2.008 Design & Manufacturing II

Spring 2004

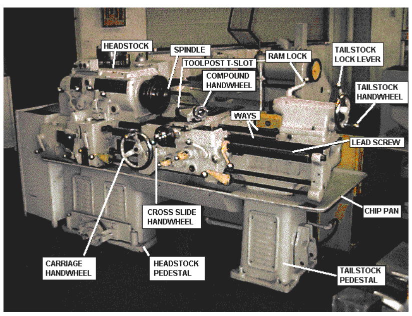
Metal Cutting I

2.008-spring-2004
S.Kim

Today, February 25th

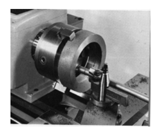
- HW#2 due before the class, #3 out on the web after the class.
  - Math Formulae, handout
- Lab groups fixed, and thank you.
  - group report!!!
- Metal cutting demo
- Cutting physics

A lathe of pre WWII

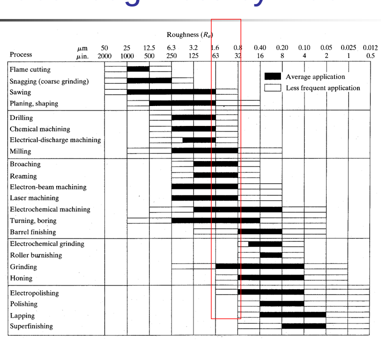


Material removal processes

- Cost:
  - Expensive $100 - $10,000
- Quality:
  - Very high
- Flexibility:
  - Any shape under the sun
- Rate:
  - Slow



Surface roughness by machining



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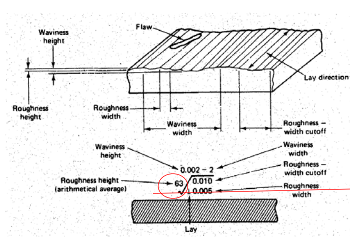
Machined Surface



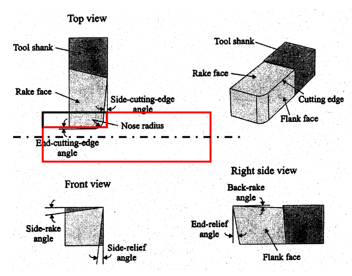
Rough	1000
Medium	500
Avg.	125
Better than Avg.	63
Fine	32
Very fine	16
Extremely fine	8

μ inch

Cutting processes

- Why do we study cutting physics?
  - Product quality: surface, tolerance
  - Productivity: MRR↑, Tool wear↓
- Physics of cutting
  - Mechanics
  - Force, power
- Tool materials
- Design for manufacturing

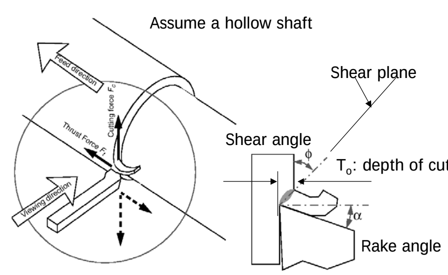
Cutting Tools



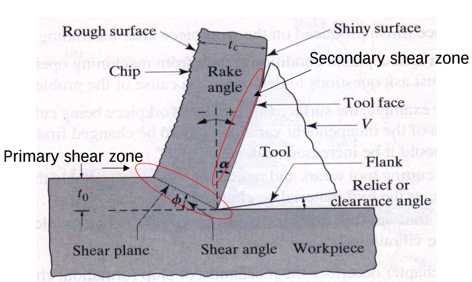
Cutting process modeling

- Methods: Modeling and Experiments
- Key issues
  - How does cutting work?
  - What are the forces involved?
  - What affect does material properties have?
  - How do the above relate to power requirements, MRR, wear, surface?

Orthogonal cutting in a lathe

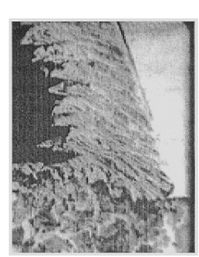


Cutting tool and workpiece..

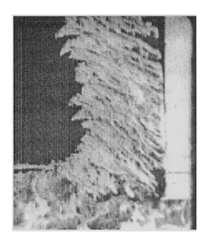


Varying rake angle α:

- α

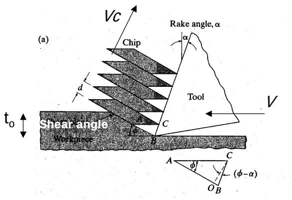


α = 0



Basic cutting geometry

- We will use the orthogonal model



Continuity

$V \cdot t_o = V_c \cdot t_c$

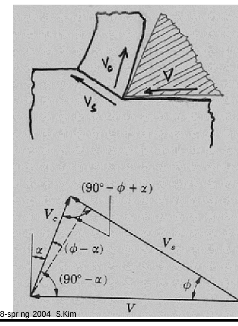
t_c: *chip thickness*

t_o: *depth of cut*

Cutting ratio: *r <1*

$$\frac{V_c}{V} = \frac{t_o}{t_c} = r = \frac{\sin(\varphi)}{\cos(\varphi - \alpha)}$$

Velocity diagram in cutting zone



Law of sines

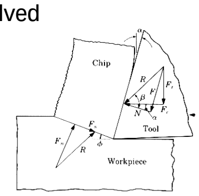
$$\frac{V}{\cos(\varphi - \alpha)} = \frac{V_s}{\cos(\alpha)} = \frac{V_c}{\sin(\varphi)}$$

$$\frac{V_c}{V} = \frac{t_o}{t_c} = r = \frac{\sin(\varphi)}{\cos(\varphi - \alpha)}$$

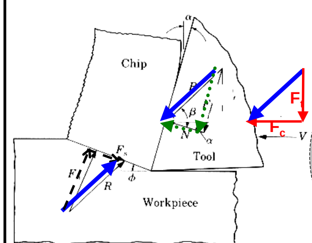
$$V_c = \frac{V \sin(\varphi)}{\cos(\varphi - \alpha)}$$

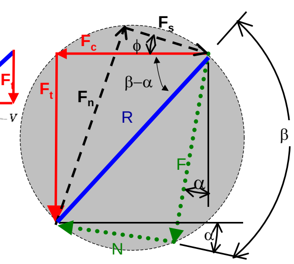
Forces and power

- FBD at the tool-workpiece contact
- What are the forces involved
  - Thrust force, Ft
  - Cutting force, Fc
  - Resultant force, R
  - Friction force, F
  - Normal Force, N
  - Shear Force, Fs, Fn



E. Merchant's cutting diagram





Source: Kalpajkian

FBD of Forces

$F = R \cdot \sin(\beta)$

$N = R \cdot \cos(\beta)$

β = Friction Angle

$\mu = \tan(\beta)$

$Ft = R \cdot \sin(\beta - \alpha)$

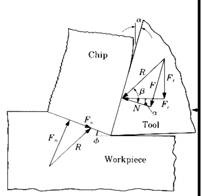
$Fc = R \cdot \cos(\beta - \alpha)$

$$F_s = F_c \cdot \cos(\varphi) - F_t \cdot \sin(\varphi) = R\cos(\varphi + \beta - \alpha)$$

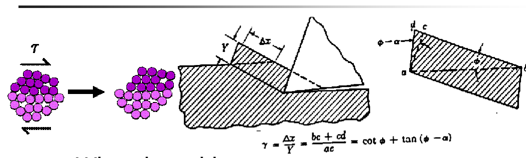
$$F_n = F_c \cdot \sin(\varphi) + F_t \cdot \cos(\varphi)$$

$$\mu = \frac{F}{N} = \frac{F_t + F_c \cdot \tan(\alpha)}{F_c - F_t \cdot \tan(\alpha)}$$

Typcially: $0.5<\mu<2$



Analysis of shear strain



- What does this mean:
  - Low shear angle = large shear strain
- Merchant's assumption: Shear angle adjusts to minimize cutting force or max. shear stress
- Can derive:

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

Shear angle

$$F_c = R \cdot \cos(\beta - \alpha)$$

$$F_s = F_c \cdot \cos(\varphi) - F_t \cdot \sin(\varphi) = R\cos(\varphi + \beta - \alpha)$$

$$F_c = F_s \cos(\beta - \alpha) / \cos(\varphi + \beta - \alpha)$$

F_s = As.σs (area of shear plane. shear strength)

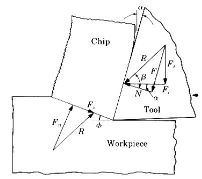
$$F_c = \sigma_s \frac{A}{\sin\varphi} \cos(\beta - \alpha) / \cos(\varphi + \beta - \alpha)$$

$$dF_c/d\varphi = 0 \longrightarrow \phi = 45^o + \frac{\alpha}{2} - \frac{\beta}{2}$$

Things to think about

- As rake angle decreases or friction increases
  - Shear angle decreases
  - Chip becomes thicker
  - Thicker chip = more energy dissipation via shear
  - More shear = more heat generation
  - Temperature increase!!!

$$\varphi = 45^o + \frac{\alpha}{2} - \frac{\beta}{2}$$



Power

Power input : $F_c \cdot V$ => shearing + friction

Power for shearing : $F_s \cdot V_s$

Specific energy for shearing : $u_s = \frac{F_s \cdot V_s}{w \cdot t_o \cdot V}$ ← MRR

Power dissipated via friction : $F \cdot V_c$

Specific energy for friction : $u_f = \frac{F \cdot V_c}{w \cdot t_o \cdot V}$

Total specific energy : $u_s + u_f = \frac{F \cdot V_c}{w \cdot t_o \cdot V} + \frac{F_s \cdot V_s}{w \cdot t_o \cdot V}$

Experimantal data

Specific energy (rough estimate)

Approximate Energy Requirements in Cutting Operations (at drive motor, corrected for 80% efficiency; multiply by 1.25 for dull tools).

Material	Specific energy W · s/mm³	Specific energy hp · min/in.³
Aluminum alloys	0.4–1.1	0.15–0.4
Cast irons	1.6–5.5	0.6–2.0
Copper alloys	1.4–3.3	0.5–1.2
High-temperature alloys	3.3–8.5	1.2–3.1
Magnesium alloys	0.4–0.6	0.15–0.2
Nickel alloys	4.9–6.8	1.8–2.5
Refractory alloys	3.8–9.6	1.1–3.5
Stainless steels	3.0–5.2	1.1–1.9
Steels	2.7–9.3	1.0–3.4

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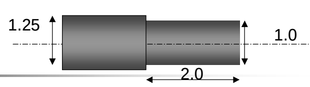
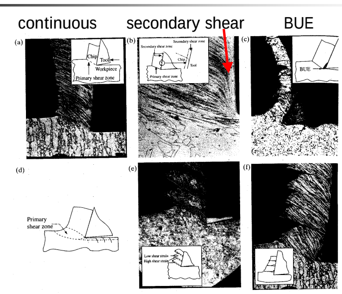
Example



- Consider the turning with a rod, from 1.25 inch diameter to 1.0.
- to; depth of cut, 0.005 inch
- f; feed rate, 0.025 inch/rev
- ω; spindle speed, 1000 rpm
- uf;specific energy for friction
- us;specific energy for shear, 0.35 hp min/in³
- 1 hp = 550 ft.lbf/s

- How many passes?
- Tools speed?
- Time to make this part?
- V c max?
- Max power needed?
- Initial cutting force?

Cutting zone pictures



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