IE-352
Summer Semester 1432-33 H
MANUFACTURING PROCESSES - 2

Homework 3 Answers

Answer ALL of the following questions:

1. In an orthogonal cutting operation, spindle speed is set to provide a cutting speed of 1.8 m/s. The width and depth of cut are 2.6 mm and 0.30 mm, respectively. The tool rake angle is 8°. After the cut, the deformed chip thickness is measured to be 0.49 mm. Determine (a) shear plane angle, (b) shear strain, and (c) material removal rate (the volume of material removed every second).

Given:

cutting speed: $V = 1.8\ \frac{m}{s}$
width: $w = 2.6\ mm$
thicknesses: $t_0 = 0.30\ mm,\ t_c = 0.49\ mm$
rake angle: $\alpha = 8°$

Required:

a) $\phi = ?$

b) $\gamma = ?$

c) $R_{MR} = ?$

Solution:

a) ϕ *can be obtained from:*

$$\tan\phi = \frac{r\cos\alpha}{1 - r\sin\alpha}$$

$$r = \frac{t_o}{t_c} = \frac{0.30\ mm}{0.49\ mm} = 0.612$$

$$\Rightarrow \phi = \tan^{-1}\left[\frac{0.612\cos 8°}{1 - 0.612\sin 8°}\right] = \tan^{-1} 0.663$$

$$\Rightarrow \boldsymbol{\phi = 33.5°}$$

b) γ *can be obtained from:*

$$\gamma = \cot\phi + \tan(\phi - \alpha)$$

$$\Rightarrow \gamma = \cot 33.5° + \tan(33.5° - 8°)$$

$$\Rightarrow \boldsymbol{\gamma = 1.987}$$

c) R_{MR} *(material removal rate) is the volume of material removed (i.e. cut) every second which can be obtained from:*

$$R_{MR} = wt_oV = (2.6\ mm)(0.30\ mm)[(1.8\ {}^{m}/_{s})(1000\ {}^{mm}/_{m})]$$

$$\Rightarrow \boldsymbol{R_{MR} = 1404\frac{mm^3}{s}}$$

2. Assume that, in orthogonal cutting, the rake angle is 25° and the coefficient of friction is 0.2. Use the cutting ratio equation to determine the percentage increase in chip thickness when the friction is doubled.

Given:

rake angle: $\alpha = 25°$
coefficients of friction: $\mu_1 = 0.2$, $\mu_2 = 2\mu_1 = 0.4$

Required:

percentage increase in chip thickness
i.e. $\frac{t_{c_2} - t_{c_1}}{t_{c_1}} = \frac{t_{c_2}}{t_{c_1}} - 1 = ?$

Solution:

- cutting ratio equation:

$$r = \frac{t_o}{t_c} = \frac{\sin\phi}{\cos(\phi-\alpha)}$$

Rearranging: $\Rightarrow t_c = t_o\frac{\cos(\phi-\alpha)}{\sin\phi}$

- Assuming rake angle (α) and depth of cut (t_o) are kept constant$\Rightarrow$

$$\frac{t_{c_2}}{t_{c_1}} = \frac{t_o\frac{\cos(\phi_2-\alpha)}{\sin\phi_2}}{t_o\frac{\cos(\phi_1-\alpha)}{\sin\phi_1}} = \frac{\cos(\phi_2-\alpha)\sin\phi_1}{\cos(\phi_1-\alpha)\sin\phi_2}$$

- We lack the values for the shear angles($\phi_1$and ϕ_2), so we use:

$$\phi = 45° + \frac{\alpha}{2} - \frac{\beta}{2}$$

Note how we use this equation since $\mu_1$and $\mu_2 < 0.5$

Also, note:

$$\beta_1 = \tan^{-1}\mu_1 = \tan^{-1}0.2 = 11.31°$$

$$\beta_2 = \tan^{-1}\mu_2 = \tan^{-1}0.4 = 21.80°$$

$\Rightarrow$

$$\phi_1 = 45° + \frac{\alpha}{2} - \frac{\beta_1}{2} = 45° + \frac{25°}{2} - \frac{11.31°}{2} = 51.85°$$

$$\phi_2 = 45° + \frac{\alpha}{2} - \frac{\beta_2}{2} = 45° + \frac{25°}{2} - \frac{21.80°}{2} = 46.60°$$

- Substituting in chip thickness formula we generated$\Rightarrow$

$$\frac{t_{c_2}}{t_{c_1}} = \frac{\cos(46.60° - 25°)\sin 51.85°}{\cos(51.85° - 25°)\sin 46.60°} = 1.13$$

$\Rightarrow$

increase in chip thickness$= \frac{t_{c2}}{t_{c_1}} - 1 = 1.13 - 1 = \mathbf{13}\%$

3. A turning operation is performed on stainless steel with hardness 200 HB (with specific energy of 2.8 J/mm^3), cutting speed = 200 m/min, feed = 0.25 mm/rev, and depth of cut = 7.5 mm. How much power will the lathe draw in performing this operation if its mechanical efficiency is 90%?

Given:

total specific energy: $u_t = 2.8\ \frac{J}{mm^3}$
cutting speed: $V = 200\ \frac{m}{min}$
feed: $f = 0.25\ \frac{mm}{rev}$
depth of cut: $t_0 = 7.5\ mm$
mechanical efficiency: $\eta_{mech} = 90\%$

Required:

Total power drawn from source: $Power_{source} = ?$

Solution:

- cutting power is related to power from source through:
  $Power_c = Power_{source} * \eta_{mech}$
  or
  $$Power_{source} = \frac{Power_c}{\eta_{mech}}$$
- also, total specific energy:

$$u_t = \frac{total\ cutting\ power}{material\ removal\ rate} = \frac{Power_c}{R_{MR}}$$

- Since turning operation is involved ⇒

  $R_{MR} = f t_0 V$

  $= (0.25\ mm)(7.5\ mm)\left[\left(200\ \frac{m}{min}\right)\left(1000\ \frac{mm}{m}\right)\left(\frac{min}{60\ sec}\right)\right]$

  $= 6250 \frac{mm^3}{s}$

- Thus,

  $Power_c = u_t * R_{MR} = \left(2.8\ \frac{J}{mm^3}\right)\left(6250\ \frac{mm^3}{s}\right) = 17500\ \frac{J}{s}$

  $= 17.5\ kW$

- Substituting into the source power equation:

$$\boldsymbol{Power_{source}} = \frac{Power_c}{\eta_{mech}} = \frac{17.5\ kW}{0.9} = \mathbf{19.44\ kW}$$

4. With a carbide tool, the temperature in a cutting operation is measured as 650°C when the speed is 90 m/min and the feed is 0.05 mm/rev. What is the approximate temperature if the speed is doubled? What speed is required to lower the maximum cutting temperature to 480°C?

Given:

- first operation:
  - cutting temperature: $T_1 = 650\ °C$
  - cutting speed: $V_1 = 90\ \frac{m}{min}$
  - feed: $f = 0.05\ \frac{mm}{rev}$

Required:

a) second operation:
   - $V_2 = 2V_1$
   - $T_2 = ?$

b) third operation:
   - $T_3 = 480\ °C$
   - $V_3 = ?$

Solution:

- equation for mean temperature in orthogonal cutting (note, it is not mentioned if it is turning on a lathe or not):

$$T = \frac{0.000665Y_f}{\rho c}\sqrt[3]{\frac{V t_0}{K}}$$

- since, $Y_f, \rho c, K$ are material dependent, and assuming constant depth of cut (t_0) and rearranging equation above:

  $$\frac{T}{\sqrt[3]{V}} = \frac{0.000665Y_f}{\rho c}\sqrt[3]{\frac{t_0}{K}} = C$$

  Thus,

  $$\frac{T_1}{\sqrt[3]{V_1}} = \frac{T_2}{\sqrt[3]{V_2}}$$

a) second operation:

$$T_2 = \frac{\sqrt[3]{V_2}}{\sqrt[3]{V_1}}T_1 = \sqrt[3]{\frac{2V_1}{V_1}}T_1 = \sqrt[3]{2}T_1 = (1.26)(650\ °C)$$

$$\Rightarrow \boldsymbol{T_2 = 819\ °C}$$

b) third operation:

$$\sqrt[3]{V_3} = \frac{T_3}{T_1}\sqrt[3]{V_1} = \frac{480\ °C}{650\ °C}\sqrt[3]{90} = 3.309$$

$$\Rightarrow V_3 = 3.309^3$$

$$\Rightarrow \boldsymbol{V_3 = 36.2\ \frac{m}{min}}$$

Alternative Solution:

- assuming this was a turning operation, and using equation for mean temperature in turning on a lathe

  $T_{mean}\, \alpha\, V^a f^b$

  or: $T_{mean} = C\, V^a f^b$

  assuming constant feed (f), and using $a = 0.2$, $b = 0.125$ (since given that this is carbide tool)

$\Rightarrow T_{mean} = C\, V^a f^b$

$\frac{T_{mean_1}}{V_1^{0.2}} = \frac{T_{mean_2}}{V_2^{0.2}}$

a) second operation:

$$T_{mean_2} = \frac{V_2^{0.2}}{V_1^{0.2}} T_{mean_1} = \left(\frac{2V_1}{V_1}\right)^{0.2} T_{mean_1} = (2^{0.2})(T_{mean_1})$$
$$= (1.15)(650\,°C)$$

$$\Rightarrow \boldsymbol{T_2 = 747\,°C}$$

b) third operation:

$$V_3^{0.2} = \frac{T_3}{T_1} V_1^{0.2} = \frac{480\,°C}{650\,°C} 90^{0.2} = 1.816$$

$$\Rightarrow V_3 = 1.816^{\frac{1}{0.2}} = 1.816^5$$

$$\Rightarrow \boldsymbol{V_3 = 19.8\,\frac{m}{min}}$$

Note that the second solution did not produce a significantly large difference in final temperature, and yet a large difference in cutting speeds.

5. Let $n = 0.5$ and $C = 90$ in the *Taylor* equation for tool wear. What percent decrease in cutting speed is required to cause a (a) 2-fold (i.e. 200%) and (b) 10-fold (i.e. 1000%) increase in tool life?

Solution:

Taylor Equation for tool life:

$\boldsymbol{VT^n = C}$

$n = 0.5;\ C = 90$

$\Rightarrow VT^{0.5} = 90 \Rightarrow V_1 T_1^{\ 0.5} = V_2 T_2^{\ 0.5}$

a) $T_2 = T_1 + 200\% T_1 = 3T_1$

$\Rightarrow\ V_1 T_1^{\ 0.5} = V_2 (3T_1)^{0.5}$

$\Rightarrow\ V_1 = \sqrt{3} V_2$

$$\Rightarrow \frac{V_2}{V_1} = \frac{1}{\sqrt{3}} = 0.577$$

$$\Rightarrow \frac{V_1 - V_2}{V_1} = 1 - \frac{V_2}{V_1} = 1 - 0.577 = 0.423 \Rightarrow \textit{decrease in cutting speed} = \mathbf{42.3\%}$$

Note, less than half speed reduction is required for tool life to triple

b) $T_3 = T_1 + 1000\% T_1 = 11T_1$

$$\Rightarrow V_1 T_1^{0.5} = V_3 (11T_1)^{0.5}$$

$$\Rightarrow V_1 = \sqrt{11} V_3$$

$$\Rightarrow \frac{V_3}{V_1} = \frac{1}{\sqrt{11}} = 0.302$$

$$\Rightarrow \frac{V_1 - V_3}{V_1} = 1 - \frac{V_3}{V_1} = 1 - 0.302 = 0.698 \Rightarrow \textit{decrease in cutting speed} = \mathbf{69.8\%}$$