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FORMULA SHEET

for

GATE-ME MACHINING & MACHINE TOOL OPERATIONS

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OUR COURSES

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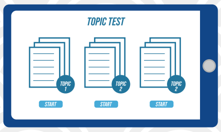

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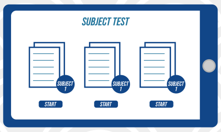

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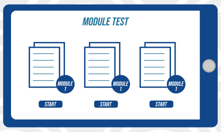

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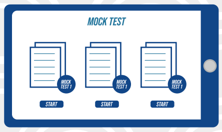

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MACHINING AND MACHINE TOOL OPERATIONS

MACHINING:

machining is a manufacturing process in which a sharp cutting tool is used to cut away material to leave the desired part shape. The predominant cutting action in machining involved shear deformation of the work material to form a chip; as chip is removed a new surface is exposed.

The process of removing metal can be done by using two types of cutting tools:

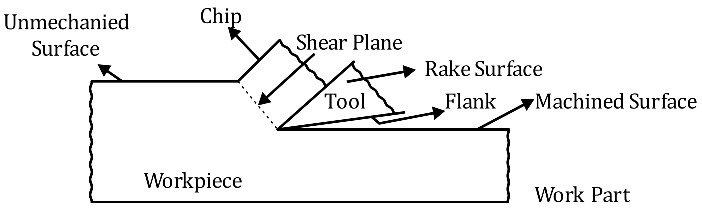
1. Single point cutting tools.
    - Ground type.
    - Tipped type.
2. Multi point cutting tools.
    - Drill bit.
    - Milling cutter.
    - Grinding wheel etc.

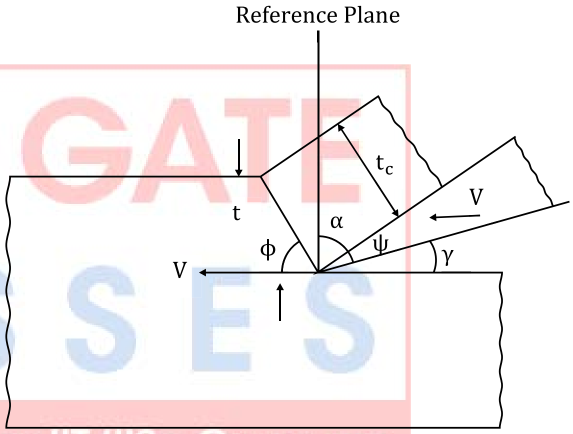
MRR obtained from multipoint cutting tool is more than that from single point cutting tool. The life of multipoint cutting tools is more than single point cutting tool .

Methods Of Machining:

- Orthogonal cutting or 2D cutting.
- Oblique cutting or 3D cutting.

Orthogonal Metal Cutting:





α = Orthogonal rake angle

γ = Clearance angle or relief angle

ϕ = shear angle

ψ = Lip angle or knife angle or wedge angle or cutting angle.

t = Uncut chip thickness or unperformed chip thickness = d (depth of cut)

$\Rightarrow t = d$ (in orthogonal cutting)

In turning:

$t = f \sin\lambda \quad \lambda$

= Principal cutting edge angle, f = feed rate

Turning is an oblique cutting but it can be converted into orthogonal cutting for analysis.

$t_c \rightarrow$ chip thickness

$$r = \frac{t}{t_c}$$

r = Chip thickness ratio or cutting ratio.

$t_c > t$ (always)

i.e., $r < 1$

Rack Surface:

The surface along which the chip moves upward is called 'rack surface' of tool.

Flank or Flank Surface:

The other surface which is relieved to avoid rubbing with the machined surface is called flank.

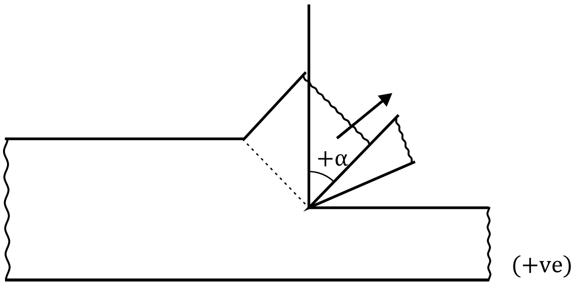
Rake angle (α):

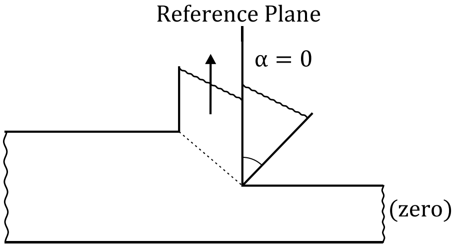
Angle of inclination of rake surface from reference Plane i.e., normal to horizontal machined surface.

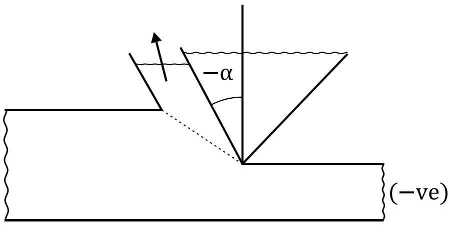
Clearance angle or relief angle(γ):

Angle of inclination of clearance or flank surface from the finished surface.

Discussion on Rake angle:







Positive Rake:

- Reduce cutting force.
- Reduce cutting power.

Positive rake angle is recommended.

- Machining low strength material
- Low power machine
- Long shaft of small diameter
- Setup lacks strength and rigidity
- Low cutting speed
- Cutting tool material: HSS (High speed steel)

Negative rake angle:

- Increases edge strength.
- Increases life of the tool
- Increases cutting force.
- Requires high cutting speeds.
- Requires ample power.
- Heavy impact loads

Negative rake angle is recommended.

- Machining high strength alloy
- High speed cutting
- With rigid setup
- Cutting tool material-ceramic, carbide

Zero rake:

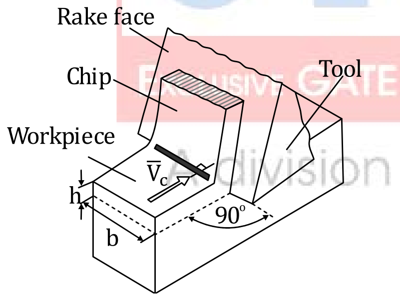
- To simplify design and manufacturing of the form tools
- Increases tool strength.
- Avoid digging of the tool into the workpiece.
- Brass is turned with zero rake angle.
- CI uses zero rake angle.

Clearance angle:

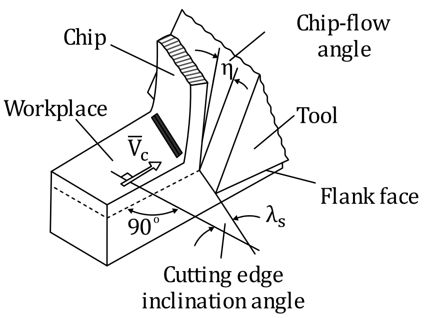
- Provided to avoid rubbing of tool (flank) with the machined surface.
- Reduce tool wear.
- Increase tool life.
- Must be positive (3° – 15°).

TYPES OF MACHINING:

Orthogonal



Oblique:



Orthogonal cutting

1. Cutting edge of the tool is $\perp_r$ to the direction of cutting velocity.
2. The cutting edge is wider than the workpiece width and extends beyond the workpiece on either side. Also, the width of the workpiece is much greater than the depth of cut.
3. The chip generated flows on the rake face of the tool with chip velocity perpendicular to the cutting edge.
4. The cutting forces act on along two directions only i.e., 2-D cutting.

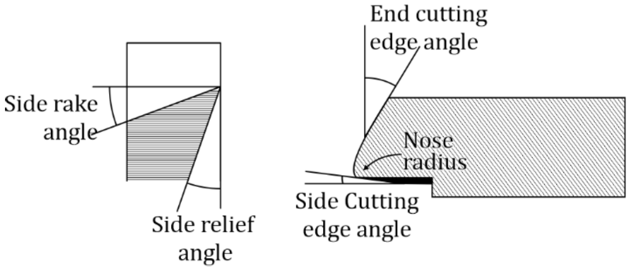
Geometry of a single Point Turning Tool:

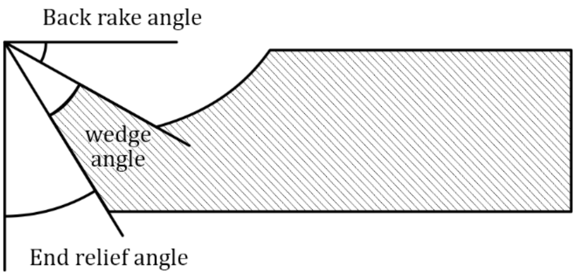
Classification: (According to the number of major cutting edges (points) involved).

- **Single point:** turning, shaping, planning, slotting tools, parting tools etc.
- **Double Point:** Drilling Tools
  Drilling tools – two cutting edges
- **Multipoint**: Milling, broaching, hobbing tools, saw, grinding wheel etc.

System of Description of tool Geometry:

a. Machine reference system: ASA or ANSI
b. Tool reference system: ORS and NRS
c. Work reference system: WRS





Back Rake Angle (α_b):

- It is the angle between the face of the tool and the base of the shank or holder and is usually measured in a plane perpendicular to the base and parallel to the length of the tool.
- It affects the ability of the tool to sheer the work material and form the chip.
- In turning positive back rake angle take the chips away from the machined surface, whereas negative back rake angle directs the chips on the machined surface.

Side Rake Angle (Axial Rake) (α_s)

- It is the angle between the face of the tool and the base of the shank or holder, and it usually measures in a plane perpendicular to the base and parallel to the width.
- Increase in the side rake angle reduces the chip thickness in turning.

End Relief Angle (γ_e)

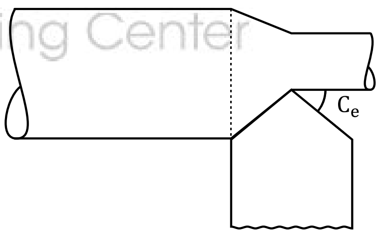
- It is the angle between the portion of the end flank immediately below the end cutting edge and a line drawn through these cutting edges $\perp_r$ to the bases. It is usually measured in a plane $\perp_r$ to the end flank.
- End relied angle prevents friction on the flank of the tool.

Side Relief Angle:

- It is the angle between the portion of the side flank immediately below the side cutting edge and a line drawn through this cutting edge $\perp_r$ to the base.
- It is a measured in a plane $\perp_r$ to the side flank.

End Cutting Edge Angle, (ECEA) (C_e)

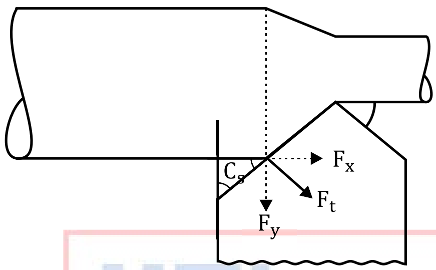
- The end cutting edge angle is the amount that the end cutting edge slopes away from the nose of the tool, so that it will clear the finished surface on the workpiece, when cutting with the side cutting edge.



- It prevents the trailing end of the cutting edge of tool from rubbing again the work piece.
- A larger end cutting edge angle weakness the tool. It is usually kept between 8° to 15°.

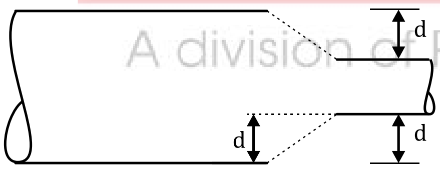
Side Cutting Edge Angle (C_s)

- It is the angle which prevents interference as the tool enters the work materials. (Normally 15°- 30°).
- Larger this angle, the greater the component of force tending to separate the work and the tool. (May include chatter).



$$F_x = F_t \sin(90° - C_s)$$
$$F_y = F_t \cos(90° - C_s)$$
$$F_y = F_t \sin C_s$$

- At its increased value it will have more of its length in action for a given depth of cut.



d = depth of cut

- As its increased value, it produces thinner and wider chip that will distribute the cutting tool (increase tool life).
- Zero SCEA is desirable when machining casting and forging with hard and scaly skins because of the least amount of tool edge should be exposed to the destructive action of the skin.

Lip Angle or Cutting Angle or Knife Angle or Wedge Angle:

- Lip angle depends on the rake and clearance angle provided on the tool and determine the strength of the cutting edge.
- A larger lip angle permits machining of harder metals, allow heavier depth of cut, increase tool life, better heat dissipation.

Nose Radius:

- It is the curvature of the tool tip.
- It strengthens the tool nose and provide better surface finish.

$$h = \frac{f^2}{8R}$$

- But too large a nose radius will induce chatter.
- If nose radius increased cutting force and cutting power increased.
- Tool life increases with increase of nose radius.

Tool Designation (ANSI) or ASA

$(\alpha_b - \alpha_s)$ ······ $(\gamma_e - \gamma_s)$ ······ $(c_e - c_s)$ ······ R

Rake — Relief — Cutting edge

To remember easily follow the rule

- Rake, relief, cutting edge.
- Side will come second.
- Finish with nose radius (inch)

Orthogonal Rake System (ORS)

$i - \alpha - \gamma - \gamma_1 - C_e - \lambda - R$

- Inclination angle:(i)- orth rake(α), - side relief (γ)- end relief (γ_1)- End cutting edge (C_e)- Approach (λ)- nose radius (R in mm).
- Approach angle $(\lambda) = 90° - C_s$
- (sometimes λ is called principal cutting edge angle (orthogonal cutting)].
- For orthogonal, cutting $i = 0$
- For oblique cutting, $i \neq 0$.

0- 5- 6- 7- 9- 15- 1(mm) [ASA]

↓

$\lambda = 0$

0- 5- 6- 7- 9- 75- 1(mm) [ORS]

↓

$i = 0$

Inter Conversion Between ASA and ORS

$\tan\alpha = \tan\alpha_s \sin\lambda + \tan\alpha_b \cos\lambda$

$\tan\alpha_b = \cos\lambda \tan\alpha + \sin\lambda \tan i$

$\tan\alpha_s = \sin\alpha \tan\alpha - \cos\lambda \tan i$

$\tan i = -\tan\alpha_s \cos\lambda + \tan\alpha_b \sin\lambda$

When $i = 0 \Rightarrow \tan\alpha_s \cos\lambda = \tan\alpha_b \sin\lambda$

Critical Correlations:

When $\lambda = 90°,\ \alpha_s = \alpha$

When $i = 0, \alpha_n = \alpha$

When $i = 0$ and $\lambda = 90°, \alpha_s = \alpha_n = \alpha$

[Pure Orthogonal cutting]

λ is principal cutting-edge angle.

i = inclination angle.

α_s = Side rake angle (ASA)

α = Orthogonal rake angle (ORS)

α_n = normal rake angle (NRS)

$$h = \frac{f}{\tan(C_s) + \cot(C_e)}$$

f → feed rate

Shear Angle (ϕ)

$$r = \frac{t}{t_c} = \frac{l_c}{l} = \frac{V_c}{V} = \frac{\sin\phi}{\cos(\phi - \alpha)} = \frac{1}{h}$$

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

where,

r = chip thickness ratio or cutting ratio; $r < 1$

$h = 1/r =$ inverse of chip ratio or chip reduction factor or chip compression ratio; $h > 1$.

Cutting Shear Strain(ε):

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

$$\varepsilon = \frac{\cos\alpha}{\sin\phi \cdot \cos(\phi - \alpha)}$$

If $\alpha = 0$

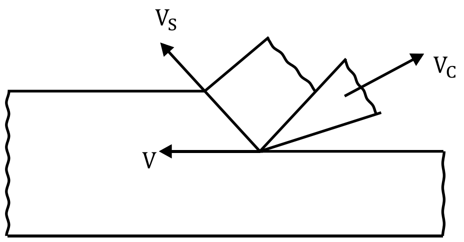
$$\varepsilon = \cot\phi + \tan\phi$$

$$= x + \frac{1}{x} \geq 2$$

If $\phi = 45°, \alpha = 0$

$\Rightarrow \varepsilon_{min} = 2$

Velocities in Metal Cutting:



- The velocity of the tool relative to the workpiece (V) is called the cutting speed.

- The velocity of the chip relative to the work, V_s is called the shear velocity.
- The velocity of the chip relative to the tool, V_c, is called chip velocity.

Expression for Velocities in Metal Cutting:

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

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

$$\frac{V_s}{V} = \frac{\cos\alpha}{\cos(\phi-\alpha)}$$

Shear Strain Rate:

(Note: It is not shear strain, it is rate of shear strain i.e., flow).

$$\varepsilon = \frac{d\varepsilon}{dt} = \frac{V_s}{\text{Thickness of shear zone } (t_s)}$$

Cause of Chip Formation

Yielding → in ductile material

↓

Shear yielding

Brittle fracture → in brittle material

Types of Chips:

1. Continuous chip
2. Discontinuous chip
3. Continuous chip with BUE
4. Serrated chip

- Conditions for forming discontinuous chip of irregular size and shape.
  - Work material brittle (such as grey cast iron)
- Conditions for forming discontinuous chips of regular size and shape.
  - Work material – ductile but hard and work hard enable.
  - Feed-large
  - Tool rake – negative
  - Cutting fluid – absent or inadequate
  - Cutting speed – low
- Conditions for forming continuous chip without BUE (Built up edge)
  - Work material – Ductile
  - Cutting velocity – high
  - Feed – low
  - Rake angle – Positive and high
  - Cutting fluid – both cooling and lubricating
- Conditions for forming continuous chip with BUE.
  - Work material – Ductile
  - Cutting velocity – Medium
  - Feed – medium
  - Cutting fluid – absent or inadequate

Effects of BUE formation:

- Harmful effects:
  - Poor surface finish
  - It unfavorably changes the rake angle at the tool tip causing an increase of cutting force i.e., power consumption.
  - Induce vibration.

- Good effect
  - BUE protects cutting edge of the tool i.e., increases tool life.

Reduction or Elimination of BUE:

- Increase

  ↑ cutting speed

  ↑ rake angle
- Reduce

  ↓ feed

  ↓ depth of cut
- Use

  Cutting fluid

  Change cutting tool materials (as Cermet's)

Serrated Chips:

- Serrated chips, also called segmented or non-homogeneous chips, are semi-continuous chips with zones of low and high shear strain.
- Metals with low thermal conductivity and strength that decreases sharply with temperature, such as titanium exhibit this behaviour, the chips have saw tooth like appearance.

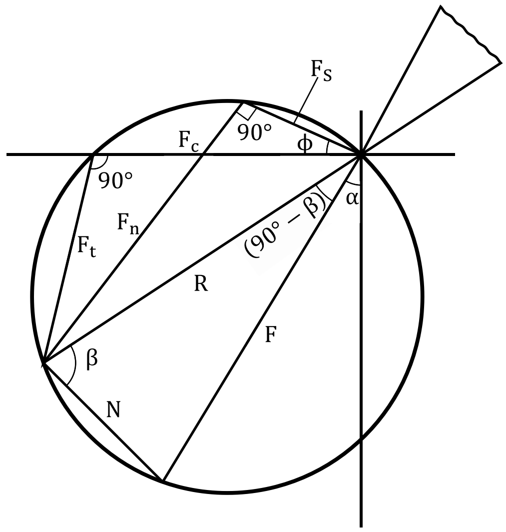
Force and Power in Metal Cutting:

Shear Force $(F_S) = \tau_s \cdot A_S = \tau_s = \dfrac{b\,t}{\sin\phi}$

Normal shear force $(F_n) = \sigma_s \cdot A_s = \sigma_s$

$$= \frac{b\,t}{\sin\phi}$$

Merchant's Circle Diagram:



For orthogonal cutting only.

$\tan\beta = \dfrac{F}{N} = \mu$

$\Rightarrow \beta = \tan^{-1}(\mu) =$ Friction angle

From Merchant's Analysis

$$\boxed{\phi = \frac{\pi}{4} + \frac{\alpha}{2} - \frac{\beta}{2}}$$

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

$F = R\sin\beta$

$N = R\sin\beta$

$F_n = R\sin(\phi + \beta - \alpha)$

$F_s = R\cos(\phi + \beta - \alpha) = \tau_s A_s = \tau_s \dfrac{b\,t}{\sin\phi}$

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

$F_t = R\sin(\beta - \alpha)$

Limitations of use of Merchant Circle Diagram (MCD)

1. MCD is valid only for orthogonal cutting.
2. By the ratio F/N, the MCD gives apparent (not actual) co-efficient of friction.

Force Relation:

Note: If F_c and F_t are known

No need to use merchant theory.

$F = F_c \sin\alpha + F_t \cos\alpha$

$N = F_c \cos\alpha - F_t \sin\alpha$

$F_n = F_c \sin\phi + F_t \cos\phi$

$F_s = F_c \cos\phi - F_t \sin\phi$

Metal Removal Rate (MRR)

$MRR = A_C . V = b\,t\,V = f\,d\,V$

$b = mm, t = mm, V = mm/min$

where,

A_c = cross-sections are of uncut chip (mm^2)

V =cutting speed = π D N, mm/min

D = mm, N = rpm

Power consumed during cutting.

$P = F_c \times V$

Where,

F_c = Cutting Force (in N)

V = Cutting speed = πDN/60, m/sec

Specific Energy of cutting (e), J/mm^3

$$e = \frac{Power}{MRR} = \frac{F_C \cdot V}{b\,t\,V}$$

TOOL MATERIALS:

Carbon steels (High carbon steels):

Composition: C = 0.8 to 1.3%, Si = 0.1 to 0.4%; Mn = 0.1 to 0.4%

High Speed Steel (HSS):

Composition of general HSS

18% tungsten-used to increase hot hardness and stability.

4% chromium – used to increase strength.

1% vanadium – used to maintain keenness of cutting edge.

Cast Non-Ferrous Tools (Stellite):

Cemented Carbides: It is produced by powder metallurgy technique with sintering at 1500°C. The two basic groups of carbides used for machining operations are tungsten carbide and titanium carbide.

Ceramics and Sintered Oxides: There are two principal families of ceramic cutting tool materials alumina base ceramic and silicon-nitride (Si N) base ceramic.

Diamond: Single crystal diamond and poly-crystalline diamond (Compacts)

Cubic Boron Nitride (CBN):

UCON: it is developed by union carbide in the USA. It consists of columbium 50%, titanium 30%, tungsten 20%.

Cutting Fluids:

Cutting fluids are sometimes called cutting oil or coolant or lubricant.

Purpose of Cutting Fluids:

- Reduce friction and wear, thus improving tools life and surface finish.
- Reduce forces and energy consumption.
- Cool the cutting zone, thus reducing workpiece temperature and distortion.
- Wash way the chips.

- Protect the newly machined surfaces from Environment corrosion.

Types of Cutting Fluid:

a. Water

b. Oils

1. Soluble oil: it contains 80% water, soap, and mineral oil. Soap helps as an emulsifying agent.
2. Straight oil: it contains mineral oils, kerosene, and low viscosity petroleum products.
3. Mixed oil: it is a combination of straight mineral and fatty oil.

Emulsion, Semi-synthetics, and Synthetics.

Tool Life:

It can be defined as the time a newly sharpened tool will cut satisfactorily before it becomes necessary to remove it and regrind or replace it.

Other criteria one sometimes used to evaluate tool life:

a. Change in the quality of the machine surfaces.

b. Change in the magnitude of the cutting force resulting changes in machine and workpiece dimensions to change.

c. Change in the cutting temperature.

The selection of the current cutting speed has an important bearing of the economics of all metal-cutting operations. To measure the tool life the **Taylor Tool Life Relationship** is used.

$VT^n = C$

Where V = Cutting speed, m/sec

T = Tool life, min (it is the time that it takes to develop a certain flank wear land).

C = a constant equal to the intercept of the curve and the ordinate or the cutting speed. Actually, it is the cutting speed for a tool life of one minute.

n = Slope of the curve $n = \tan\theta$

$$= \frac{\log V_1 - \log V_2}{\log T_2 - \log T_1}$$

values of n and C differ depending on the work and tool materials.

Cutting speed is the most significant process variable in tool life; however, depth of cut and feed rate are also important thus, tool life relation can be modified as follows:

$VT^n d^x f^y = C$

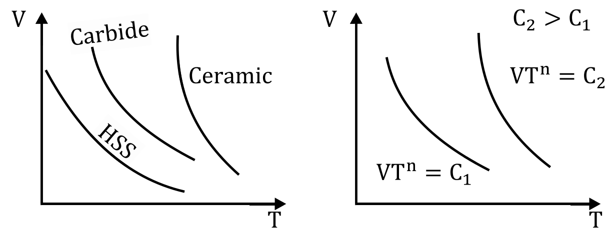
Where d is the depth of cut, f is the feed rate (mm/rev).

Variables Affecting Tool Life:

- Process variables - Tool material – Tool geometry
- Workpiece material - Cutting fluid.

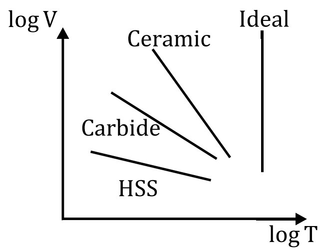
Tool Life Equation

$VT^n = C$

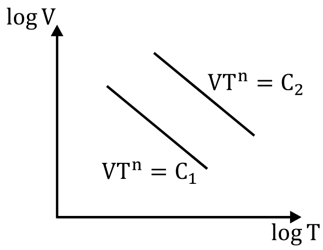


$VT^n = C$

$\Rightarrow \log V + n \log T = \log C$



If same material



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