x+l} \right) - \sinh^{-1} \left( \frac{y-m}{x+l} \right) \right\} \right. \\ & + |x-l| \left\{ \sinh^{-1} \left( \frac{y-m}{x-l} \right) - \sinh^{-1} \left( \frac{y+m}{x-l} \right) \right\} \\ & + |y+m| \left\{ \sinh^{-1} \left( \frac{x+l}{y+m} \right) - \sinh^{-1} \left( \frac{x-l}{y+m} \right) \right\} \\ & \left. + |y-m| \left\{ \sinh^{-1} \left( \frac{x-l}{y-m} \right) - \sinh^{-1} \left( \frac{x+l}{y-m} \right) \right\} \right] \end{aligned}$$

Temperatura média

$$\bar{\theta} = \frac{\int_{-l}^l \int_{-m}^m (\theta) dx dy}{4lm}$$

# Temperatura em usinagem de metais

## TEORIA GERAL

$$\bar{\theta} = \frac{2 q_e m}{\pi l k} \left[ \frac{l}{m} \sinh^{-1} \left( \frac{m}{l} \right) + \sinh^{-1} \left( \frac{l}{m} \right) + \frac{1}{3} \left( \frac{m}{l} \right) + \frac{1}{3} \left( \frac{l}{m} \right)^2 - \frac{1}{3} \left\{ \left( \frac{l}{m} \right)^2 + 1 \right\} \left\{ 1 + \left( \frac{m}{l} \right)^2 \right\}^{\frac{1}{2}} \right]$$

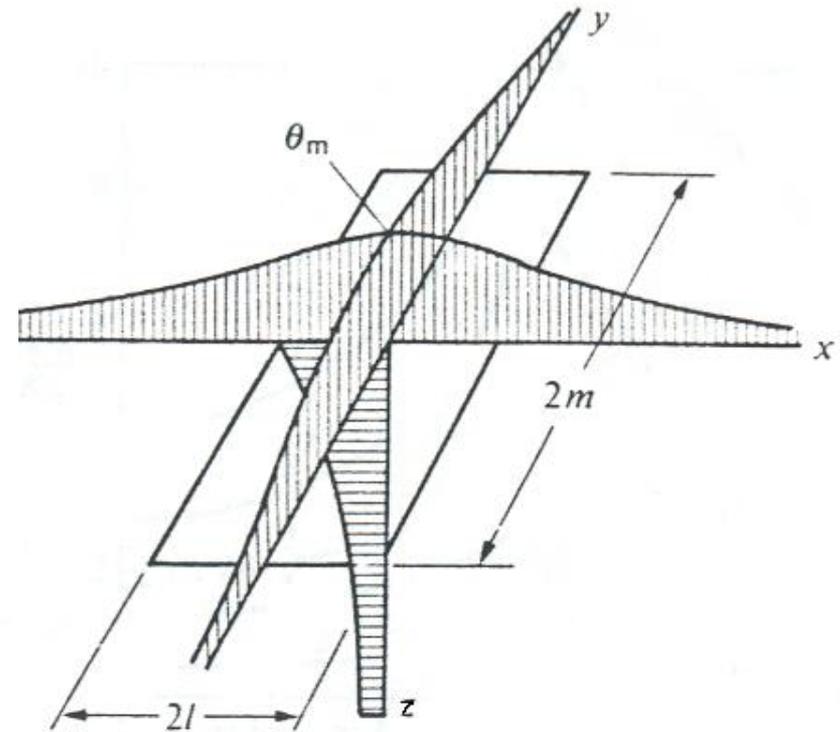
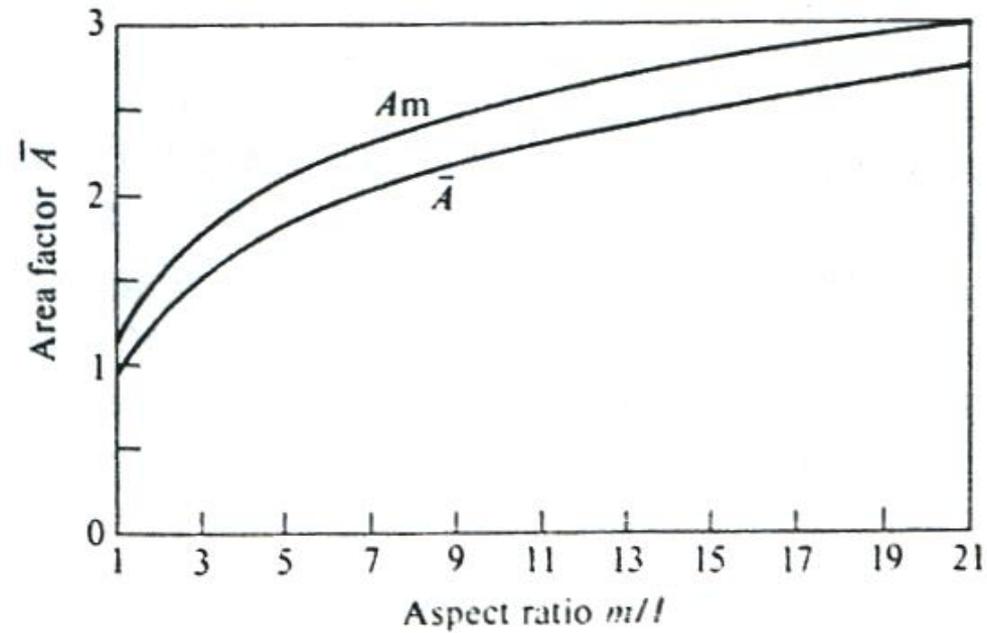
Simplificando-se ainda mais

$$\bar{\theta} = \frac{q_e m}{k} \bar{A} \quad \bar{A} = \frac{2 \cdot l}{\pi \cdot m} \left[ \ln \left( \frac{2 \cdot m}{l} \right) + \frac{1}{3} \left( \frac{l}{m} \right) + \frac{1}{2} \right]$$

$$\theta_{m\acute{a}x} = \frac{q_e m}{k} A_m \quad A_{m\acute{a}x} = \frac{2 \cdot l}{\pi \cdot m} \left[ \ln \left( \frac{2 \cdot m}{i} \right) + 1 \right]$$

# Temperatura em usinagem de metais

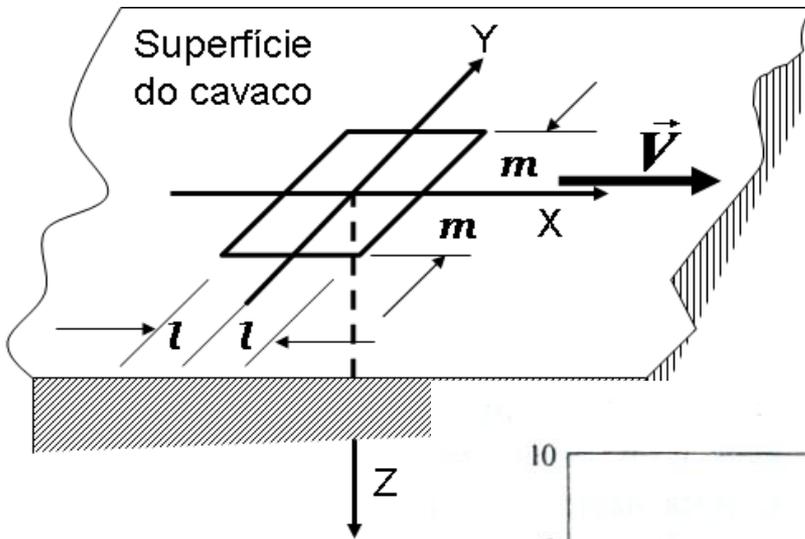
## TEORIA GERAL



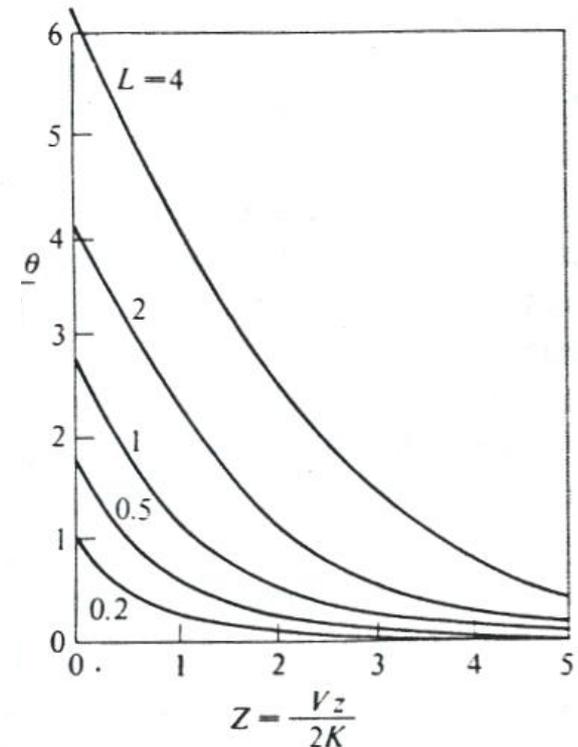
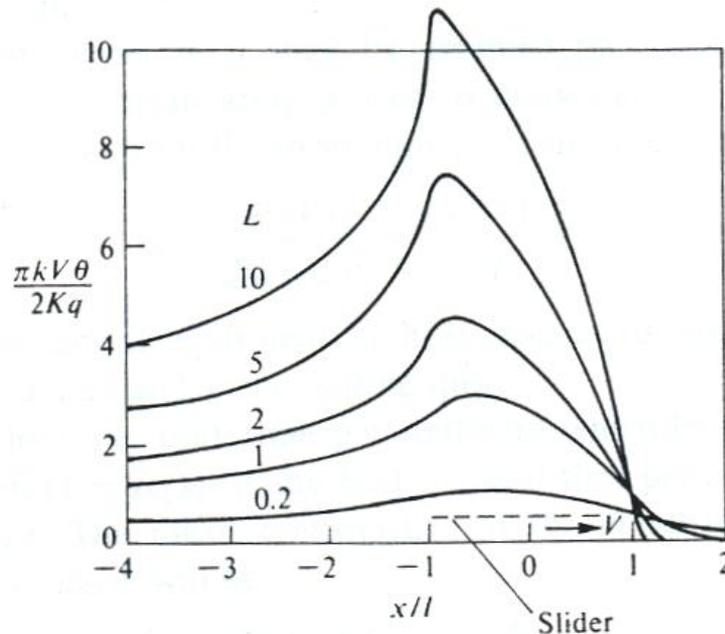
# Temperatura em usinagem de metais

## TEORIA GERAL

Calor fluindo para o corpo móvel

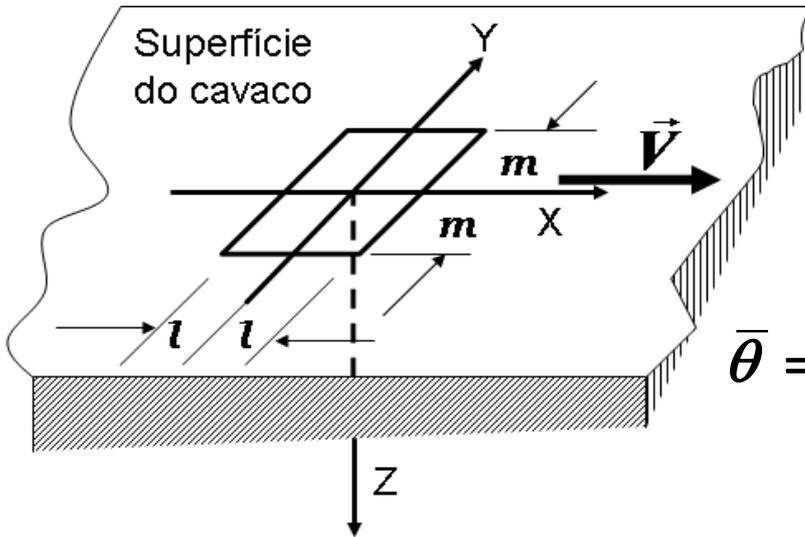


$$L = \frac{V' \cdot l}{2 \cdot K}$$



# Temperatura em usinagem de metais

## TEORIA GERAL



$$\bar{\theta} = 0,754 \frac{q_v \cdot l}{k \cdot \sqrt{L}} \quad \theta_{\text{máx}} = 1,130 \frac{q_v \cdot l}{k \cdot \sqrt{L}}$$

$q_v$  = calor fluindo para o corpo semi-infinito oriundo de uma fonte móvel.

$$\bar{\theta} = 0,754 \frac{(R \cdot q_v) \cdot l}{k_1 \cdot \sqrt{L}} \quad \bar{\theta} = \left[ (1 - R) \cdot q_e \right] \frac{m}{k_2} \bar{A}$$

$R$  = fração do calor que flui para o corpo móvel;

$(1 - R)$  = fração de calor que flui para o corpo estacionário;

$k_1$  e  $k_2$  = Condutividade térmica do material móvel e do estacionário, respectivamente.

$$R = \frac{1}{1 + \frac{0,754 \cdot (k_2/k_1)}{\sqrt{L} \cdot \bar{A} \cdot (m/l)}}$$

# Temperatura em usinagem de metais

Temperatura no plano de cisalhamento ( $\Delta T_Z$ ):

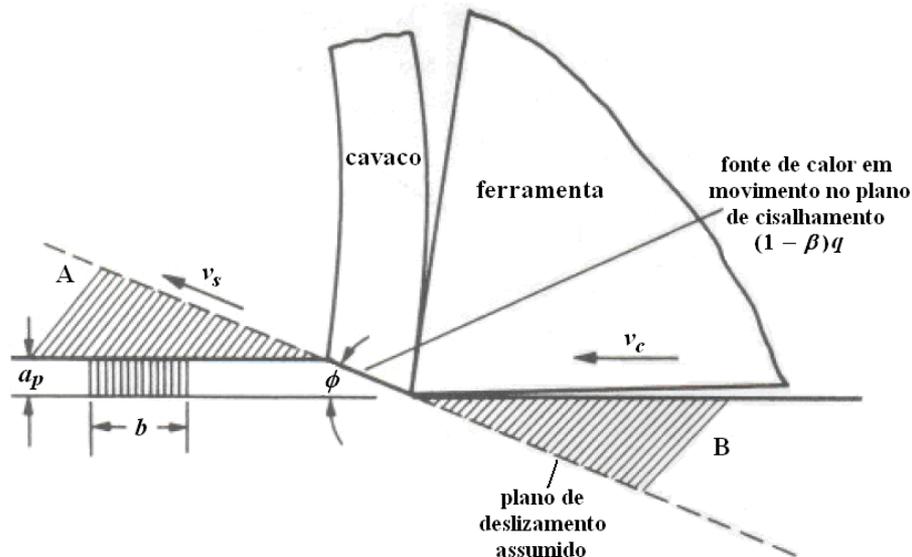
$$q_1 = \frac{F_Z \cdot v_Z}{h \cdot b \cdot \csc \phi}$$

$$u_Z = \frac{F_Z \cdot v_Z}{h \cdot b \cdot v_C}$$

$$q_1 = \frac{u_Z \cdot v_C}{\csc \phi}$$

$$\Delta T_Z = \frac{u_Z}{c_1 \cdot \rho_1}$$

$$\Delta T_Z = (R_1 \cdot q_1) \frac{\csc \phi}{v_c \cdot c_1 \cdot \rho_1}$$



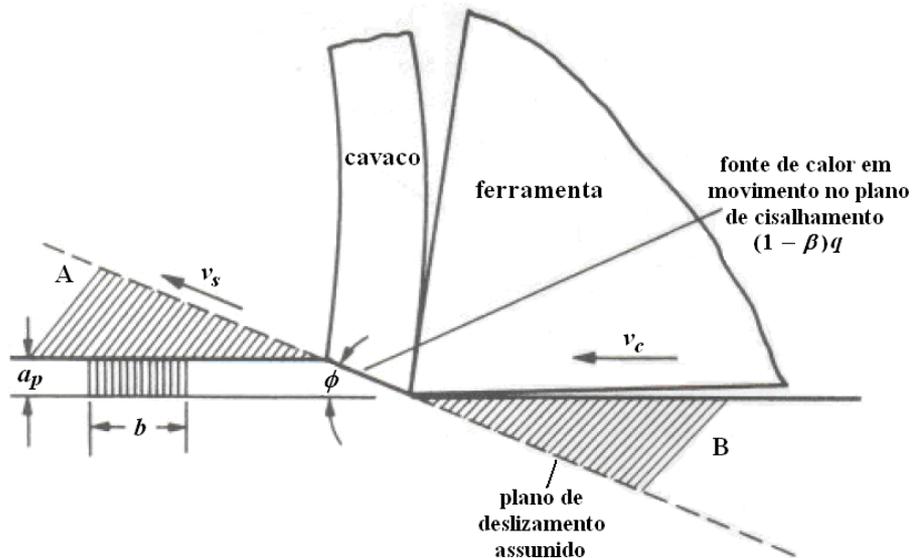
# Temperatura em usinagem de metais

Temperatura no plano de cisalhamento ( $\Delta T_Z$ ):

$$\Delta T_Z = [(1 - R_1) \cdot q_1] \cdot 0,754 \frac{h \cdot \csc \phi}{2 \cdot k_1 \cdot \sqrt{L_1}} \quad L_1 = \frac{v_Z \cdot h \cdot \csc \phi}{4 \cdot K_1}$$

$$R_1 = \frac{1}{1 + 1,326 \sqrt{\frac{K_1 \cos \gamma}{\sin \phi \cos(\phi - \gamma)}}}$$

$$K_1 = \frac{k_1}{\rho_1 \cdot c_1}$$



# Temperatura em usinagem de metais

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Temperatura na Interface cavaco-ferramenta ( $\Delta T_f$ ):

$$q_2 = \frac{F_T \cdot v_{CAV}}{l_c \cdot b} = \frac{u_f \cdot v_c \cdot h}{b} \quad \Delta \bar{T}_f = \frac{0,754 \cdot (R_2 \cdot q_2) \cdot l_c}{2 \cdot k_2 \cdot \sqrt{L_2}}$$

$k_2$  = Condutividade térmica do material do cavaco na temperatura  $T_f$ .

$L_2$  = dado por:

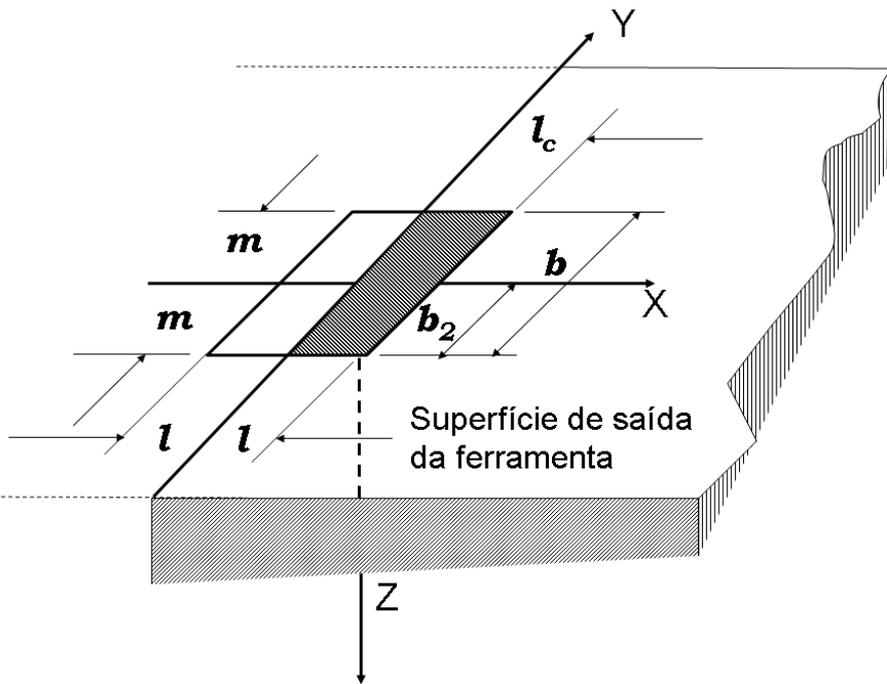
$$L_2 = \frac{v_{CAV} \cdot l_c}{4 \cdot K_2}$$

$$\Delta \bar{T}_{cav} = \Delta \bar{T}_f + \Delta \bar{T}_z = \frac{0,377 \cdot (R_2 \cdot q_2) \cdot l_c}{k_2 \cdot \sqrt{L_2}}$$

$$\frac{m}{l} \Rightarrow \frac{b}{2 \cdot l_c}$$

# Temperatura em usinagem de metais

Temperatura na ferramenta ( $\Delta T_{fer}$ ):



$$\left(\frac{m}{l}\right) \Rightarrow \frac{b_2}{l_c}$$

$$\Delta T_{fer} = [(1 - R_2) \cdot q_2] \frac{b_2/2}{k_3} \bar{A}$$

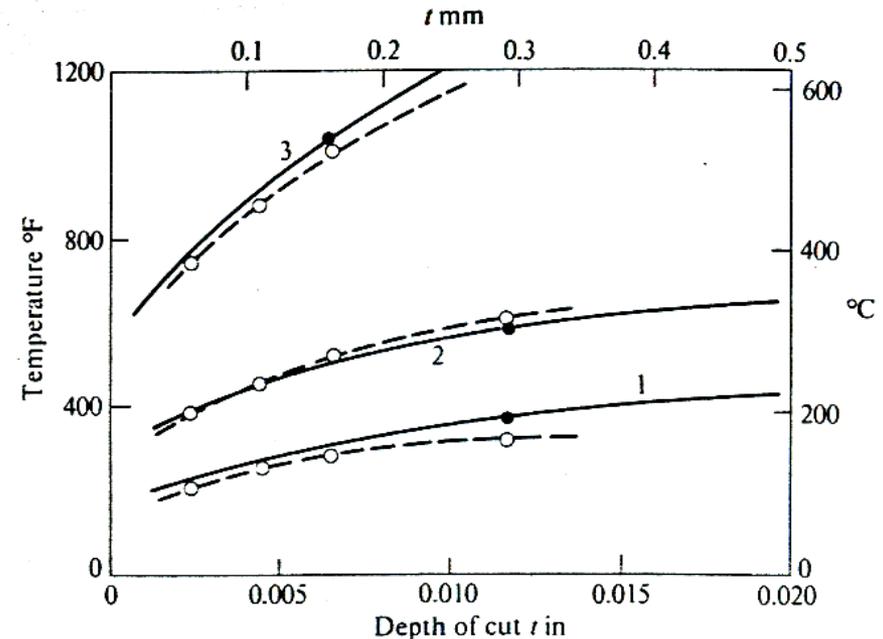
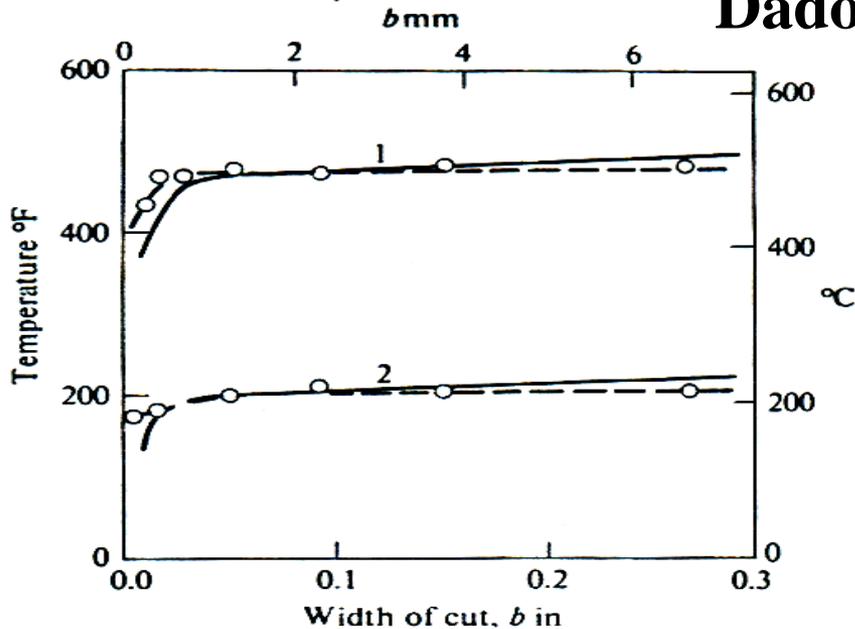
$$R_2 = \frac{X - \Delta T_Z}{(X + Y)}$$

$$X = q_2 \frac{b_2 \bar{A}}{K_3}$$

$$Y = q_2 \frac{0,377 l_c}{K_2 \sqrt{L_2}}$$

# Temperatura em usinagem de metais

## Dados experimentais



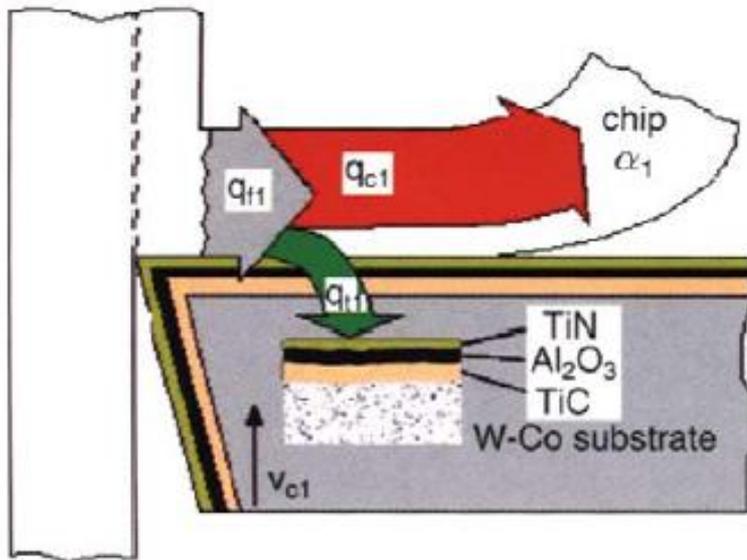
aço ABNT1113, ferramenta de metal duro K2S,  $\gamma=20^\circ$ ,  $a_p=0,6$  mm. Dados “1”  $v_c=69$  m/min e “2”  $v_c=4,5$  m/min.

aço ABNT1113, ferramenta de metal duro K2S,  $\gamma=20^\circ$ ,  $a_p=0,6$  mm. Dados “1”  $v_c=3$  m/min, “2”  $v_c=18$  m/min e “3”  $v_c=137$  m/min.

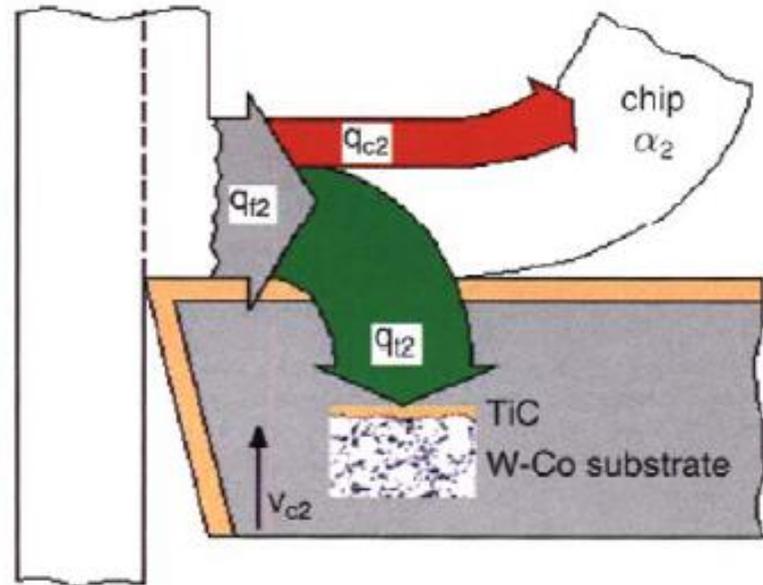
# Temperatura em usinagem de metais

## Distribuição de energia entre as partes

(a) AISI 1045



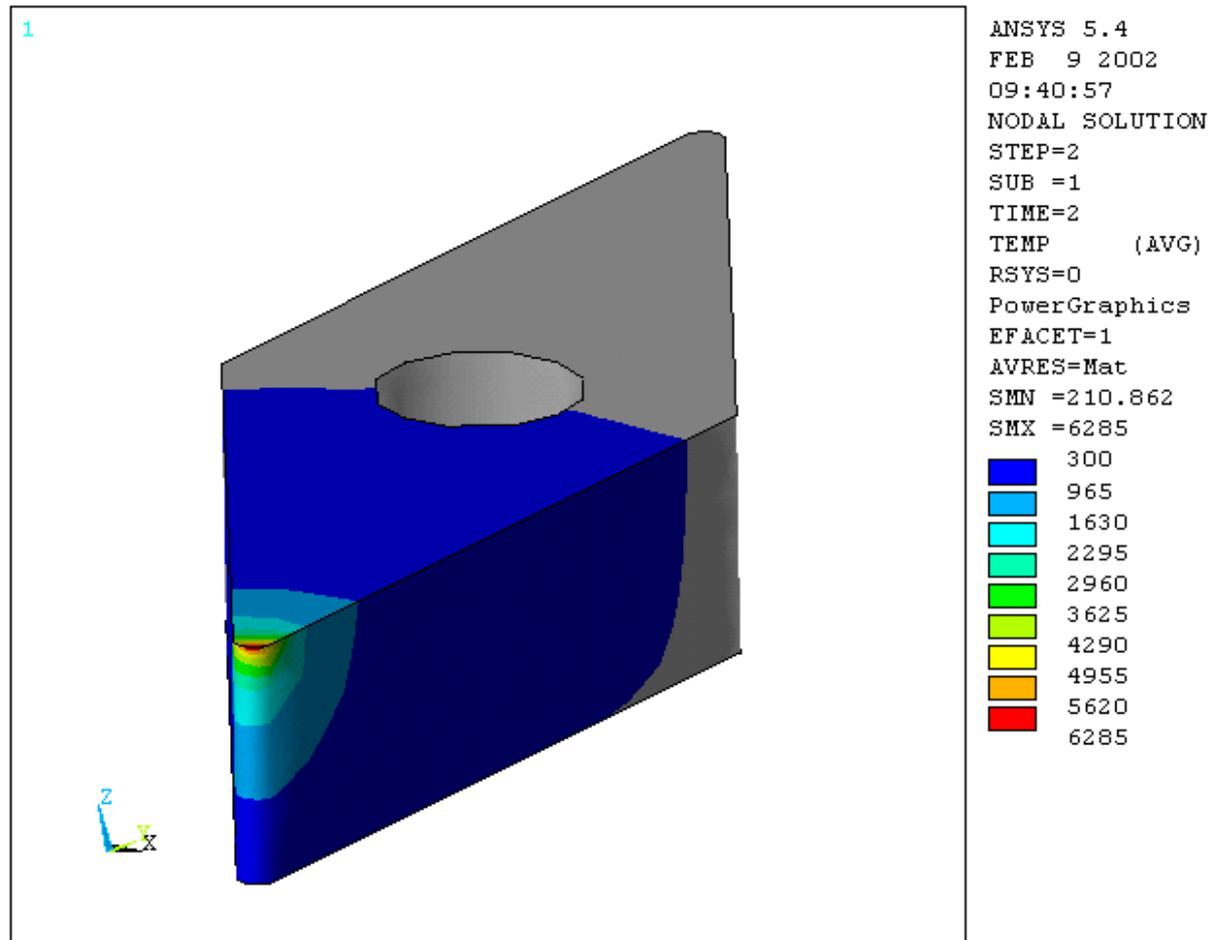
(b) AISI 304



$q_{f1} < q_{f2}$  frictional heat flux;  $q_{c1} > q_{c2}$  heat flow to the chip;  $q_{t2} > q_{t1}$  heat flow to the substrate;  $\alpha_1 > \alpha_2$  thermal diffusivity;  $v_{c1} = v_{c2}$  cutting speed;  $t_{c1} \approx t_{c2}$  contact temperature

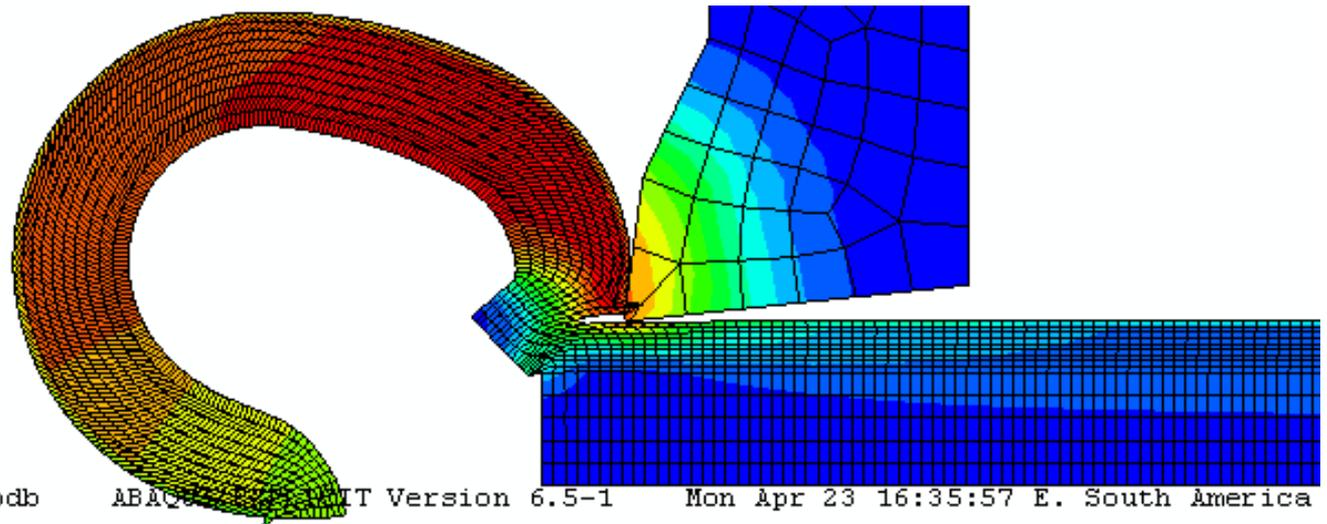
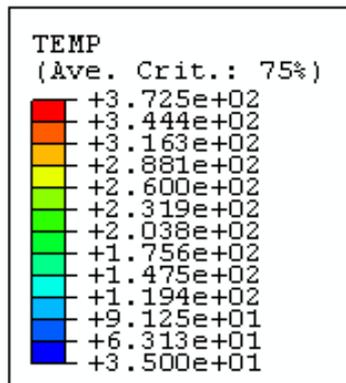
# Temperatura em usinagem de metais

## Distribuição de Temperatura na ferramenta usando FEM



# Temperatura em usinagem de metais

## Distribuição de Temperatura na ferramenta, peça, cavaco e fluido de corte usando FEM



2

3

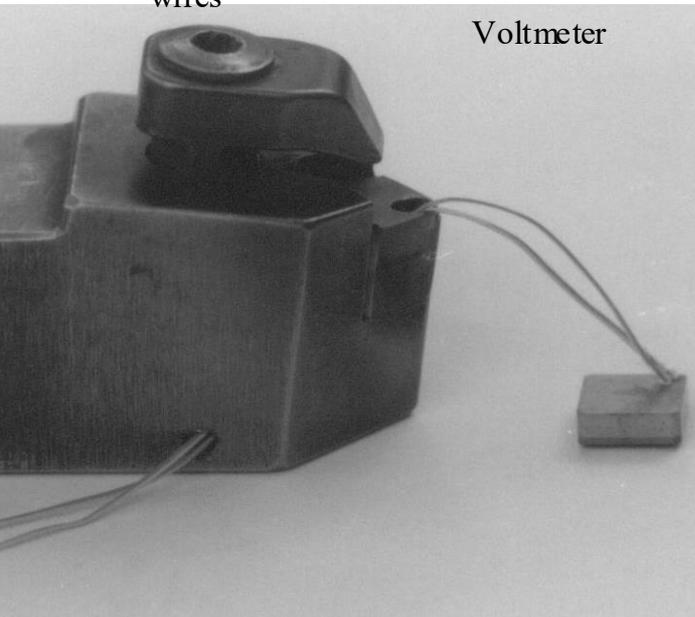
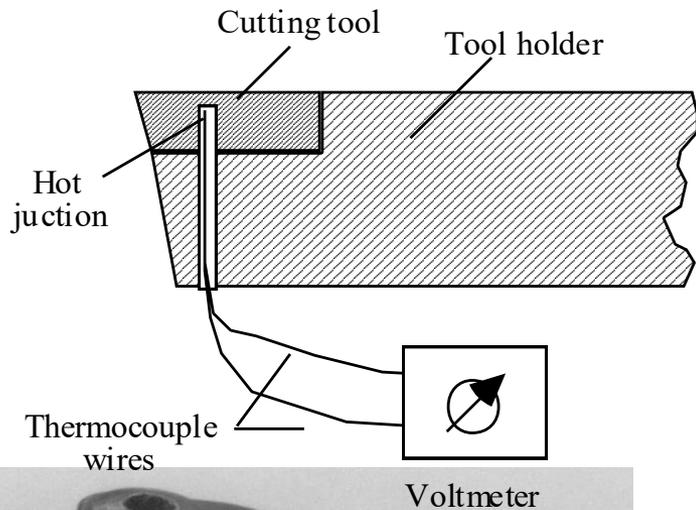
1 ODB: tstJC2.odb  
Step: move

ABAQUS/CAE Version 6.5-1

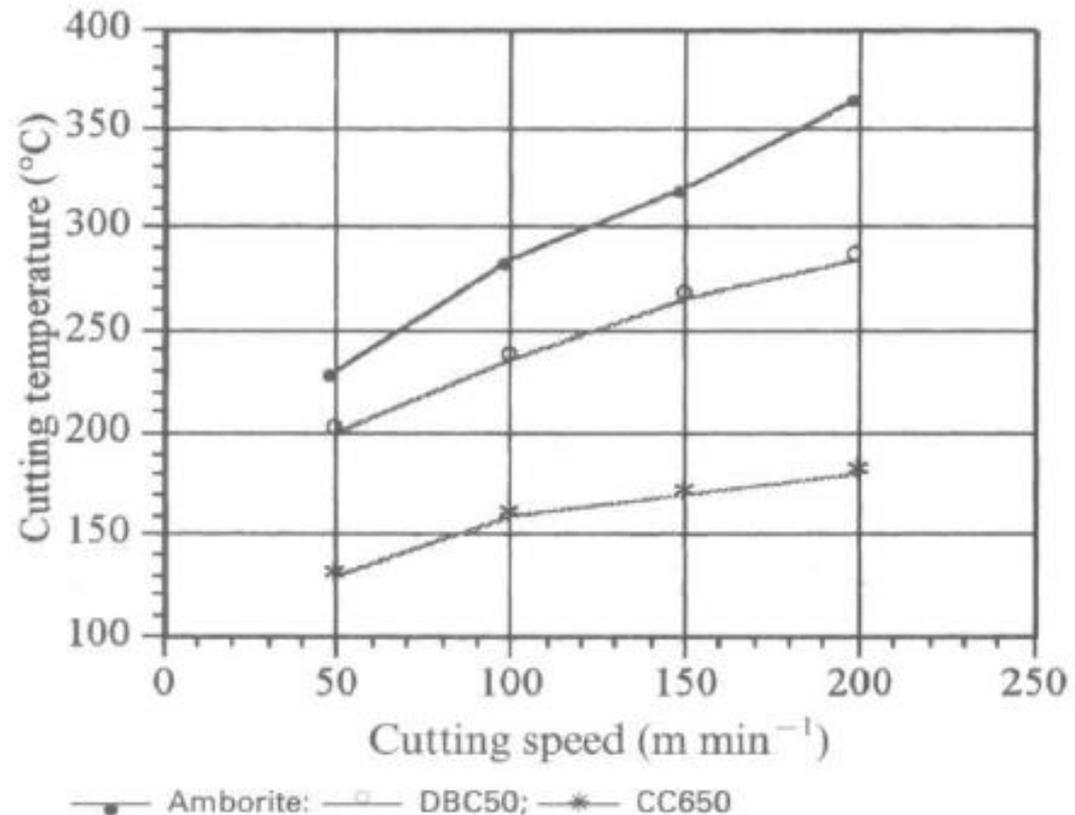
Mon Apr 23 16:35:57 E. South America

# Temperatura em usinagem de metais

## Temperatura na Formação de Cavacos - Estimativas Experimentais



### Termopar inserido na ferramenta/peça

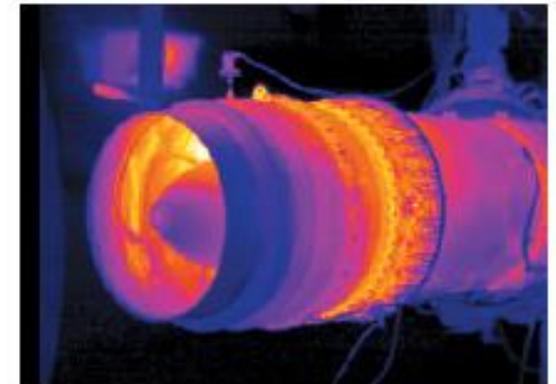
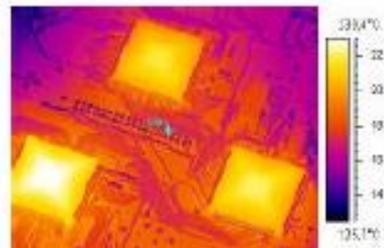
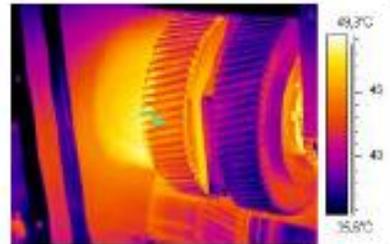
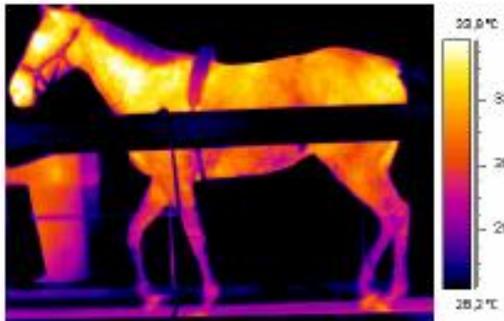
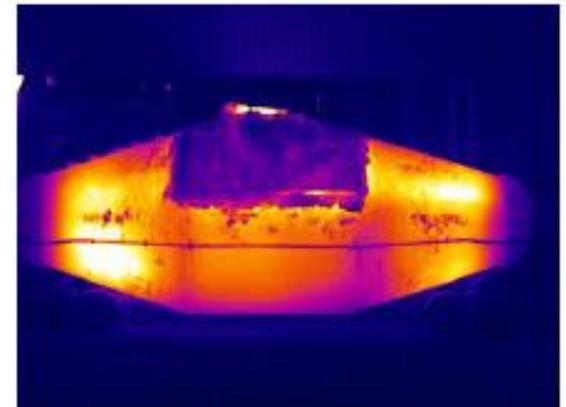
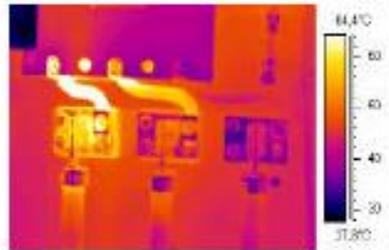




# Temperatura em usinagem de metais

## Temperatura na Formação de Cavacos - Estimativas Experimentais

### Termo-imagens



# Temperatura em usinagem de metais

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## Temperatura na Formação de Cavacos - Estimativas Experimentais

### Termo-imagens



1975

1980



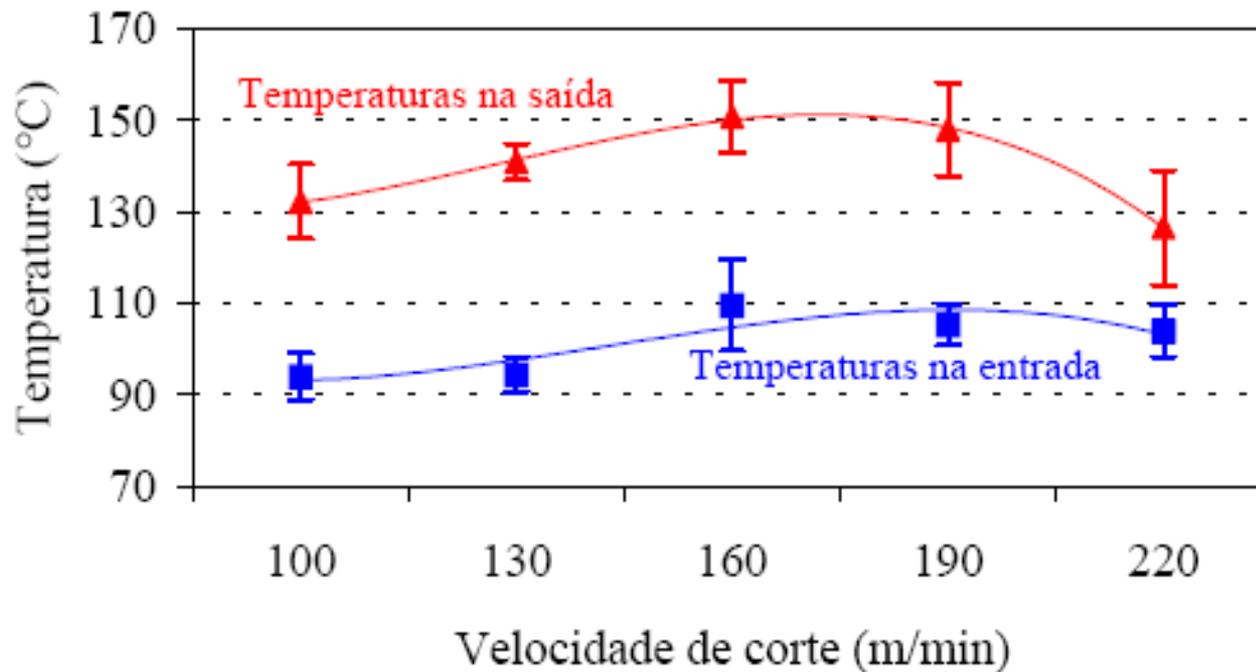
1994



# Temperatura em usinagem de metais

## Temperatura na Formação de Cavacos - Estimativas Experimentais

### Termo-imagens



# Temperatura em usinagem de metais

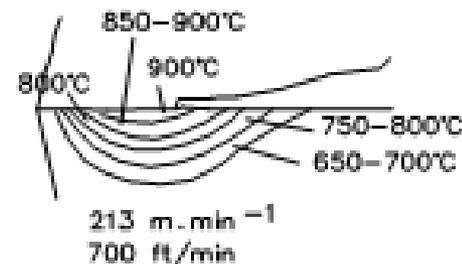
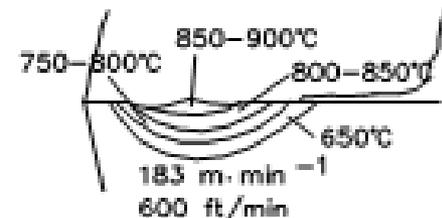
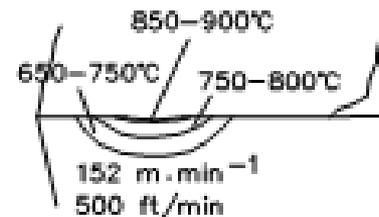
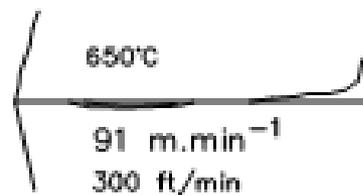
## Temperatura na Formação de Cavacos - Estimativas Experimentais

- Vernizes termosensíveis.

- Propriedades metalográficas

- Sais com diferentes temperaturas de fusão

- Filmes depositados por PVD.



# Temperatura em usinagem de metais

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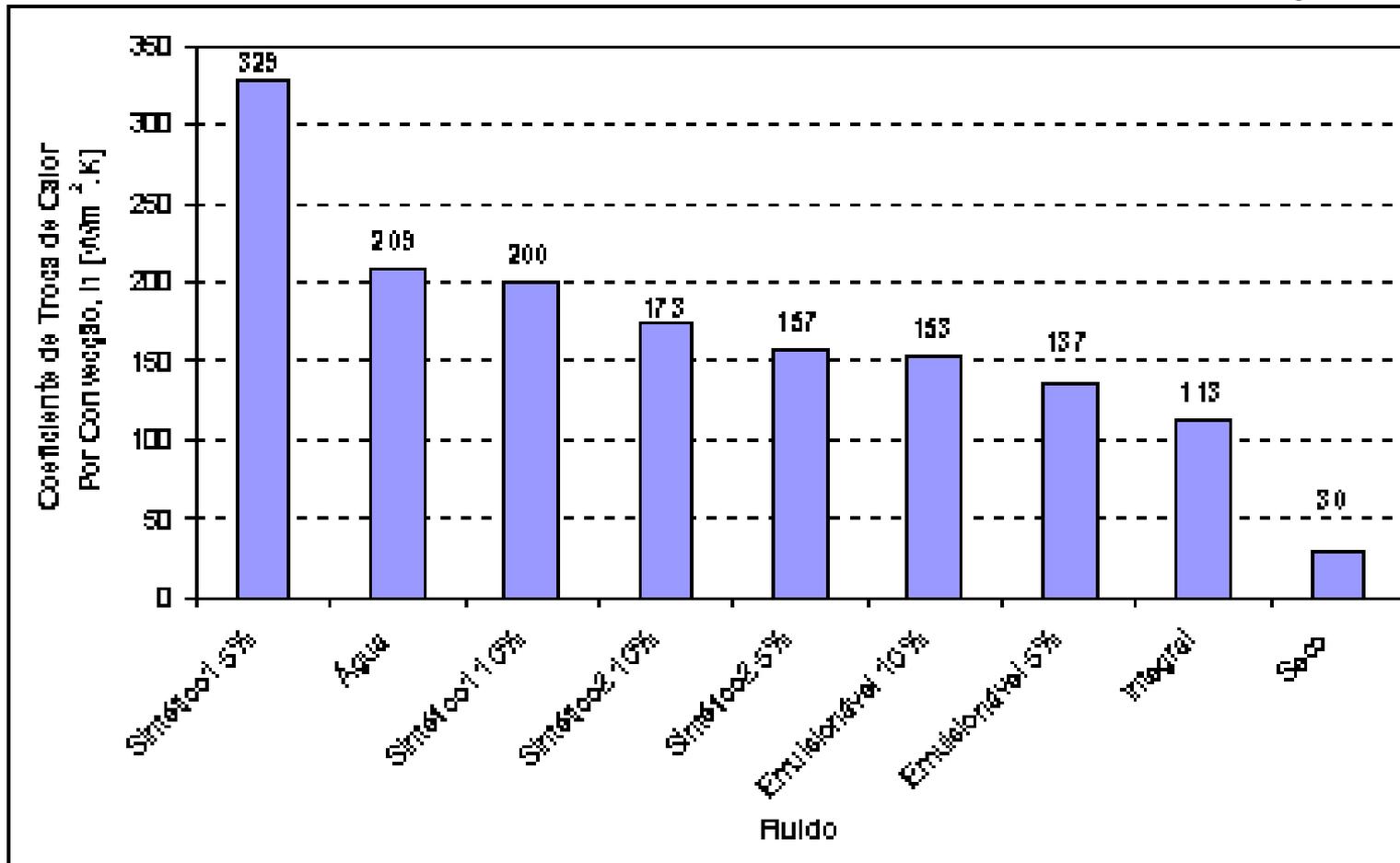
## Aplicação de Fluidos de Corte em Usinagem



# Temperatura em usinagem de metais

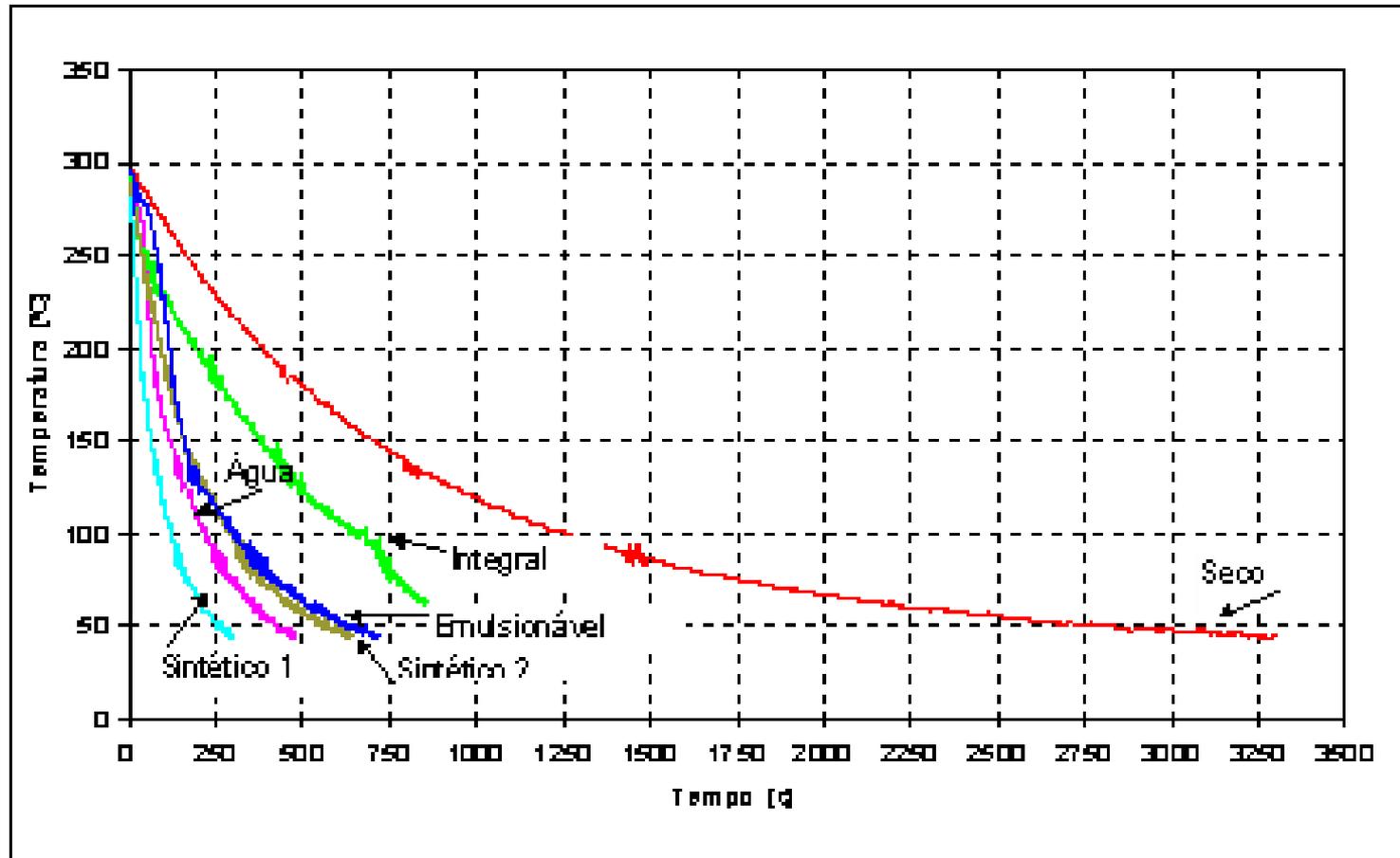
Classificação dos fluidos de corte

- Óleos;
- Emulsões;
- Soluções



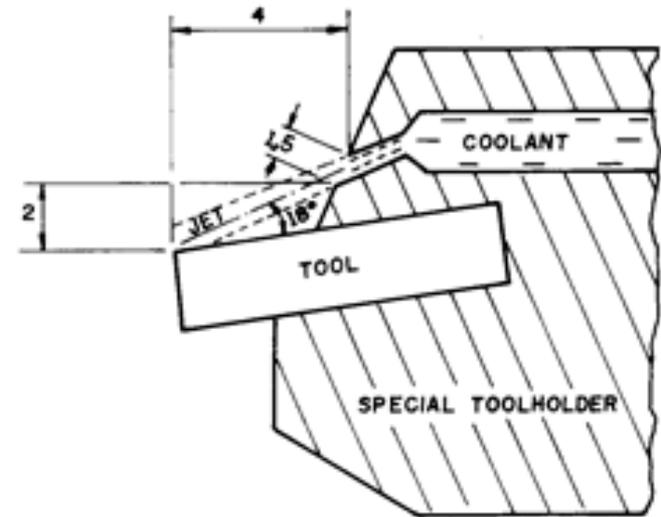
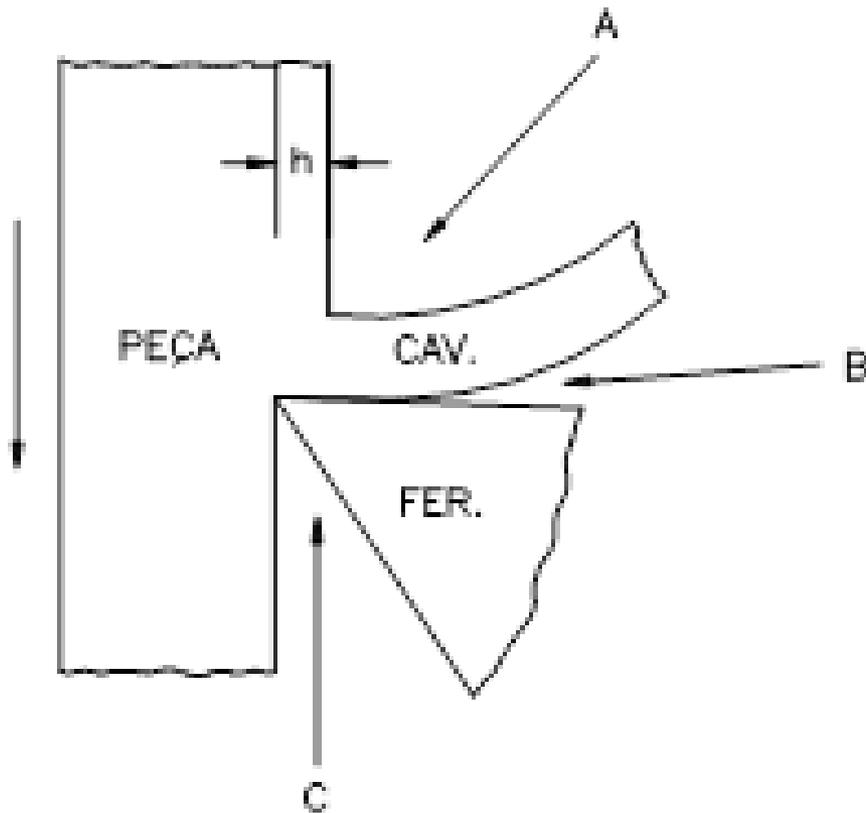
# Temperatura em usinagem de metais

Tempo de resfriamento



# Temperatura em usinagem de metais

Direções de aplicação do fluido de corte



# Temperatura em usinagem de metais

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## Seleção de fluidos de corte

Retificação  
Serramento  
Torneamento  
Aplainamento  
Furação  
Fresamento  
Rosçamento com ferramenta de perfil  
Mandrillamento  
Furação profunda  
Geração de dentes de engrenagens  
Rosçamento externo com cossinete  
Rosçamento interno com macho  
Brochamento externo  
Brochamento interno



S  
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