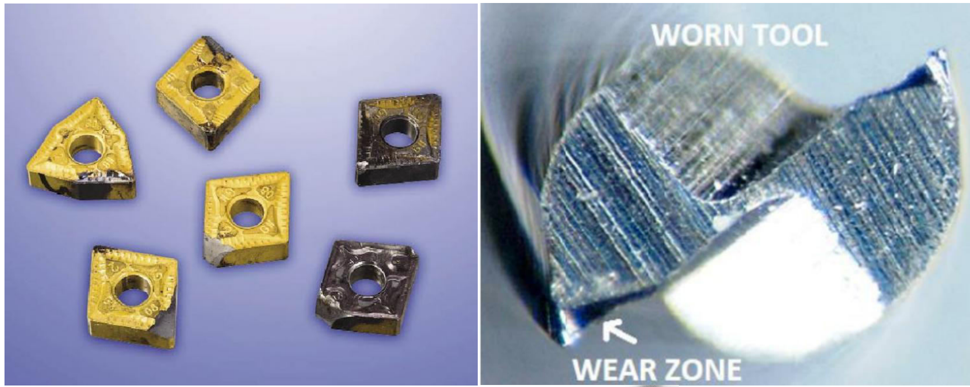
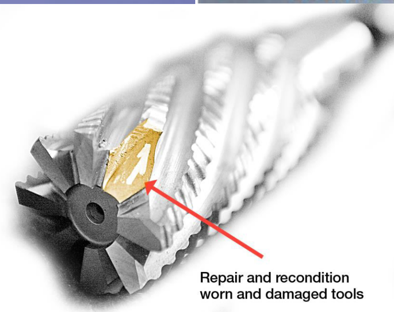
ME338 – Manufacturing Process II
Lecture 7 : Tool wear & Tool life

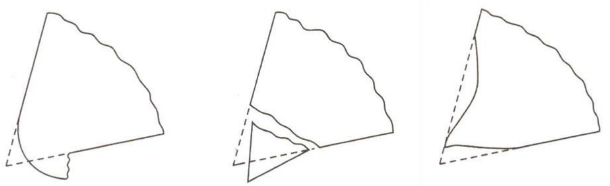
Pradeep Dixit
Department of Mechanical Engineering
Indian Institute of Technology Bombay

Worn cutting tools

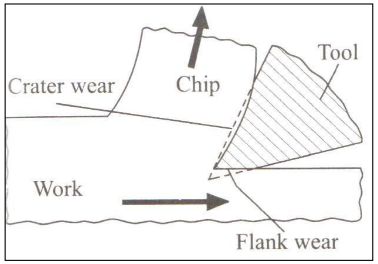




Tool wear and failure : conditions



(a) Plastic deformation (b) Mechanical breakage (c) Failure through gradual wear



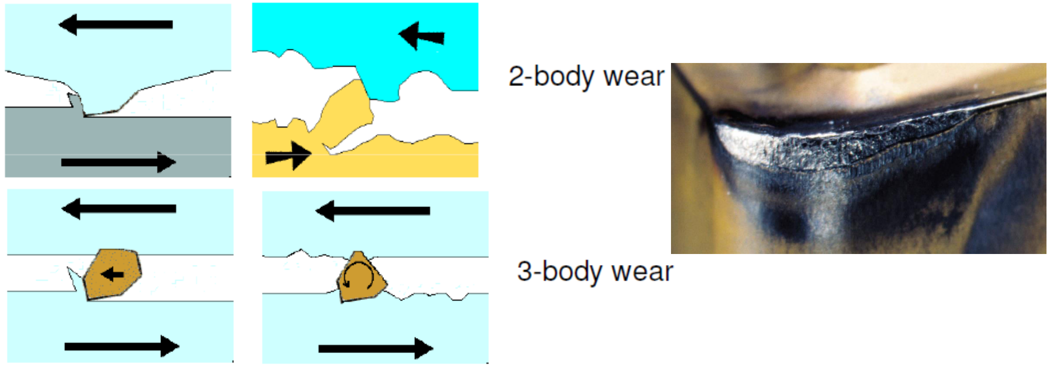
- Tool failure – plastic deformation
- Occurs at High Temperature
- W/P material with poor conductivity
- Temperature accumulation
- Tool tip melting
- Occurs in Titanium

- Tool failure – fracture
- Gross Fracture and Edge Chipping are two failure modes
- Interrupted cutting has severe fracture
- More likely at tool leaving then engaging

Tool wear - mechanism

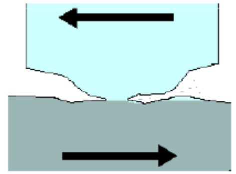
- Wear: loss of material from a surface
- Blunt cutting tool: large power consumption, poor surface finish
- Wear usually take place along
  - Rake surface – 'craters'
  - Flank surface – flank wear
- Possible reasons:
  - Plastic deformation – high temp, large stress
  - Mechanical breakage – large stress, insufficient strenght
  - Blunting of tool edge due to gradual wear
- Tool wear mechanism
  - Adhesive wear, Abrasive wear, diffusion wear, Corrosive wear, Fatigue wear

Abrasive wear



- Mechanical wear process >> loss of material by micro-cutting action
- If one of the surface contains hard particles, then during sliding, may dislodge materials from other surface by ploughing action
- Abrasive wear resistance increases with hardness
- Abrasive wear resistance – proportional to hardness

Adhesive wear



- When the bodies in contact are of similar nature, the asperities on the contacting surfaces tends to get welded
- Sliding causes fracture of these welded junctions and material is lost from both surfaces
- Mechanical wear process; wear particles generated from the softer of two contacting surfaces; characterized by metal transfer from softer to harder body.

- Archard's wear equation:
  - V: volume of wear
  - K: wear coefficient
  - L: sliding distance
  - N: normal load
  - H: hardness of the softer surface

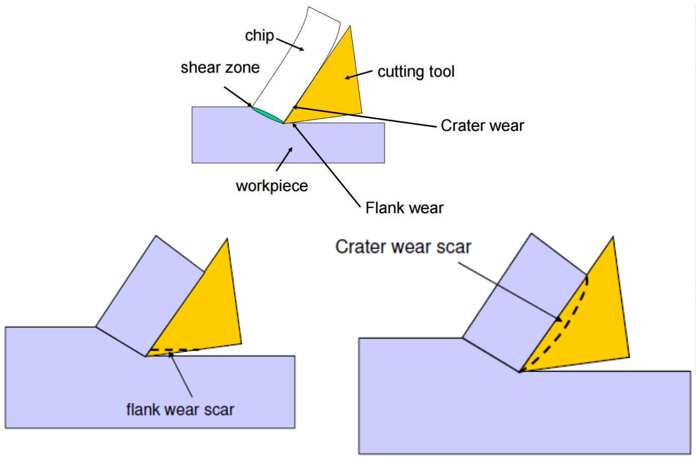
$$V = K\left(\frac{LN}{3H}\right)$$

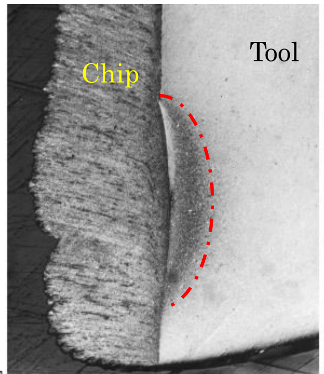
Diffusion and Corrosive wear

- Diffusion wear
  - movement of atoms in metallic crystal lattice from higher concentration to lower concentration
  - Rate of diffusion depends upon the concentration gradient and temperature
  - Diffusion rate increases exponentially with temperature
  - Wear due to diffusion is dominant at high temperature region, esp for high speed machining
- Corrosive wear:
  - Chemical wear process
  - Due to chemical reactions between the surface and environment (water, oxygen, acids, etc.)
  - Example: solution wear of cemented carbide cutting tool materials when cutting ferrous metals at high speeds

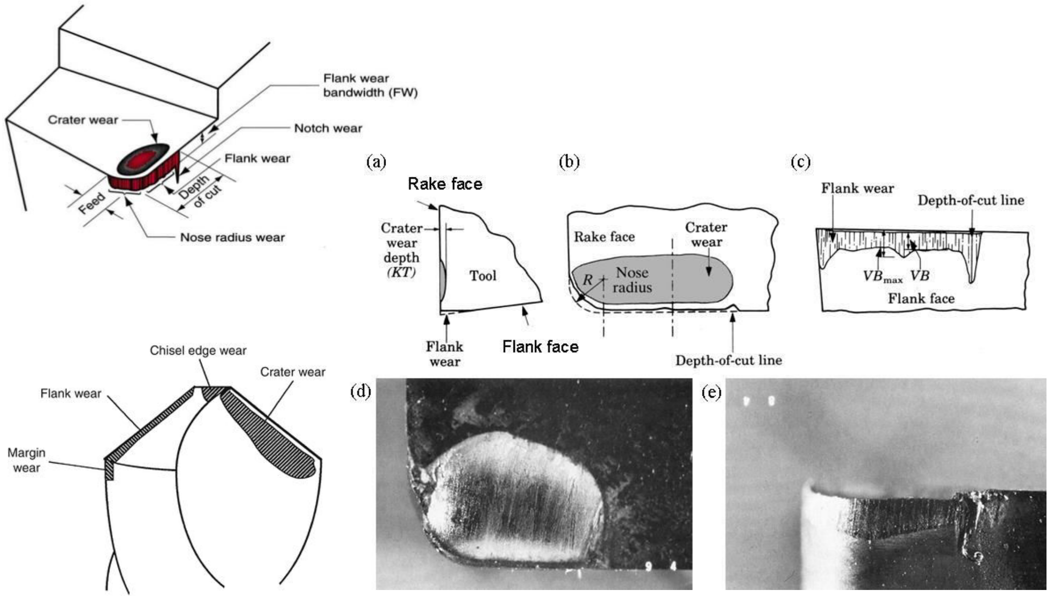
Tool wear : Crater (rake) and Flank wear

- Crater wear: wear scar on rake face of tool
  - Possible mechanisms: adhesion, abrasion, diffusion (at high cutting speeds)
- Flank wear: wear scar on flank face of tool
  - Possible mechanisms: adhesion, abrasion (due to rubbing of flank face against cut surface)





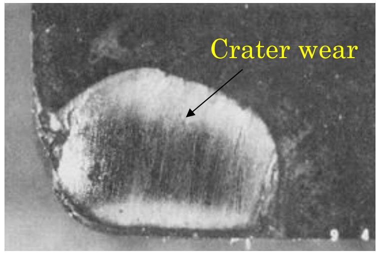
Flank and crater wear

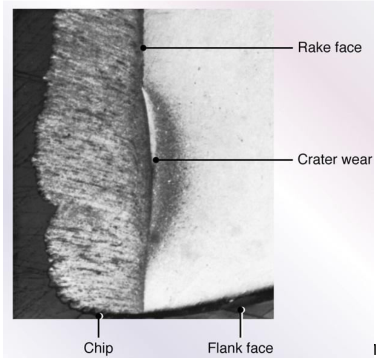


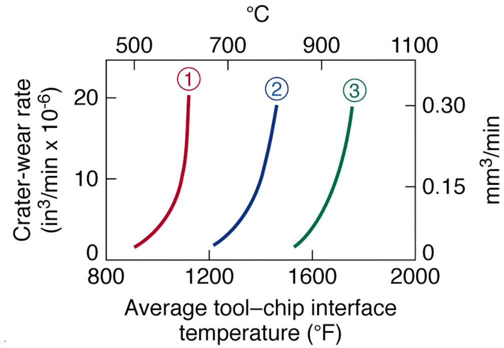
Flank wear is measured by width of wear surface

Crater Wear

- Diffusion is dominant for crater wear
- Crater wear rate increases with temperature
- Chemical affinity between tool and workpiece
- Coating of hard materials help in reducing crater wear : TiN : low friction/Al2O3: Thermal stability/ TiCN: wear resistance

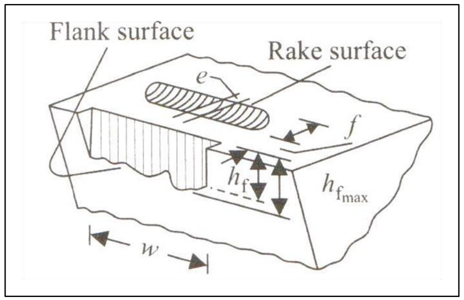






Flank and crater wear – failure criteria

End of tool life can occur either by tool Catastrophic failure or by Progressive wear of flank and/or rake face of tool



Wear criterion

Catastrophic failure

or

$h_f = 0.3$ mm High Speed Steel (HSS)

or

$h_{f_{max}} = 0.6$ mm (when wear is highly nonuniform)

$h_f = 0.3$ mm Tungsten Carbide (WC)

or

$h_{f_{max}} = 0.6$ mm (when wear is highly nonuniform)

or

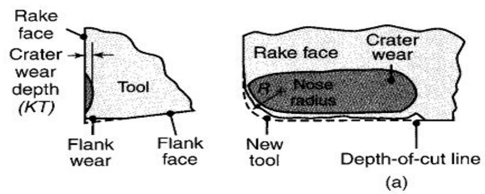
$e = (0.06 + 0.3t_1)$ mm

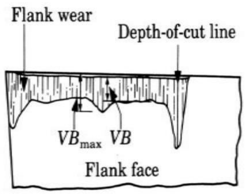
t_1 feed, Flank wear can be measured by h_f

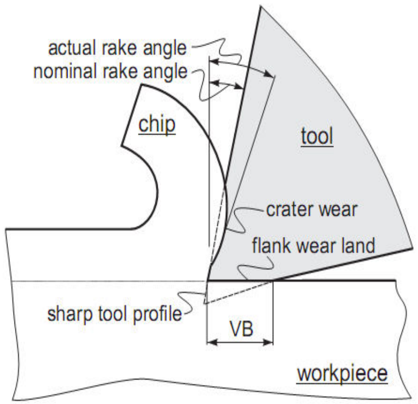
Growth of crater wear is quite complex

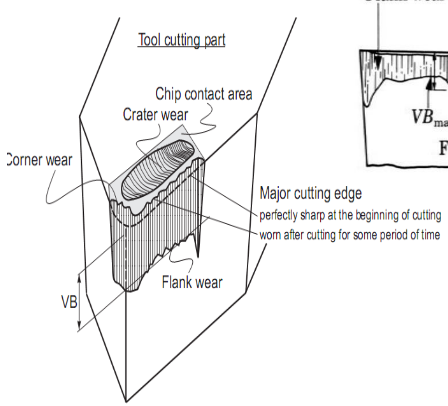
When is cutting tool is considered as failed?

- ISO Criterion for HSS, WC, Ceramic tools, flank wear land (VB) should be:
  - Catastrophic
  - VB = 0.3 mm for regular tools
  - VB_{max} = 0.6 mm for irregular tools
  - Crater wear KT = 0.06 + 0.3f,
    - f = feed; for carbide tool







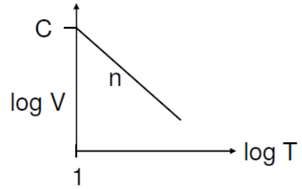


Taylor's contribution

- Frederick Winslow Taylor (1856-1915)
  - Father of Scientific Management
- Four principles of scientific management
  - Replace working by 'rule of thumb' by scientific method to study work and determine most efficient way to perform task.
  - Assign a job to worker based on their skills and capability
  - Monitor worker performance
  - Allocate work between managers and workers so that they can perform their respective roles

Taylor's contribution – Cutting speed & Tool life

- Metal cutting
  - Time / motion studies
  - Cutting tool life, machining speed
- Taylor's equation
  - Relationship between cutting speed (V) and tool life (T)
  - $VT^n = C$, n: Taylor's exponent, C: Taylor's constant
  - For HSS, n = 0.1, for WC, n = 0.2, for other ceramic n = 0.4



$$VT^n = C$$

n =Taylor's tool life exponent.
C =Taylor's tool life constant.
T =Tool life (min)
V = cutting speed (m/min)

Range of Taylor's exponent n for different materials

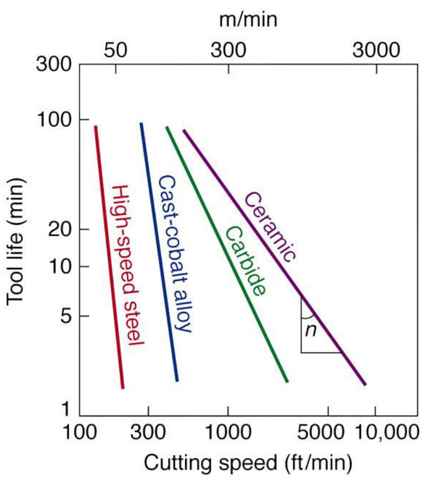
High-speed steels	0.08-0.2
Cast alloys	0.1-0.15
Carbides	0.2-0.5
Coated carbides	0.4-0.6
Ceramics	0.5-0.7

Cutting speed for various tools

Tool material	Cutting speed (m/min)
Carbon steel	5
High speed steel	30
Cemented carbide	150
Coated carbide	350
Ceramic	600

Tool-life Curves

- Tool life : The total machining time (in min) upto which a cutting tool can be used with expected results
  - Should produce desired surface finish
  - Should produce cutting force/power consumption in a given range



Extended Taylor's tool life equation

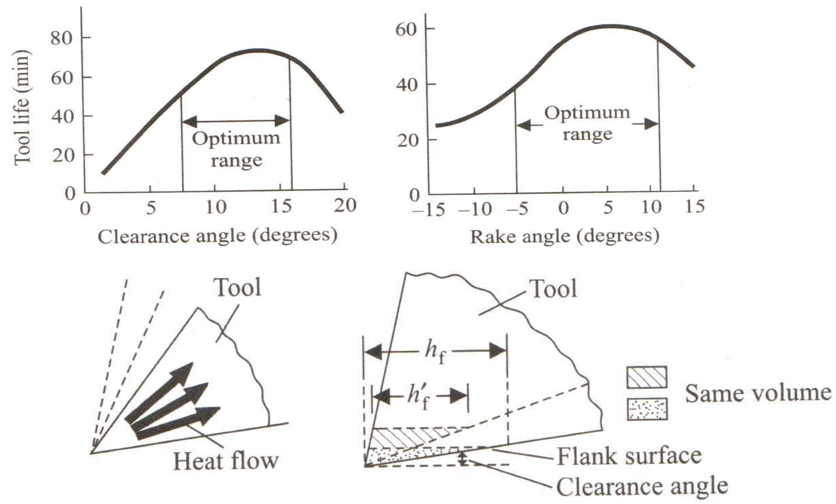
- Experiments demonstrated that feed rate (f), and depth of cut (d) also affect the tool wear and thus tool life (T)
  Large depth of cut and feed rate >> higher tool wear, reduced tool life
- Taylor equation was modified to include feed (f) and depth of cut (d)
- Extended Taylor's equation: T: $VT^n d^{n1} f^{n2} = C'$
  $n, n_1, n_2 : 0.1 - 0.4, C' > 100$

Work material	Tool material	C'	n	n1 p	n2 q
		273		0.2	
	WTiC				
		227	0.2	0.35	0.15
	10% Co				
		221		0.45	
Steel					
	WTiC				
		292	0.18	0.3	0.15
	6% Co				
Cast iron	WC	324	0.28	0.4	0.2

Example

In a production turning operation, the work part is 125 mm in diameter and 300 mm long. A feed of 0.225 mm/rev is used in the operation. If cutting speed = 3.0 m/s, the tool must be changed every 5 work parts; but if cutting speed = 2.0 m/s, the tool can be used to produce 25 pieces between tool changes. Determine the Taylor tool life equation for this job. What will be the feed if the same tool can be used for machining 50 pieces at cutting speed of 5.0 m/s?

Effect of tool angles on tool life

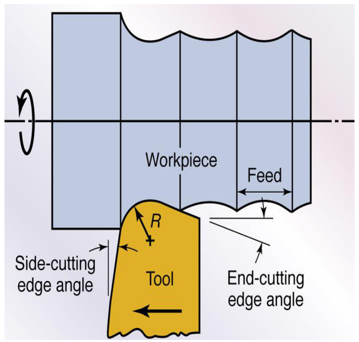


Rake angle increases, sharper tools, cutting forces reduces, however if rake angle is too high, tool becomes thinner, area available for thermal conduction reduces, higher tool wear, reduced tool life

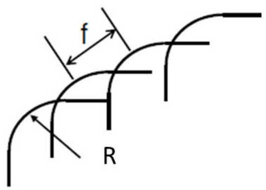
Surface Finish(SF)

- The higher the feed, and the smaller the tool-nose radius, R, the more prominent these marks will be.
- Vibration and chatter adversely affect surface finish because a vibrating tool periodically changes the dimensions of the cut.
- Surface roughness (Peak-to-valley):
  - $h_{max} \approx \frac{f^2}{8R}$ $\qquad h_t = \frac{f}{\tan\psi_s + \cot\psi_e}$
- Surface roughness (Arithmetic average):
- $h_{aa} \approx \frac{f^2}{18\sqrt{3}R}$

h: Roughness
R : Nose radius (mm)
f: feed (mm/rev)
R_t: peak-to-valley roughness
R_{aa}: arithmetic average
ψ_s : Side-cutting edge angle
ψ_e : End-cutting edge angle



Schematic illustration of feed marks on a surface being turned



Machinability

- Machinability can be defined in terms of four factors:
  - Surface finish and surface integrity of the machined part.
  - Tool life.
  - Force and power required.
  - The level of difficulty in chip control.
- Good Machinability indicates good surface finish and integrity, long tool life, and low force, and low power requirement.
- Tool life and surface roughness are considered to be the most important factors.