Temperatures in Machining

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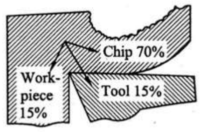
Heat generation and Disctribution

Primary zone - Shear
- Major plastic deformation occurs, so heat is generated
- Distributed between Chip and Workpiece

Secondary zone - Tool-chip interface
- Friction between Chip – Tool - Heat generation
- Distributed between Chip and Tool

Tertiary zone - Tool-work interface
- Tool edge does not remain sharp,flank rubs against the workpiece
- This heat is shared by tool, workpiece and coolant

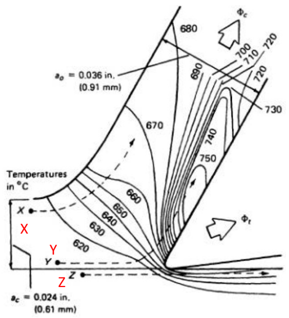
Distribution of Total Heat



Outline

- Sources of heat generation
- Heat generation in Primary and Secondary deformation zones
- Estimation of chip temperature
- Cutting fluids and their application

Temperature distribution in Tool-workpiece

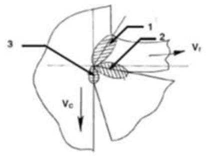


Mild steel, V = 0.38 m/s), w =6.35 mm. γ = 30°,

Point X, Y and Z:

Point X – moves towards cutting tool passes through primary shear zone.
Point Y - experience both primary and secondary zone
Point Z - inside the material

Sources of Heat generation



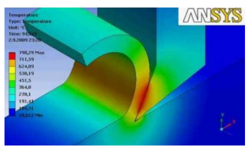
In elastic deformation, energy is stored in material as *Strain energy*
- No heat is generated

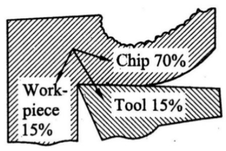
In plastic deformation
- Input energy is *mostly* converted into heat

Regions of plastic deformation in maching

- *Primary* zone 1 - Shear deformation
- *Secondary* zone 2 - Chip tool interface
- *Territory* zone 3- Work-tool interface

Effect of Temperature on Tool - Workpiece





Effect on cutting tool

- Thermal expansion of the tool - Temp may go > 700 degrees C
- Plastic deformation of cutting edges, Rapid tool wear
- Formation of build up edge ,poor surface finish, inaccuracy

Effect on Workpiece

- Distortion, Residual stresses, Poor dimensional accuracy.

Factors affecting Temperature in machining

- Cutting parameters : Cutting Speed, Feed, Depth of cut, coolant
- Tool geometry : rake angle, nose radius, tool wear
- Material properties of workpiece and tool:
  - Specific heat, Thermal conductivity
- Temperature increases for
  - Higher hardness and tensile strength materials (Ferrous, Titanium)
  - Lower thermal conductivity of workpiece
  - Low Shear angle
  - Dry cutting

Estimation of Temperature in machining

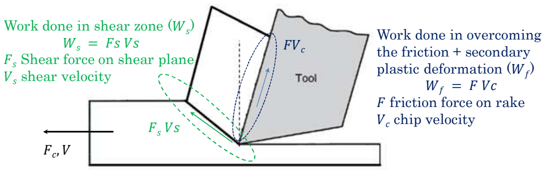
Need

- To evaluate machinability of work materials
- To evaluate Tool materials
- To select Process parameters in machining
- To analyze distortions and residual stresses in work
- To design machine elements – Thermal stresses

Techniques

- Analytical methods – Computational Modeling
- Experimental measurements

Work done (Power) in machining



Total work done in cutting $W_c = FcV = W_s + Wf$

Total work done W = work supplied by electric motor W_m
W_m = Work consumed in cutting action + Work done in feeding motion

Neglecting work in feed motion,

$$W_m \approx W_c = Ws + Wf$$

$$F_cV = FsVs + FVc$$

Distribution of cutting energy

$W_c = W_s + W_f$

- W_c = Power consumed in machining = $F_c V$
- W_s = Power consumed in primary shear zone = $F_s V_s$
- W_f = Power consumed in secondary zone = FV_c

- Typically, 60-70% of the energy in the metal cutting is consumed in the shear zone alone
- Remaining 40-30% is consumed at the tool-chip interface (assuming a perfectly sharp tool)
- Energy consumed in the Tool-workpiece contact (due to tool rubbing) is generally neglected.

Power in Primary shear zone

Power consumed in Shear zone $W_s = W_c - W_f$
$= F_cV - FV_c$

Cutting velocity (V) and chip velocity (V_c) are related by

$$V_c = rV = \frac{\sin\phi}{\cos(\phi-\gamma)}V$$

$$W_s = F_cV - FV_c = V(F_c - Fr)$$

Fraction of this power goes into chip to raise its temperature.
Typically the fraction is about 85 – 90 %.

Temperature in Primary shear zone

If γ is fraction of primary heat which goes to the work piece,
(1- γ) will be tken by chips

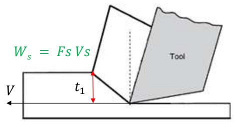
Value of γ depends upon shear angle ϕ and thermal conductivity k
(γ = 0.15-0.1)

$$\gamma = 0.15\ln\left(\frac{27.5}{\lambda\tan\phi}\right) \qquad \lambda = \frac{\rho c V t}{k}$$

γ : fraction of primary heat which conducted to the work piece,
ρ: density of workpiece material
c: specific heat of workpiece material
k: thermal conductivity of workpiece material
V : cutting Speed
t : uncut chip thickness

Temperature Rise in Primary shear zone

$W_s = F_c V - F V_c$



γ: fraction of primary heat which conducted to the work piece
(1- γ) fraction will be taken by chips.

Heat taken away by the chips = $(1-\gamma)W_s$
$= mc\Delta\theta$ c : Sp heat

Mass of material removed per unit time : $m = Vwt\rho$
Temperature rise of material passing through shear zone

$$\Delta\theta_s = \frac{(1-\gamma)W_s}{Vwt\rho c}$$

Role of cutting fluids in machining

Temperature affects the tool wear and thus productivity
- Need to reduce temperature to Increases tool life
- Reduced friction on the rake surface

Use of Cutting fluid
- Cools down chip-tool-work zone by carrying away generated heat
- Reduces the coefficient of friction at chip-tool Interface

Cutting fluids should have following properties:
- Large specific heat and good thermal conductivity,
- Low viscosity,
- Nonpoisonous/Inexpensive

Types of cutting fluids:
- Water based (contains salt or soluble oils)
- Mineral/ Synthetic oil

Temperature Rise in Secondary zone

- Maximum temperature rise $\Delta\theta_f$ when material passes through the rake surface

$$\Delta\theta_f \approx 1.13\sqrt{\frac{\lambda t_c}{l}}\left(\frac{W_f}{\rho c V w t}\right) \qquad \lambda = \frac{\rho c V t}{k}$$

- Here, l is the length of contact between tool and chip

$$\frac{l}{t_c} \approx [1+\tan(\phi-\alpha)]$$

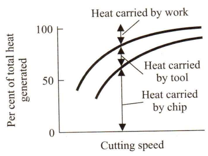
- Average temperature rise of material passing through secondary shear zone

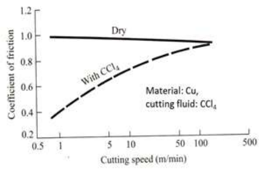
$$\Delta\theta_f = 1.13\sqrt{\frac{1}{\rho c V t \quad k[1+\tan(\phi-\alpha)]}}\frac{W_f}{w}$$

- Final temperature rise is given as :

$\Delta\theta = \Delta\theta_s + \Delta\theta_f$

Effect of cutting fluid





At higher cutting speed,

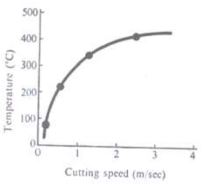
- Chip carries away most of the heat – 70-80 %
- Effectiveness of cutting fluids reduces as it take some finite time to reach the zone of cutting in work

Tool Chip overall Temperature

- Overall chip-tool interface temperature (θ_{ov}) relation from experimental studies

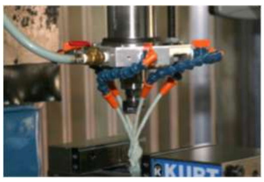
$$\theta_{ov} \propto \frac{V^{0.4} f^{0.2} t^{0.1}}{r^{0.1}}$$

- Influence of Speed is maximum
  - V > f > t
- Inverse in Nose radius r beneficial
- Increase of Shear angle ϕ beneficial
  - Reduction in Cutting Forces.

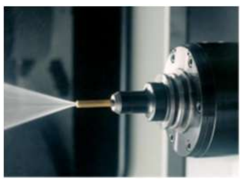


Cutting Fluid : Application methods

Cutting fluid can be applied by several ways:
- Manual brush/ By flood exposure / Through spindle cooling
- Mist cooling – small droplets through Spray



Spray cooling



Through spindle cooling