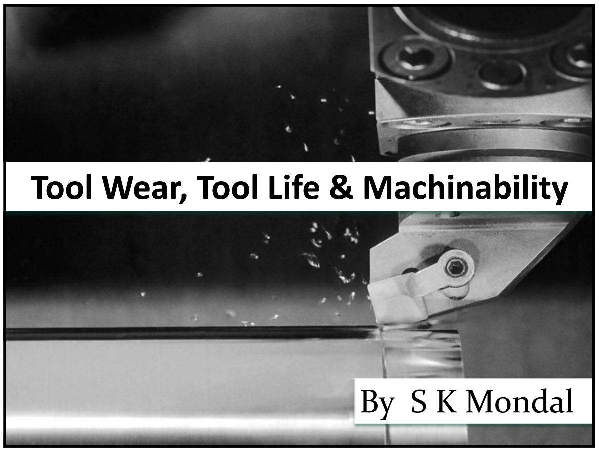
2



Tool Wear, Tool Life & Machinability

By S K Mondal

Tool Failure

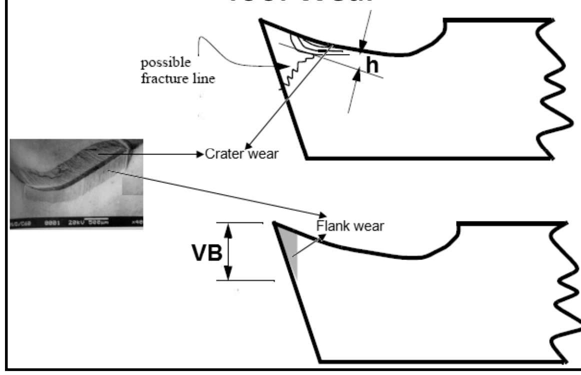
Tool failure is two types

- **1. Slow-death:** The gradual or progressive wearing away of rake face (crater wear) or flank (flank wear) of the cutting tool or both.
- **2. Sudden-death:** Failures leading to premature end of the tool
- The sudden-death type of tool failure is difficult to predict. Tool failure mechanisms include plastic deformation, brittle fracture, fatigue fracture or edge chipping. However it is difficult to predict which of these processes will dominate and when tool failure will occur.

Tool Wear

(a) **Flank Wear**
(b) **Crater Wear**
(c) **Chipping off of the cutting edge**

Tool Wear



Flank Wear: (Wear land)

Reason

- Abrasion by hard particles and inclusions in the work piece.
- Shearing of the micro welds between tool and work material.
- Abrasion by fragments of built-up-edge ploughing against the clearance face of the tool.
- At low speed flank wear predominates.
- If MRR increased flank wear increased.

Flank Wear: (Wear land)

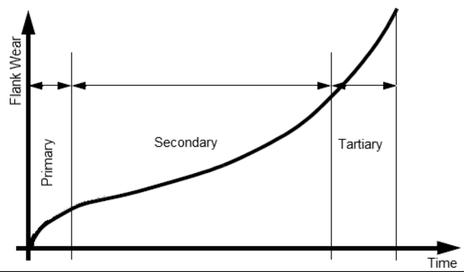
Effect

- Flank wear directly affect the component dimensions produced.
- Flank wear is usually the most common determinant of tool life.

Flank Wear: (Wear land)

Stages

- Flank Wear occurs in three stages of varying wear rates



Flank Wear: (Wear land)

Primary wear

The region where the sharp cutting edge is quickly broken down and a finite wear land is established.

Flank Wear: (Wear land)

Secondary wear

The region where the wear progresses at a uniform rate.

Flank Wear: (Wear land)

Tertiary wear

The region where wear progresses at a gradually increasing rate.

- In the tertiary region the wear of the cutting tool has become sensitive to increased tool temperature due to high wear land.
- Re-grinding is recommended before they enter this region.

Tool life criteria ISO

(A certain width of flank wear (VB) is the most common criterion)

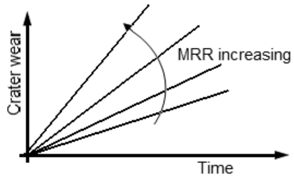
- Uniform wear: 0.3 mm averaged over all past
- Localized wear: 0.5 mm on any individual past

Crater wear

- More common in ductile materials which produce continuous chip.
- Crater wear occurs on the rake face.
- At very high speed crater wear predominates
- For crater wear temperature is main culprit and tool defuse into the chip material & tool temperature is maximum at some distance from the tool tip.

Crater wear Contd…..

- Crater depth exhibits linear increase with time.
- It increases with MRR.



- Crater wear has little or no influence on cutting forces, work piece tolerance or surface finish.

Wear Mechanism

1. Abrasion wear
2. Adhesion wear
3. Diffusion wear
4. Chemical or oxidation wear

Tool wear mechanism

Low speed	High speed	Very high speed
Mechanical properties •Abrasion •Micro fracture •Fatigue •Flow induced crack Nucleation and growth	Chemical diffusion and convection	Chemical diffusion

Why chipping off or fine cracks developed at the cutting edge

- Tool material is too brittle
- Weak design of tool, such as high positive rake angle
- As a result of crack that is already in the tool
- Excessive static or shock loading of the tool.

Why are ceramics normally provided as inserts for tools, and not as entire tools?

Ceramics are brittle materials and cannot provide the structural strength required for a tool.

List the important properties of cutting tool materials and explain why each is important.

- **Hardness at high temperatures** - this provides longer life of the cutting tool and allows higher cutting speeds.
- **Toughness** - to provide the structural strength needed to resist impacts and cutting forces
- **Wear resistance** - to prolong usage before replacement doesn't chemically react - another wear factor
- **Formable/manufacturable** - can be manufactured in a useful geometry

Tool Life

Tool Life Criteria

Tool life criteria can be defined as a predetermined numerical value of any type of tool deterioration which can be measured.

some of the ways

- Actual cutting time to failure.
- Volume of metal removed.
- Number of parts produced.
- Cutting speed for a given time
- Length of work machined.

Taylor's Tool Life Equation

based on Flank Wear

Causes

- Sliding of the tool along the machined surface
- Temperature rise

$$VT^n = C$$

Where, V = cutting speed (m/min)

T = Time (min)

n = exponent depends on tool material

C = constant based on tool and work material and cutting condition.

Values of Exponent 'n'

n = 0.08 to 0.2 for HSS tool

= 0.1 to 0.15 for Cast Alloys

= 0.2 to 0.4 for carbide tool

[IAS-1999; IES-2006]

= 0.5 to 0.7 for ceramic tool

[NTPC-2003]

Extended or Modified Taylor's equation

$$VT^n f^a d^b = C$$

Where: d = depth of cut

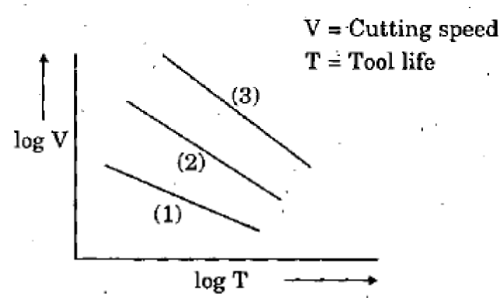
f = feed rate

$$\text{or} \quad T = \frac{C^{1/n}}{V^{1/n} . f^{1/n_1} . d^{1/n_2}}$$

$$\frac{1}{n} > \frac{1}{n_1} > \frac{1}{n_2}$$

i.e Cutting speed has the greater effect followed by feed and depth of cut respectively.

Tool Life Curve



1. HSS **2. Carbide** **3. Ceramic**

Cutting speed used for different tool materials

HSS (min) 30 m/min < Cast alloy < Carbide < Cemented carbide 150 m/min < Cermets < Ceramics or sintered oxide (max) 600 m/min

Effect of Rake angle on tool life

- If rake angle is large, smaller will be cutting angle and larger will be the shear angle. This will reduce force and power of cut i.e. ↑ tool life.
- But increasing the rake angle reduces the mass of metal behind the cutting edge resulting in poor transfer of heat i. e. ↓ tool life.
- Therefore optimum value of $\alpha = 14^0$.

Effect of Clearance angle on tool life

If clearance angle increased it reduces flank wear but weaken the cutting edge, so best compromise is 8^o for HSS and 5^o for carbide tool.

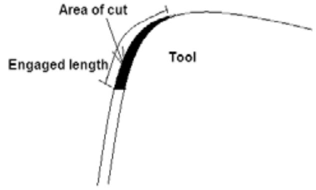
Effect of work piece on tool life

- With hard micro-constituents in the matrix gives poor tool life.
- With larger grain size tool life is better.

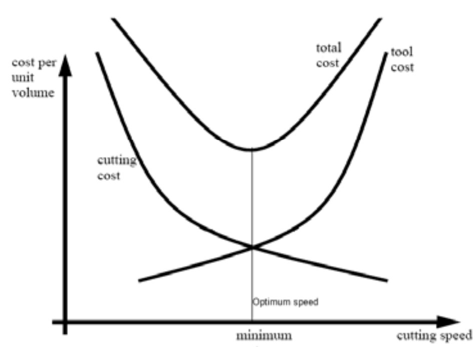
Chip Equivalent

$$\text{Chip Equivalent(q)} = \frac{\text{Engaged cutting edge length}}{\text{Plan area of cut}}$$

- It is used for controlling the tool temperature.



Economics of metal cutting



Formula

$$V_o T_o^{\,n} = C$$

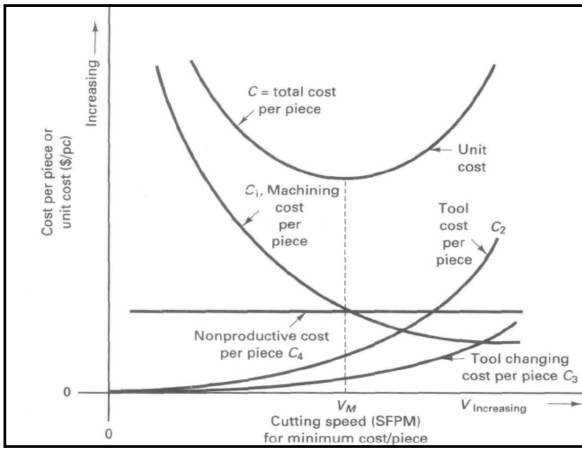
Optimum tool life for minimum cost

$$T_o = \left(T_c + \frac{C_t}{C_m}\right)\left(\frac{1-n}{n}\right) \quad \text{if } T_c, C_t \,\&\, C_m \text{ given}$$

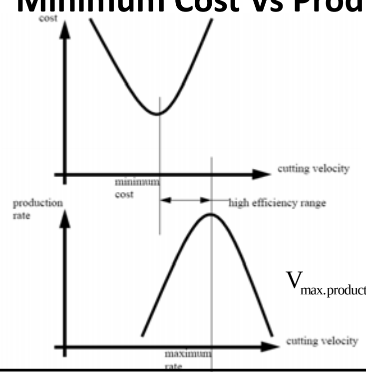
$$= \frac{C_t}{C_m}\left(\frac{1-n}{n}\right) \quad \text{if } C_t \,\&\, C_m \text{ given}$$

Optimum tool life for Maximum Productivity
(minimum production time)

$$T_o = T_c\left(\frac{1-n}{n}\right)$$



Minimum Cost Vs Production Rate



$$V_{max.production} > V_{max.profit} > V_{min.\,cost}$$

Machinability

Machinability-Definition

Machinability can be tentatively defined as 'ability of being machined' and more reasonably as 'ease of machining'.

Such ease of machining or machining characters of any tool-work pair is to be judged by:

- Magnitude of the cutting forces
- Tool wear or tool life
- Surface finish
- Magnitude of cutting temperature
- Chip forms.

Machinability-------------Contd…….

- Machinability will be high when cutting forces, temperature, surfaces roughness and tool wear are less, tool life is long and chips are ideally uniform and short.
- The addition of sulphur, lead and tellurium to non-ferrous and steel improves machinability.
- Sulphur is added to steel only if there is sufficient manganese in it. Sulphur forms manganese sulphide which exists as an isolated phase and act as internal lubrication and chip breaker.
- If insufficient manganese is there a low melting iron sulphide will formed around the austenite grain boundary. Such steel is very weak and brittle.

Machining of brittle and ductile materials

Brittle materials are relatively more machinable.

Role of microstructure on Machinability

Coarse microstructure leads to lesser value of τ_s.

Therefore, τ_s can be desirably reduced by

- Proper heat treatment like annealing of steels
- Controlled addition of materials like sulphur (S), lead (Pb), Tellerium etc leading to free cutting of soft ductile metals and alloys.

Free Cutting steels

- Addition of lead in low carbon steels and also in aluminium, copper and their alloys help reduce their τ_s. The dispersed lead particles act as discontinuity and solid lubricants and thus improve machinability by reducing friction, cutting forces and temperature, tool wear and BUE formation.
- Addition of sulphur also enhances machinability of low carbon steels by enabling its free cutting.

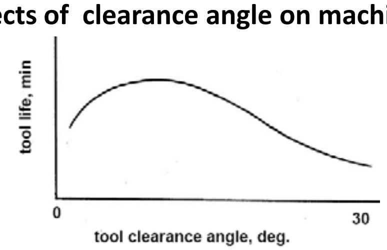
Effects of tool rake angle(s) on machinability

- As Rake angle increases machinability increases.
- But too much increase in rake weakens the cutting edge.

Effects of Cutting Edge angle(s) on machinability

- The variation in the cutting edge angles does not affect cutting force or specific energy requirement for cutting.
- Reduction in both SCEA and ECEA improves surface finish sizeably in continuous chip formation hence Machinability.

Effects of clearance angle on machinability



Inadequate clearance angle reduces tool life and surface finish by tool – work rubbing, and again too large clearance reduces the tool strength and tool life hence machinability.

Effects of Nose Radius on machinability

Proper tool nose radiusing improves machinability to some extent through

- increase in tool life by increasing mechanical strength and reducing temperature at the tool tip
- reduction of surface roughness, h_{max}

$$h_{max} = \frac{f^2}{8R}$$

Surface Roughness

- **Ideal Surface (Zero nose radius)**

Peak to valley roughness (h) = $\frac{f}{\tan SCEA + \cot ECEA}$

and (R_a) = $\frac{h}{4} = \frac{f}{4(\tan SCEA + \cot ECEA)}$

- **Practical Surface (with nose radius = R)**

$h = \frac{f^2}{8R}$ and $R_a = \frac{f^2}{18\sqrt{3}R}$

Change in feed (f) is more important than a change in nose radius (R) and depth of cut has no effect on surface roughness.

Cutting fluid

- **Cast Iron:** Machined dry or compressed air, Soluble oil for high speed machining and grinding
- **Brass:** Machined dry or straight mineral oil with or without EPA.
- **Aluminium:** Machined dry or kerosene oil mixed with mineral oil or soluble oil
- **Stainless steel and Heat resistant alloy:** High performance soluble oil or neat oil with high concentration with chlorinated EP additive.