Metal Cutting and Machine Tools

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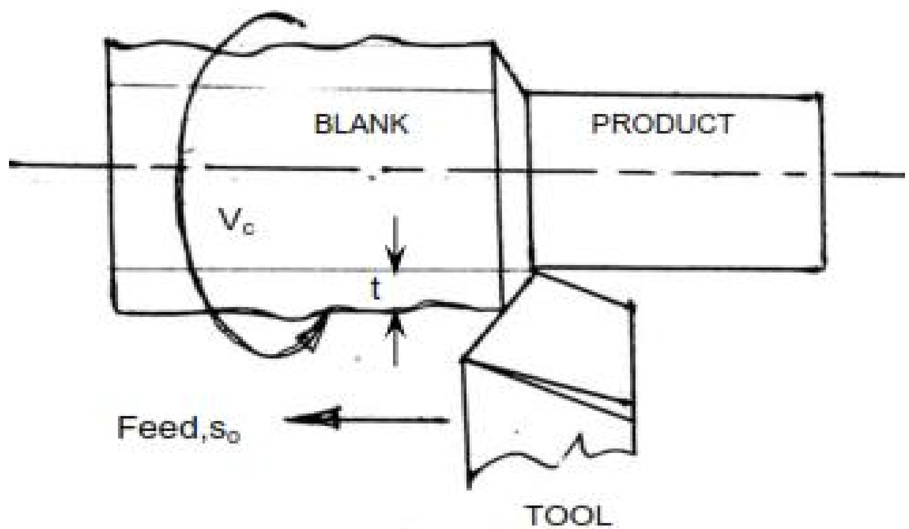
Introduction

- ✓ A family of shaping operations, the common feature of which is removal of material from a starting workpart so the remaining part has the desired shape
- ✓ Categories:
  - Machining – material removal by a sharp cutting tool, e.g., turning, milling, drilling
  - Abrasive processes – material removal by hard, abrasive particles, e.g., grinding
  - Nontraditional processes - various energy forms other than sharp cutting tool to remove material

Need of metal cutting

- ✓ Most of the engineering components such as gears, bearings, clutches, tools, screws and nuts etc. need dimensional accuracy and good surface finish for serving their purposes.
- ✓ Performing like casting, forging etc. generally cannot provide the desired accuracy and finish.
- ✓ For that such preformed parts, called blanks, need semi-finishing and finishing and it is done by machining (metal cutting).

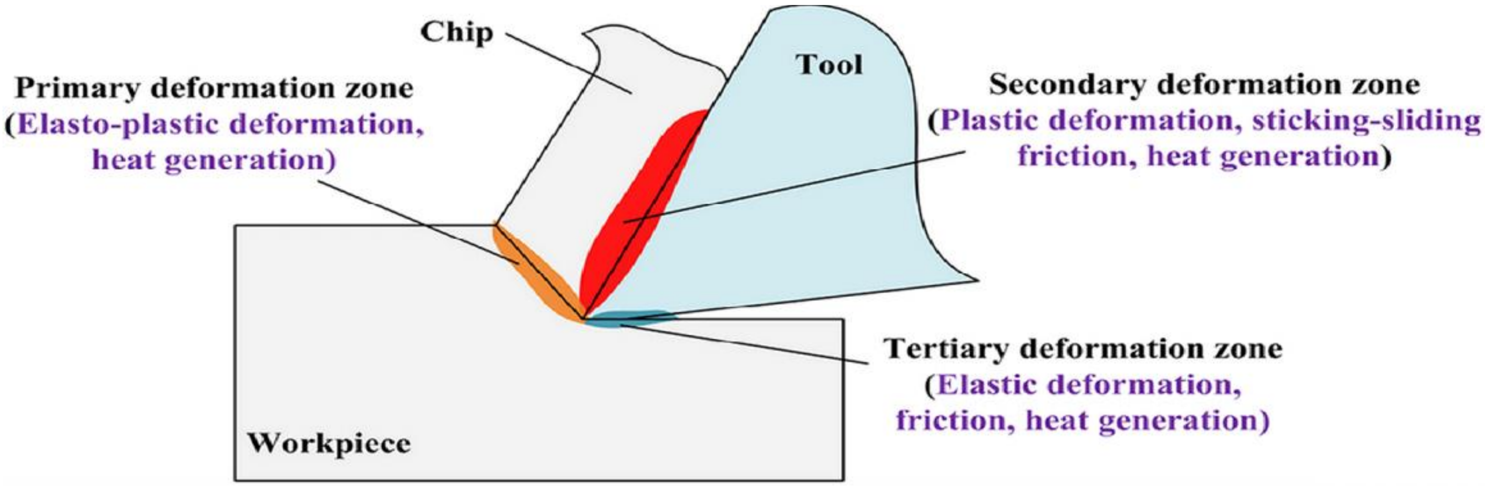
Principle



✓ A metal of irregular shape, size and surface is converted into a finished metal of desired dimension and surface by machining through proper relative motions of the tool-work pair.

Mechanics of metal cutting

- ✓ During metal cutting, the metal is severely compressed in the area in front of cutting tool.
- ✓ This causes high temp., shear and plastic flow, if the metal is ductile.



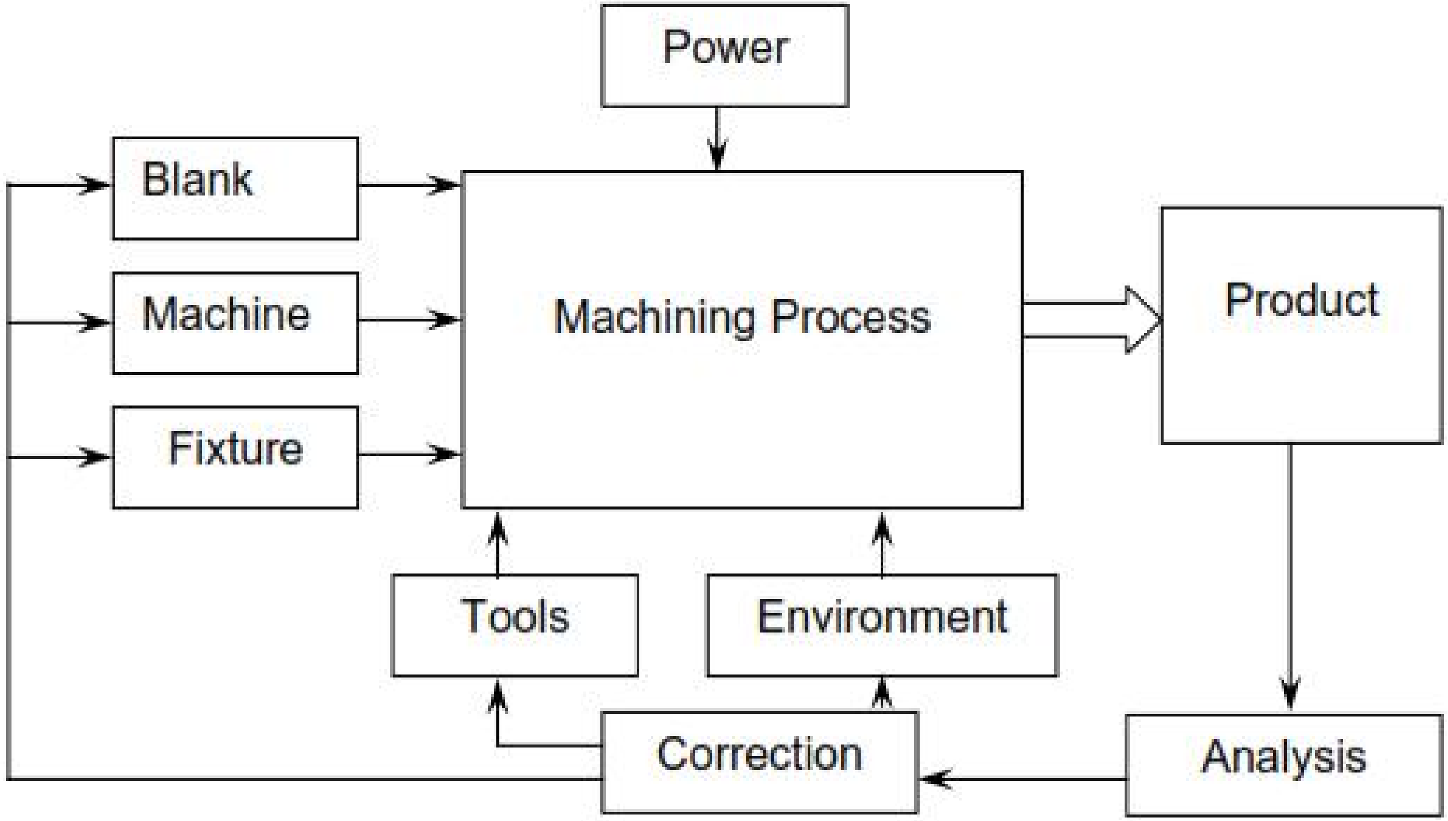
Mechanics - contd.,

- ✓ Value exceeding the ultimate strength of metal, piece will shear to form a chip.
- ✓ Process is repetitive - continuous chip is formed.

Definition of machining

- ✓ Machining is an essential process of finishing by which jobs are produced to the desired dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting tool(s) moved past the work surface(s).

Requirements of machining



Classification of machining

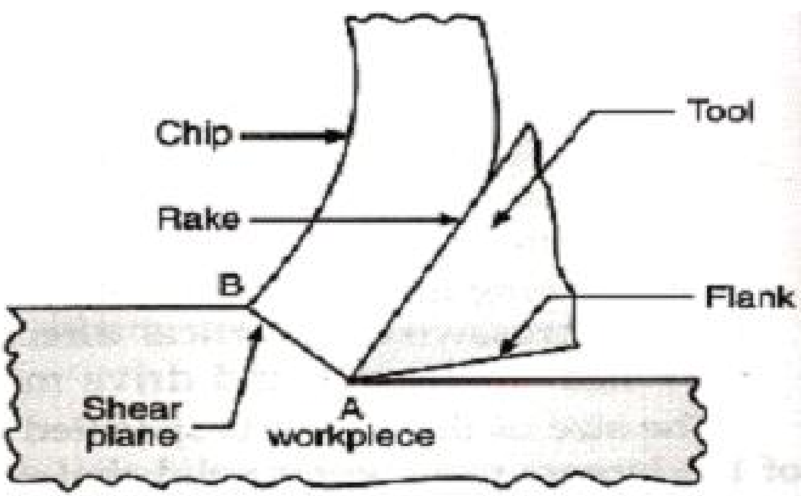
Machining processes

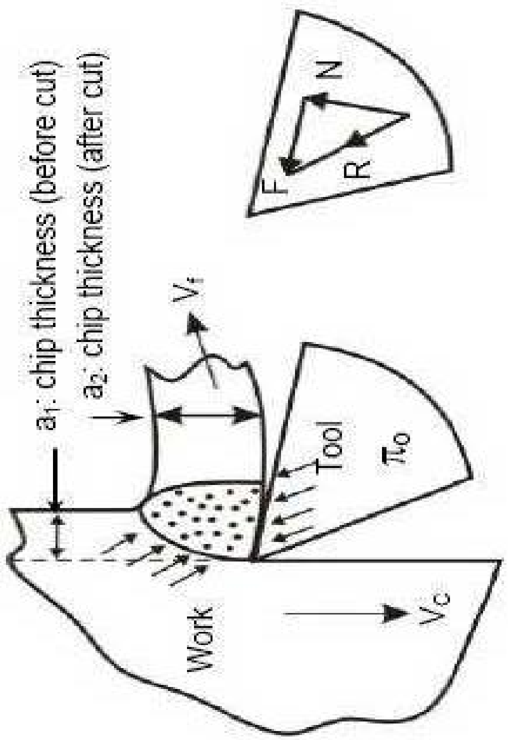
- **Single-point tool operations**
  1. Turning
  2. Boring
  3. Shaping
  4. Planing
- **Multi-point tool operations**
  1. Milling
  2. Drilling
  3. Tapping
  4. Reaming
  5. Hobbing
  6. Broaching
  7. Sawing
- **Abrasive operations**
  1. Grinding
  2. Lapping
  3. Honing
  4. Super-finishing

Theory of Metal Cutting

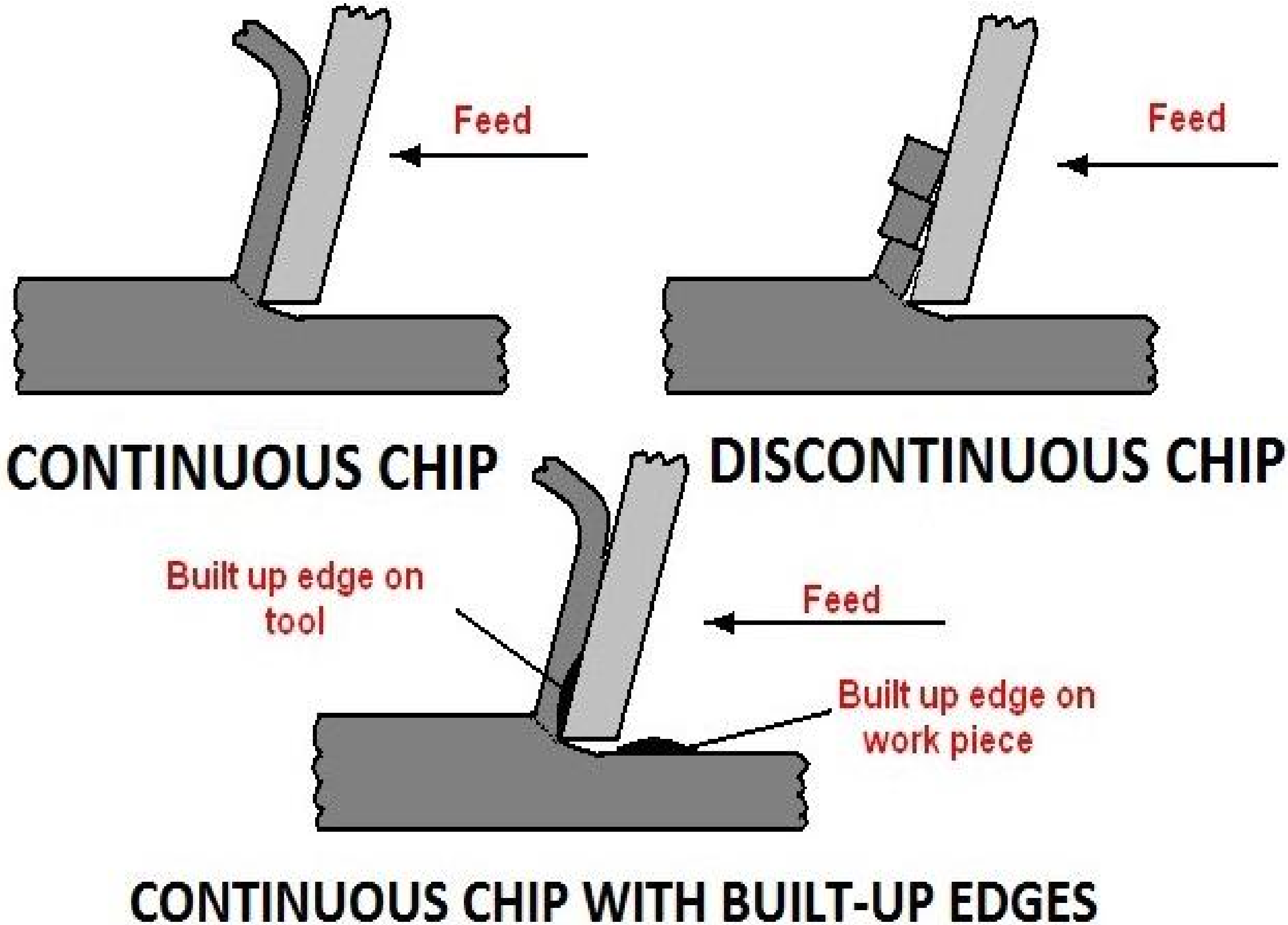
Mechanism of chip formation

- ✓ To get required stipulated dimensional accuracy and surface finish, machining is done by gradual removal of excess material from the preformed blanks in the form of chips

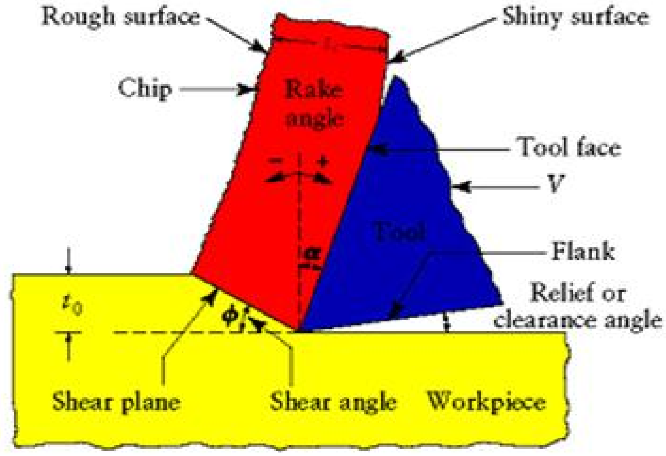


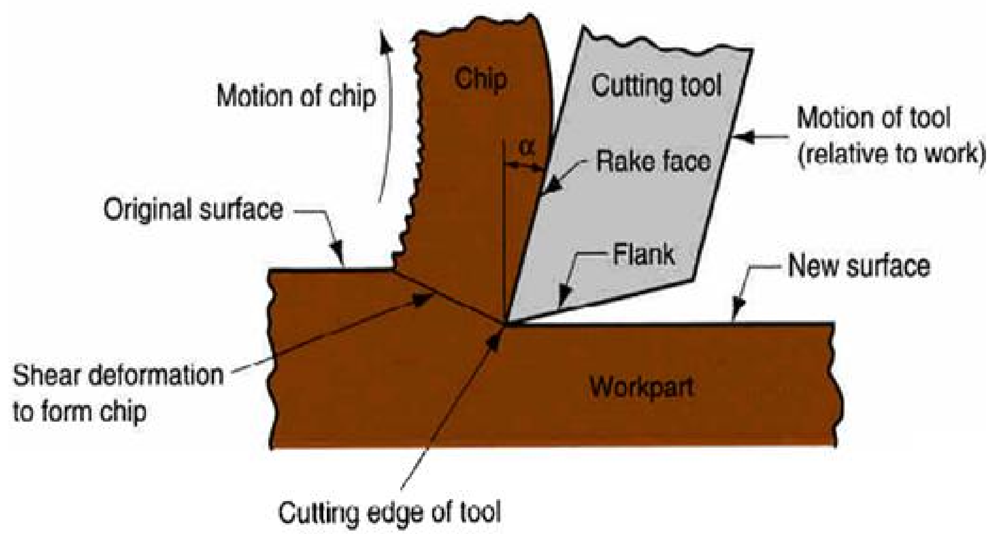


TYPES OF CHIP



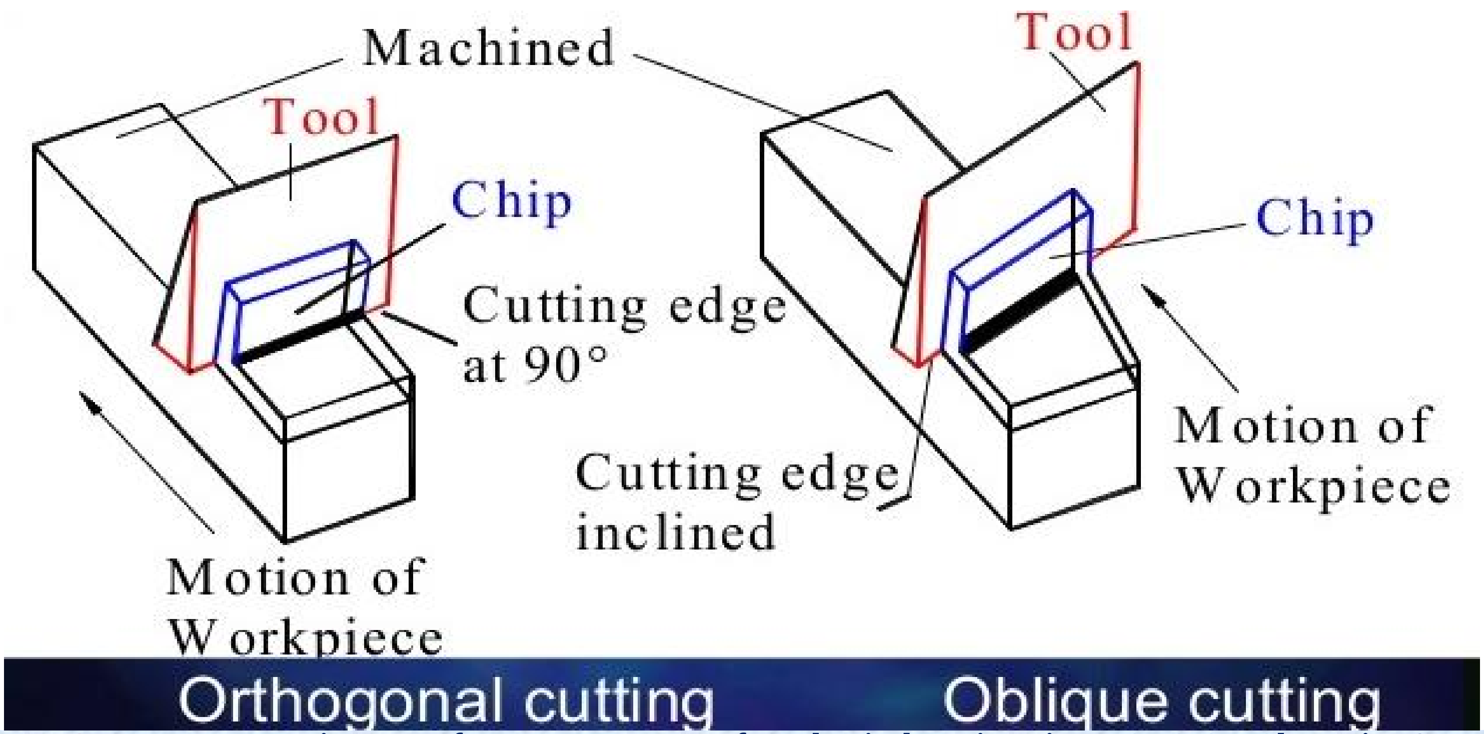
Metal cutting terminologies





Types of Cutting

- ✓ Orthogonal cutting
- ✓ Oblique cutting

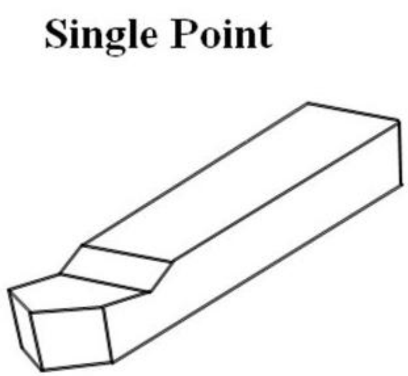


Difference b/w Orthogonal and Oblique cutting

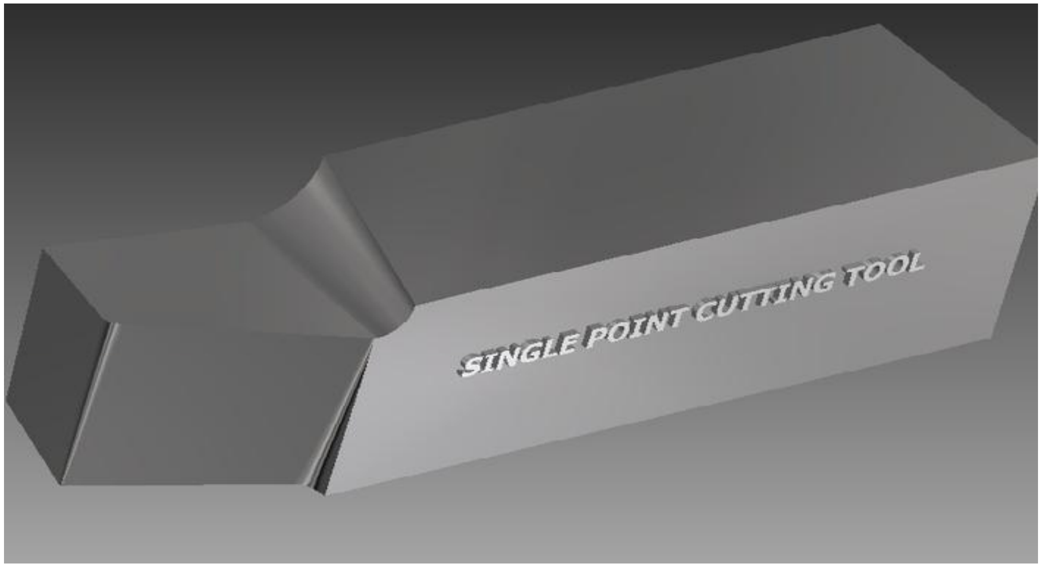
- ✓ **Orthogonal cutting**
  - Cutting edge of the tool is perpendicular to the direction of cutting velocity
  - Cutting edge is wider than the work piece width – plain strain condition
  - flow is confined to the x-z plane
  - Chip flows on the rake face with velocity perpendicular to the cutting edge
  - Cutting forces act along X and Z directions only
- ✓ **Oblique cutting**
  - Cutting edge of the tool is inclined at an angle *i* with normal to the cutting velocity
  - Chip flows on the rake face at an angle equal to *i*
  - Cutting edge extends beyond the width of work piece
  - Cutting forces act along all directions

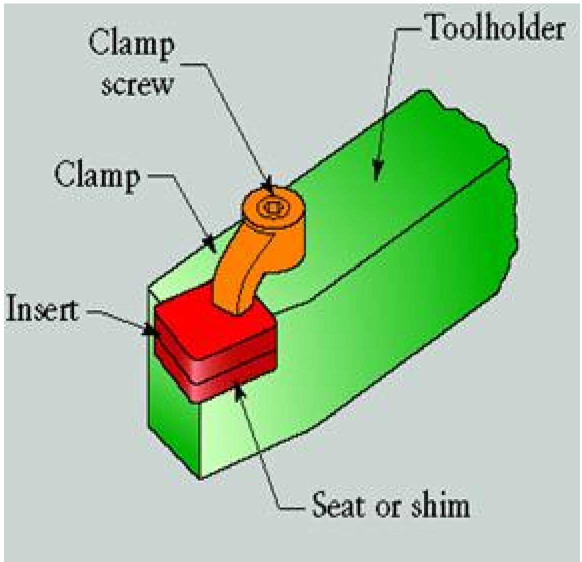
Cutting Tool

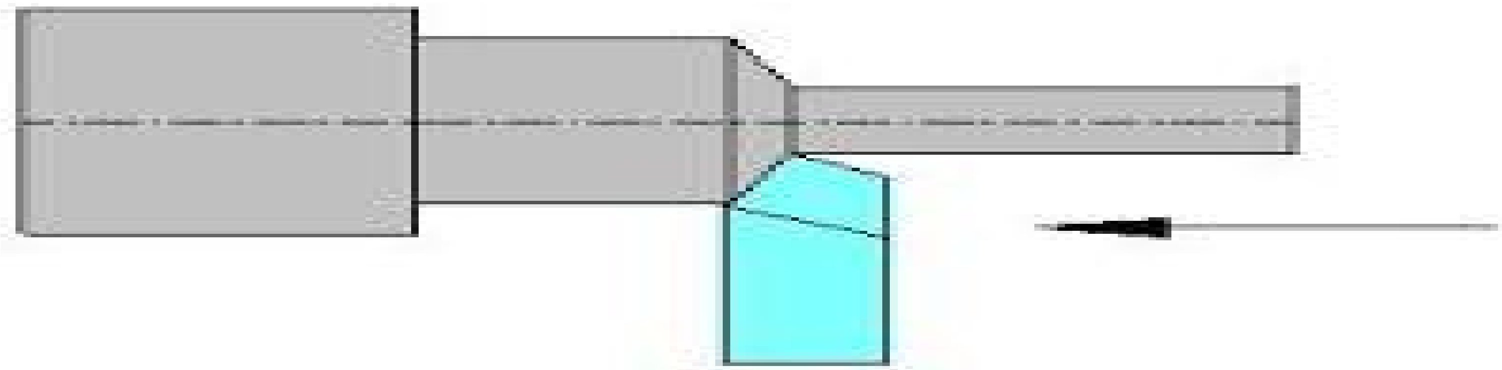
- ✓ It is one of most important components in machining process
- ✓ It must be made of a material harder than the material which is to be cut, and the tool must be able to withstand the heat generated in the metal cutting process.
- ✓ Classifications:
  - Single point
  - Two point
  - Multi point



Single Point Cutting Tool

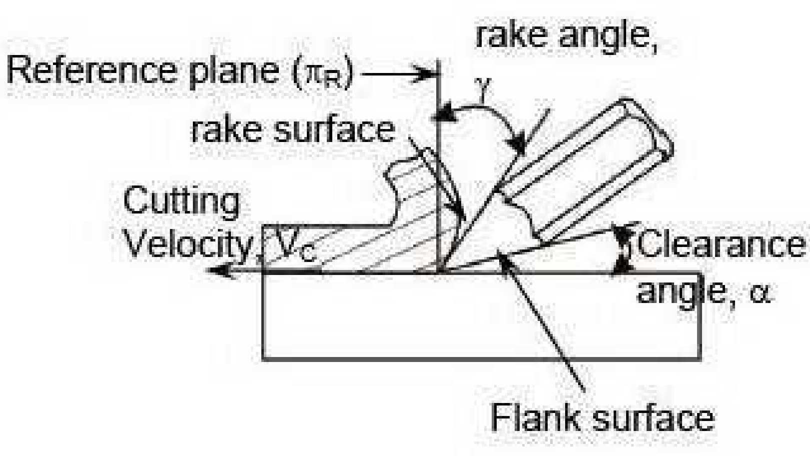


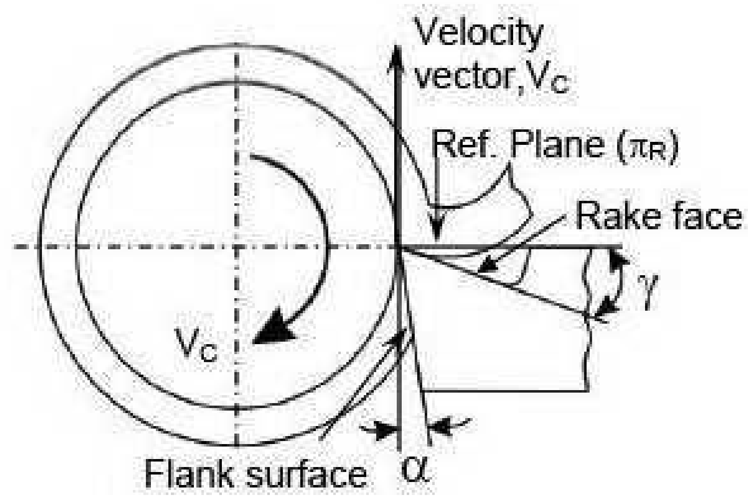




Influencing parameters

- ✓ Both material and geometry of the cutting tools play very important roles on their performances in achieving effectiveness, efficiency and overall economy of machining.





Nomenclature

- **Shank:** Main body of tool, it is part of tool which is gripped in tool holder
- **Face:** Top surface of tool b/w shank and point of tool. Chips flow along this surface
- **Flank:** Portion tool which faces the work. It is surface adjacent to below the cutting edge when tool lies in a horizontal position.
- **Point:** Wedge shaped portion where face & flank of tool meet
- **Base:** Bearing surface of tool on which it is held in a tool holder.
- **Nose radius:** Cutting tip, which carries a sharp cutting point. Nose provided with radius to enable greater strength, increase tool life & surface life.

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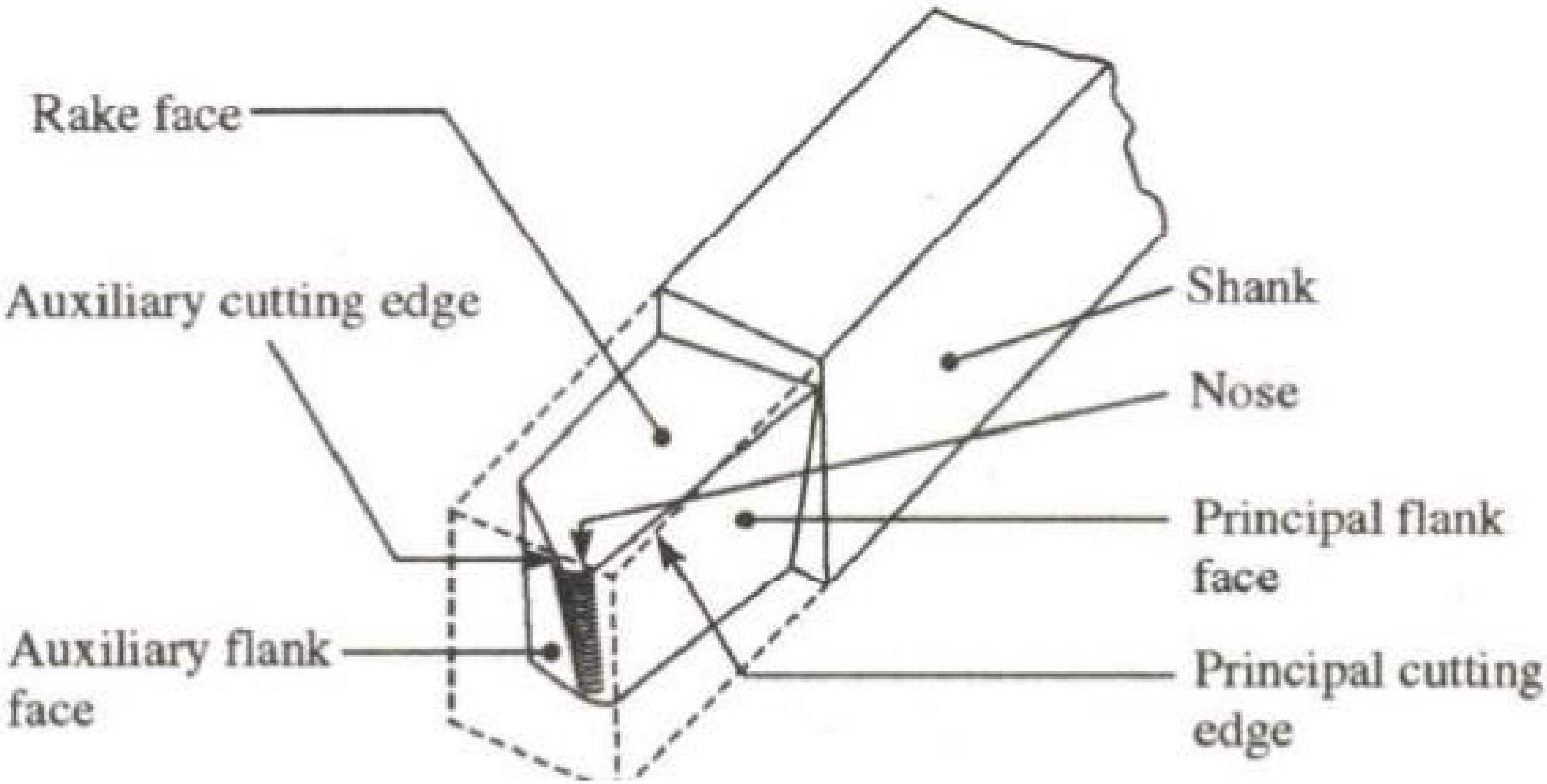
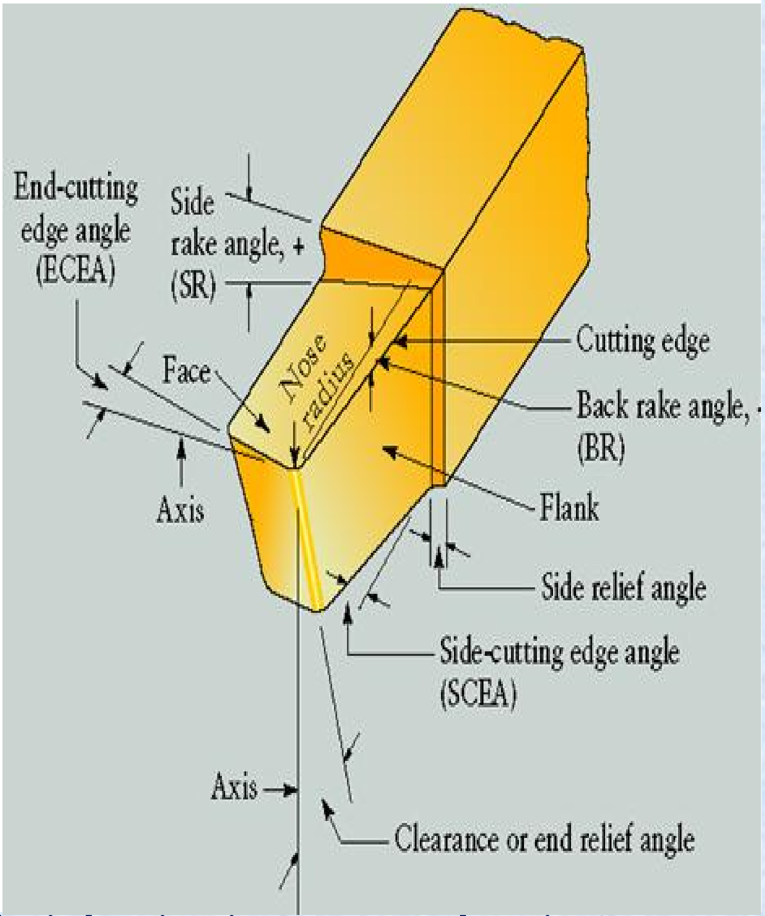


Rake face
Auxiliary cutting edge
Auxiliary flank face
Shank
Nose
Principal flank face
Principal cutting edge

Tool Geometry

✓ The most significant terms in the geometry of a cutting tool angles are:

- Relief or clearance angle
  - Side relief
  - End relief
- Rake angle
  - Back Rake angle
  - Side Rake angle
- Cutting edge angle
  - Side Cutting edge angle
  - End Cutting edge angle
- Nose Radius



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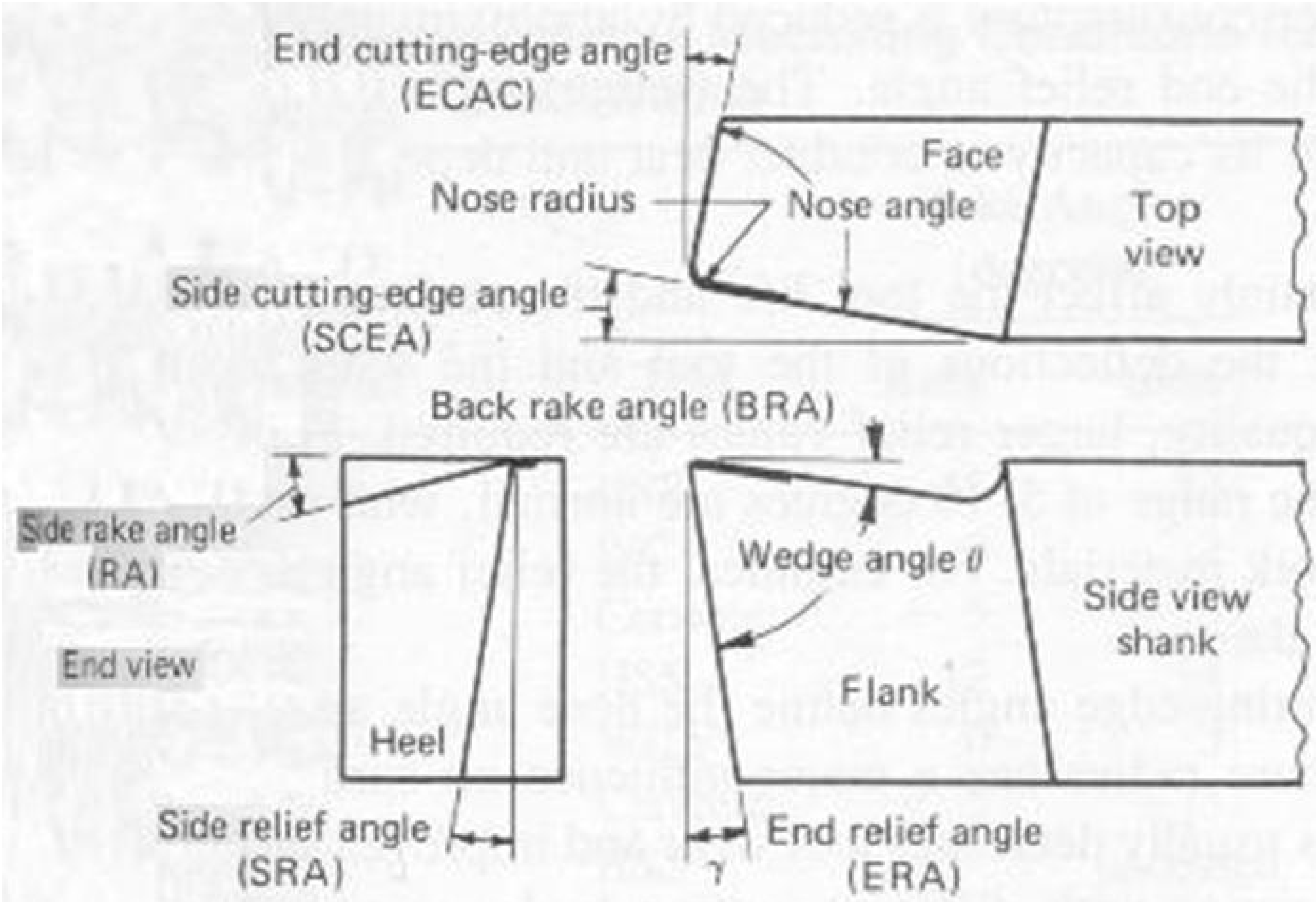
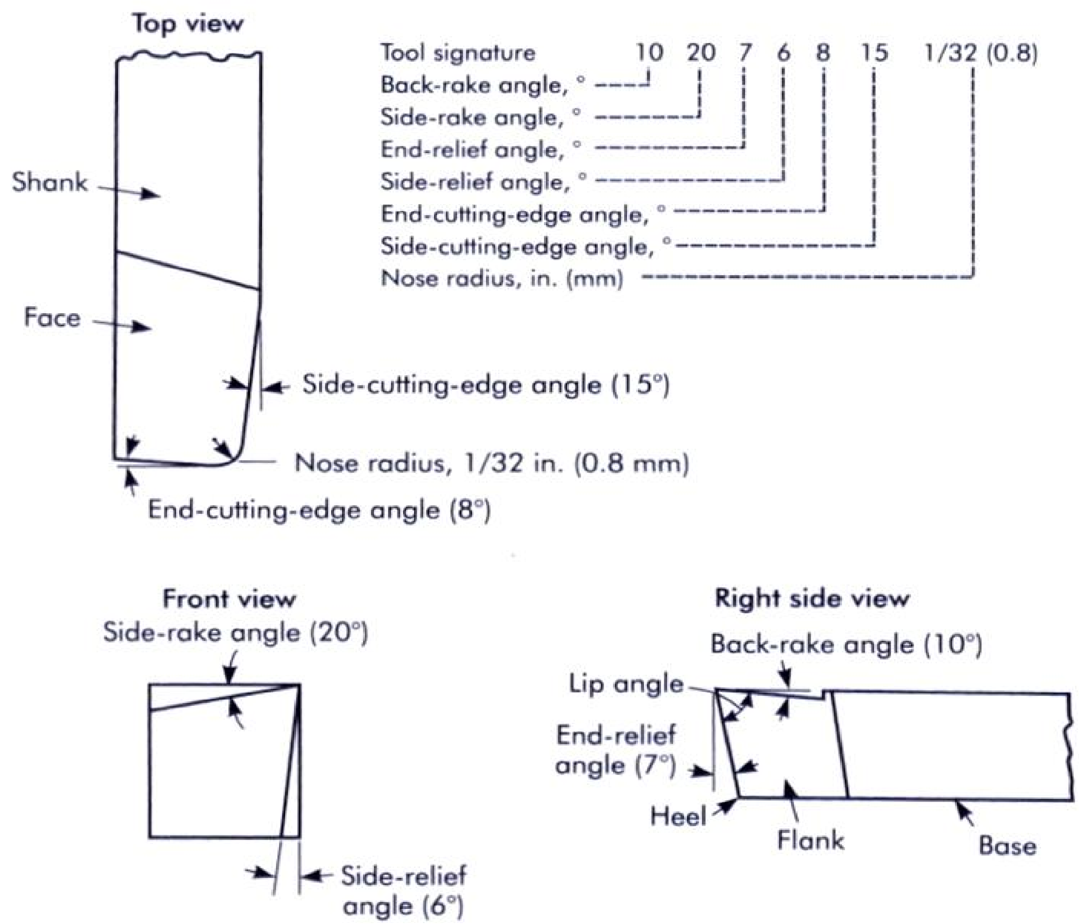

End cutting-edge angle
(ECAC)
Face
Nose radius
Nose angle
Top
view
Side cutting-edge angle
(SCEA)
Back rake angle (BRA)
Side rake angle
(RA)
Wedge angle θ
Side view
shank
End view
Flank
Heel
Side relief angle
(SRA)
End relief angle
(ERA)
γ

Tool Signature

- ✓ **The various angles of tools are mentioned in A numerical number in particular order. That order is known as tool signature**

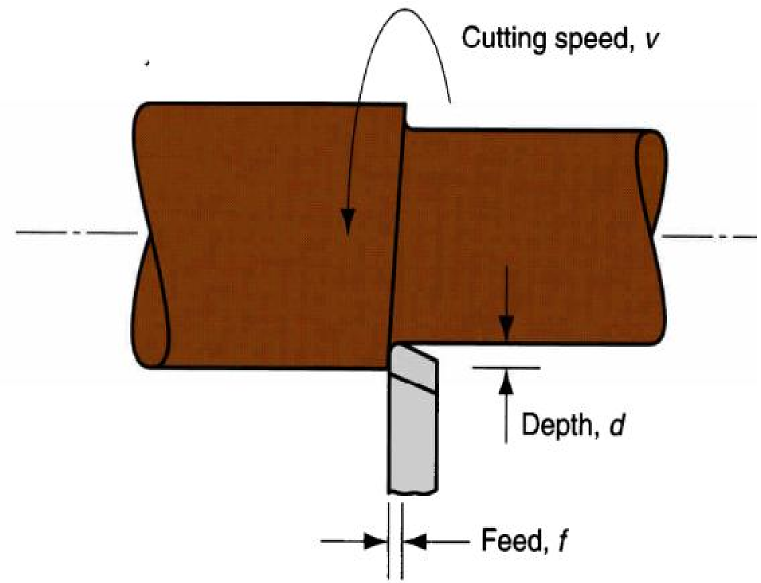


Cutting Conditions in Machining

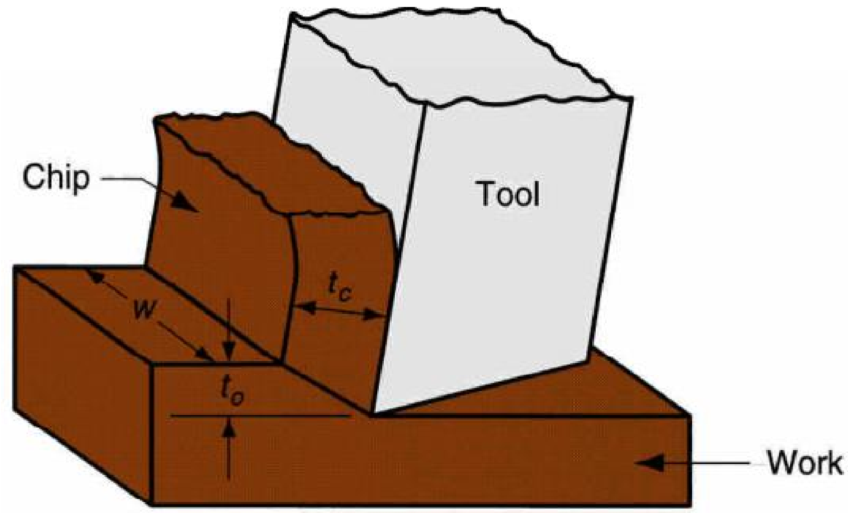
- ✓ The three dimensions of a machining process
  - Cutting speed (v) – primary motion
  - Feed (f) – secondary motion
  - Depth of cut (d) – penetration of tool below original work surface
- ✓ For certain operations, material removal rate can be found as

$$MRR = v\,f\,d$$

  - Where, v = cutting speed; f = feed; d = depth of cut



Chip thickness ratio



✓ $r = t_o/t_c$

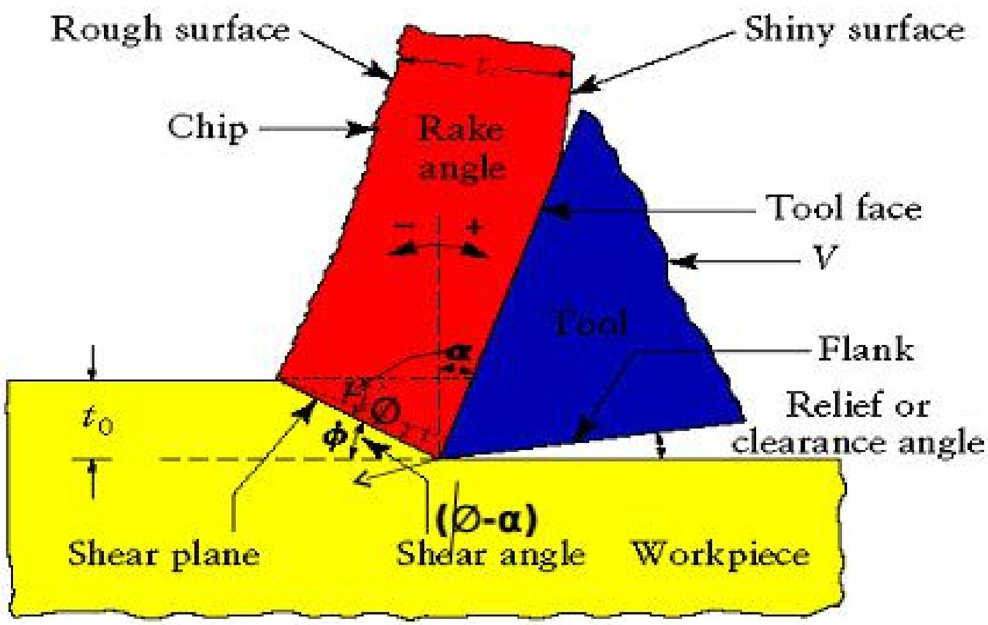
- where r = chip thickness ratio; to = thickness of the chip prior to chip formation; and tc = chip thickness after separation
- Chip thickness after cut is always greater than before, so chip ratio is always less than 1.0

Contd.,

$$r = \frac{t_o}{t_c} = \frac{l_s \sin\phi}{l_s \cos(\phi - \alpha)}$$

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

$$r = \frac{1}{r_c} = \frac{t_o}{t_c} = \frac{\sin\phi}{\cos(\phi - \alpha)}$$



Rearranging:

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

Power Requirement

The Power consumed/ work done per sec *in cutting*: $P_C = F_C \times v_C$

The Power consumed/ work done per sec *in shear*: $P_s = F_s \times v_s$

The Power consumed/ work done per sec *in friction*: $P_F = F \times v_f$

The total Power required*:*

$$\text{P} = \text{Power supplied by the motor}$$

$$\Rightarrow \text{P} = \text{Work consumed in cutting per sec} + \text{work spent in feeding per sec}$$

$$\Rightarrow \text{P} = \text{F}_c \times v_c + F_t \times \textit{feed velocity}$$

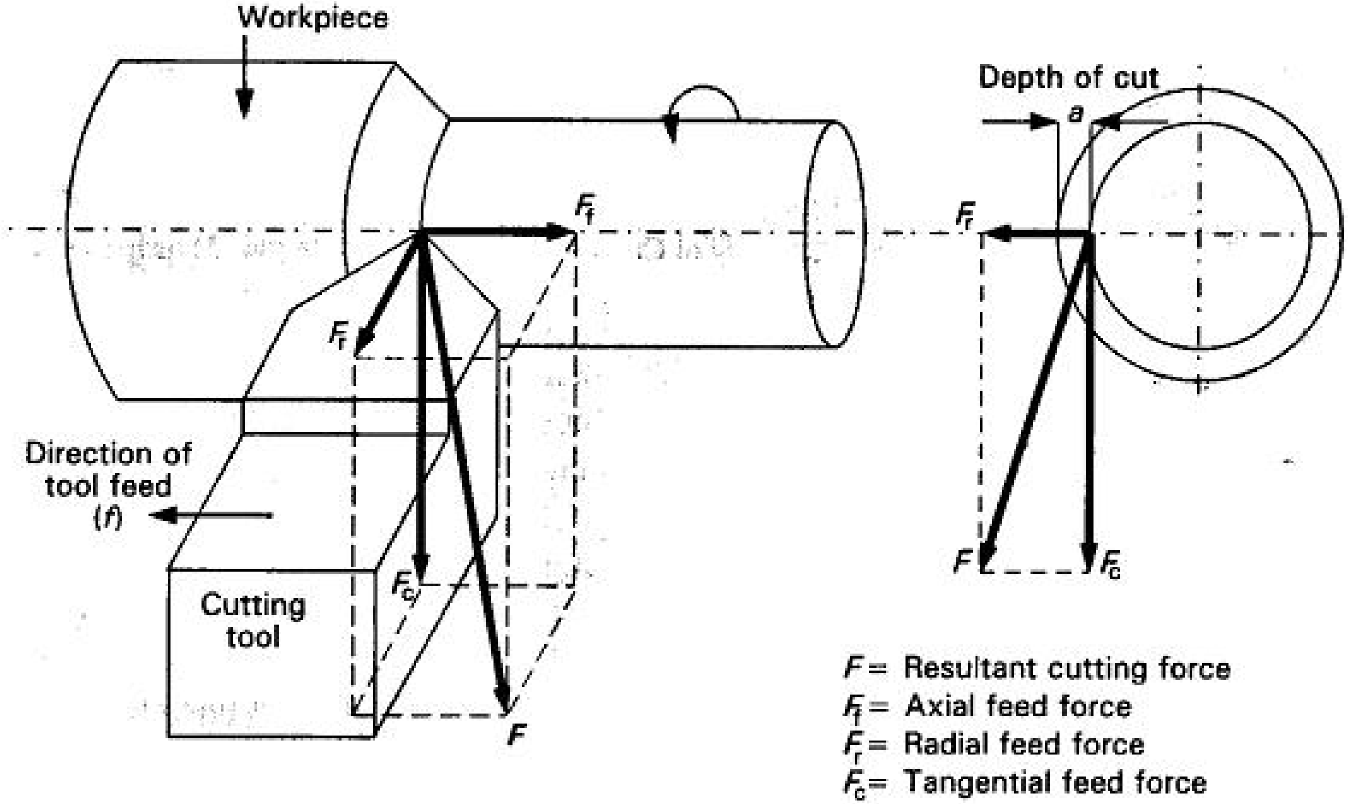
In comparison to the cutting velocity the feed velocity is very nominal. Similarly Fc is very small compared to Fc. So the work spent in feeding can be considered negligible.

Therefore, total power required in cutting $P = P_c = P_s + P_f$

Cutting Forces

Active Forces

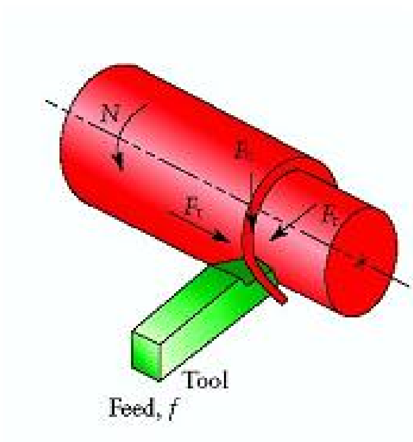
The force system in general case of conventional turning process

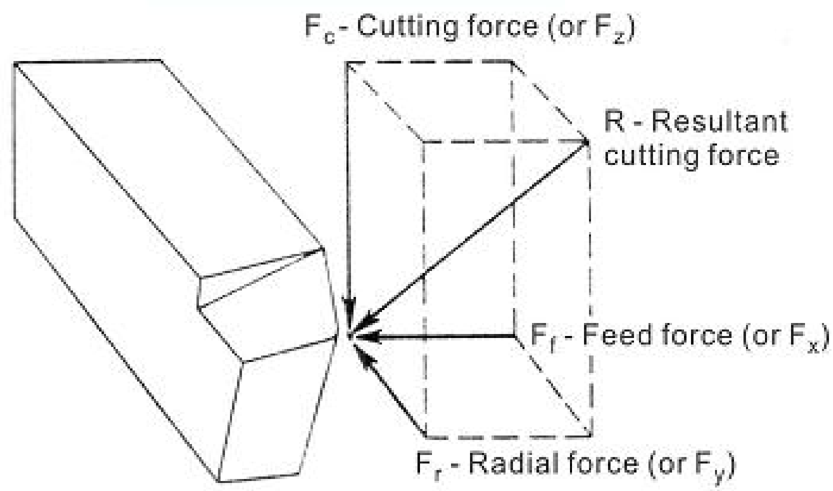


Contd.,

The largest magnitude is the vertical force F_c which in turning is larger than feed force F_f, and F_f is larger than radial force F_r.

For orthogonal cutting system F_r is made zero by placing the face of cutting tool at 90 degree to the line of action of the tool.





$$\overline{R} = \overline{F_x} + \overline{F_y} + \overline{F_z}$$
$$= \overline{F_c} + \overline{F_f} + \overline{F_r}$$

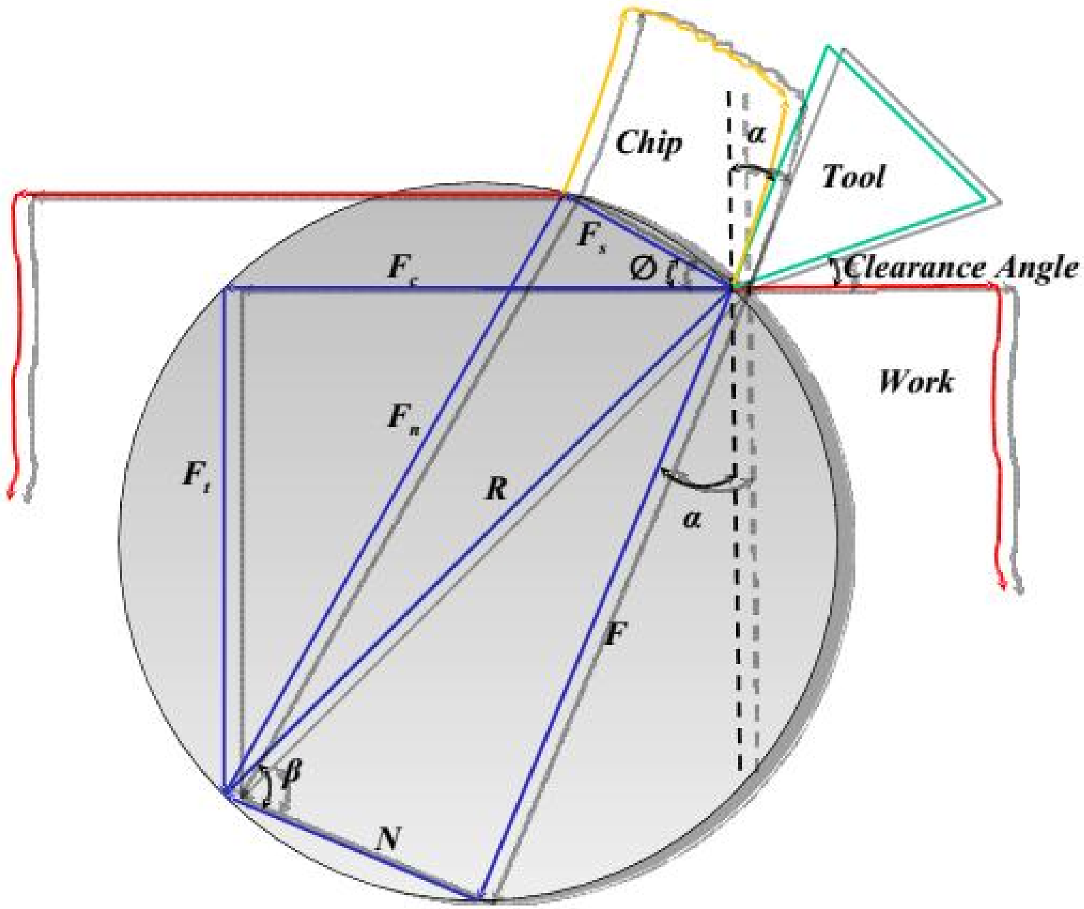
Tangential Force (Cutting Force), Feed Force, Radial Force

In orthogonal cutting

$$\overline{R} = \overline{F_c} + \overline{F_t}$$

Thrust Force

Merchant's Circle Diagram



Procedure to construct a MCD

- Set up x-y axis labeled with forces, and the origin in the centre of the page. The cutting force (Fc) is drawn horizontally, and the tangential force (Ft) is drawn vertically. (Draw in the resultant (R) of Fc and Ft.
- Locate the centre of R, and draw a circle that encloses vector R. If done correctly, the heads and tails of all 3 vectors will lie on this circle.
- Draw in the cutting tool in the upper right hand quadrant, taking care to draw the correct rake angle (α) from the vertical axis.
- Extend the line that is the cutting face of the tool (at the same rake angle) through the circle. This now gives the friction vector (F).
- A line can now be drawn from the head of the friction vector, to the head of the resultant vector (R). This gives the normal vector (N). Also add a friction angle (**β**) between vectors R and N. Therefore, mathematically, R = Fc + Ft = F + N.
- Draw a feed thickness line parallel to the horizontal axis. Next draw a chip thickness line parallel to the tool cutting face.
- Draw a vector from the origin (tool point) towards the intersection of the two chip lines, stopping at the circle. The result will be a shear force vector (Fs). Also measure the shear force angle between Fs and Fc.
- Finally add the shear force normal (Fn) from the head of Fs to the head of R.
- Use a scale and protractor to measure off all distances (forces) and angles.