MOHAMED SATHAK A J COLLEGE OF ENGINEERING

MANUFACTURING TECHNOLOGY II

UNIT – I

THEORY OF METAL CUTTING

Manufacturing Technology

Broad classification of Engineering Manufacturing Processes.

- It is extremely difficult to tell the exact number of various manufacturing processes existing and are being practiced presently because very large number of processes have been developed till now and the number is still increasing exponentially with the growing demands and rapid progress in science and technology.
- However, all such manufacturing processes can be broadly classified in four major groups as follows

Shaping or forming

- Manufacturing a solid product of definite size and shape from a given material taken in three possible states:
  - in liquid or semi-liquid state – e.g., casting, injection moulding etc.
  - in solid state – e.g., forging rolling, extrusion, drawing etc.
  - in powder form – e.g., powder metallurgical process.

Manufacturing Technology

Joining process

- Welding, brazing, soldering etc.

Removal or Cutting process

- Machining (Traditional or Non-traditional), Grinding etc.

Regenerative manufacturing Process

- Production of solid products in layer by layer from raw materials in different form:
  - liquid – e.g., stereo lithography
  - powder – e.g., selective sintering
  - sheet – e.g., LOM (laminated object manufacturing)
  - wire – e.g., FDM. (Fused Deposition Modeling)

Out of the fore said groups, Regenerative Manufacturing is the latest one which is generally accomplished very rapidly and quite accurately using CAD and CAM for Rapid Prototyping and Tooling.

Manufacturing Technology

Material Removal Processes – Metal Cutting Process

- A family of shaping operations, the common feature of which is removal of material from a starting work part so the remaining part has the desired geometry
- Traditional Process (Machining) – Material removal by a sharp cutting tool, e.g., turning, milling, drilling
- Nontraditional processes - Various energy forms other than sharp cutting tool to remove material. e.g., Laser and Electron Beam machining
- Abrasive processes – Material removal by hard, abrasive particles, e.g., grinding

Manufacturing Technology

Why Machining is Important

- Variety of work materials can be machined
  - Most frequently used to cut metals
- Variety of part shapes and special geometric features possible, such as:
  - Screw threads
  - Accurate round holes
  - Very straight edges and surfaces
- Good dimensional accuracy and surface finish

Manufacturing Technology

Disadvantages with Machining

- Wasteful of material
  - Chips generated in machining are wasted material, at least in the unit operation
- Time consuming
  - A machining operation generally takes more time to shape a given part than alternative shaping processes, such as casting, powder metallurgy, or forming

Machining in Manufacturing Sequence

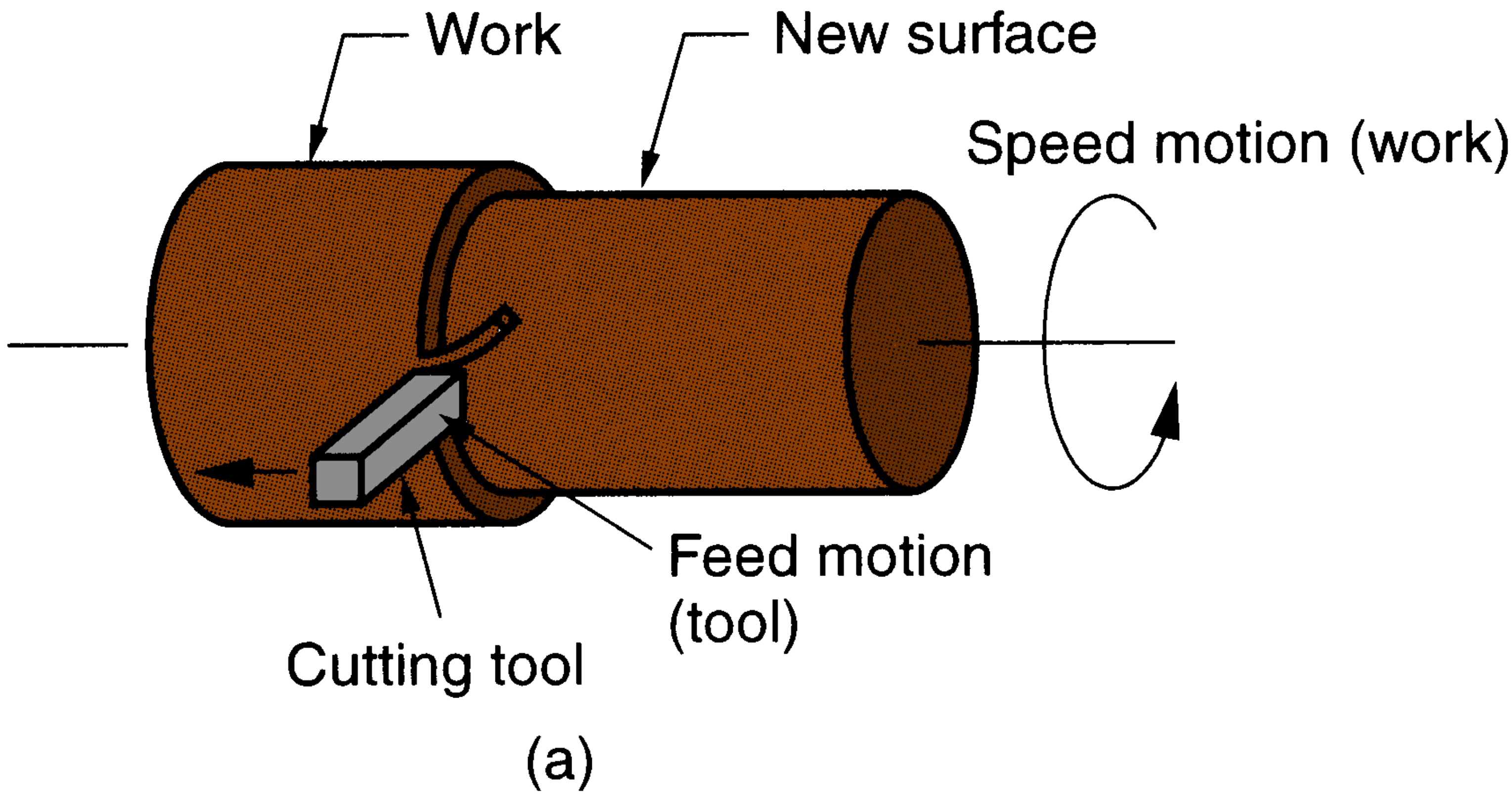
- Generally performed after other manufacturing processes, such as casting, forging, and bar drawing
  - Other processes create the general shape of the starting work part
  - Machining provides the final shape, dimensions, finish, and special geometric details that other processes cannot create

Manufacturing Technology

Machining Operations

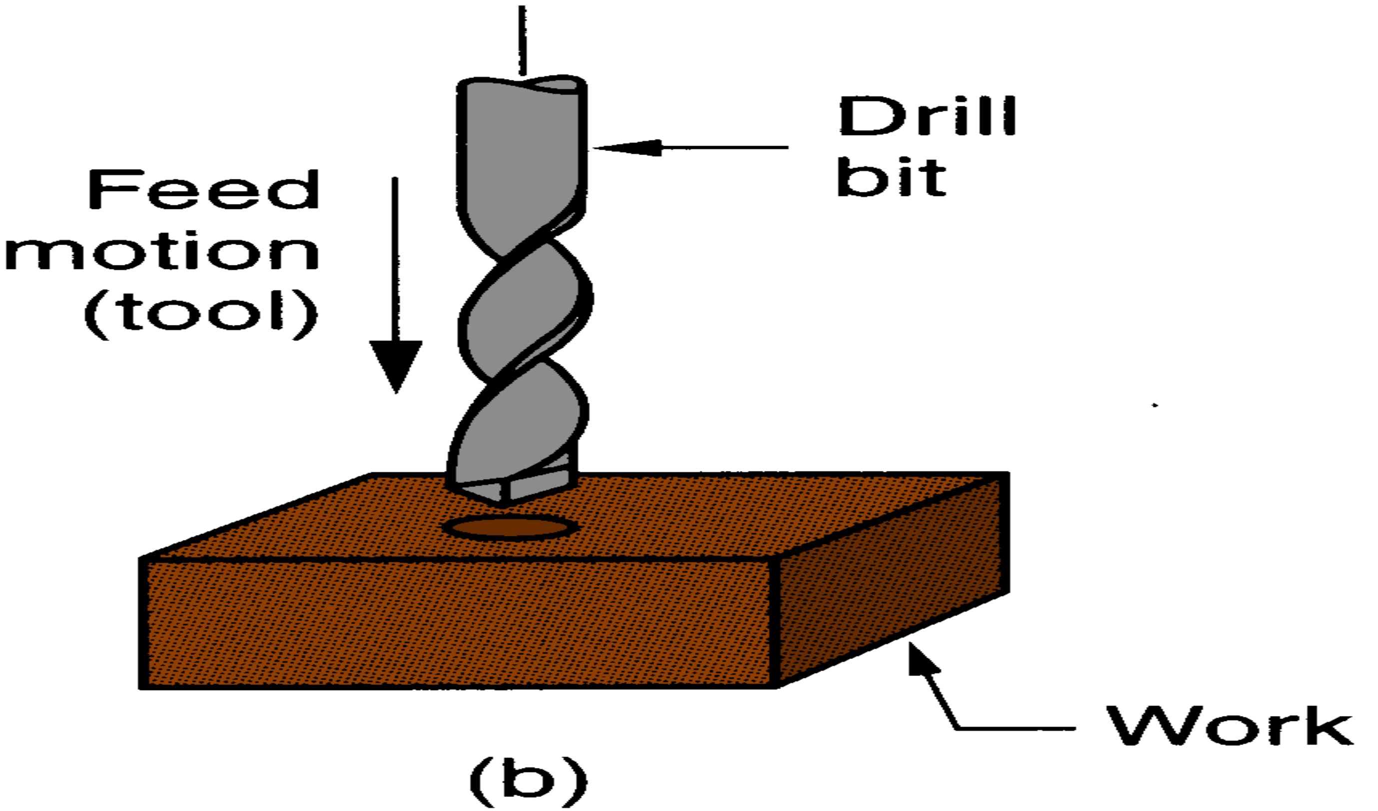
- Most important machining operations
  - Turning
  - Drilling
  - Milling
- Other machining operations
  - Shaping and planing
  - Broaching
  - Sawing

Turning



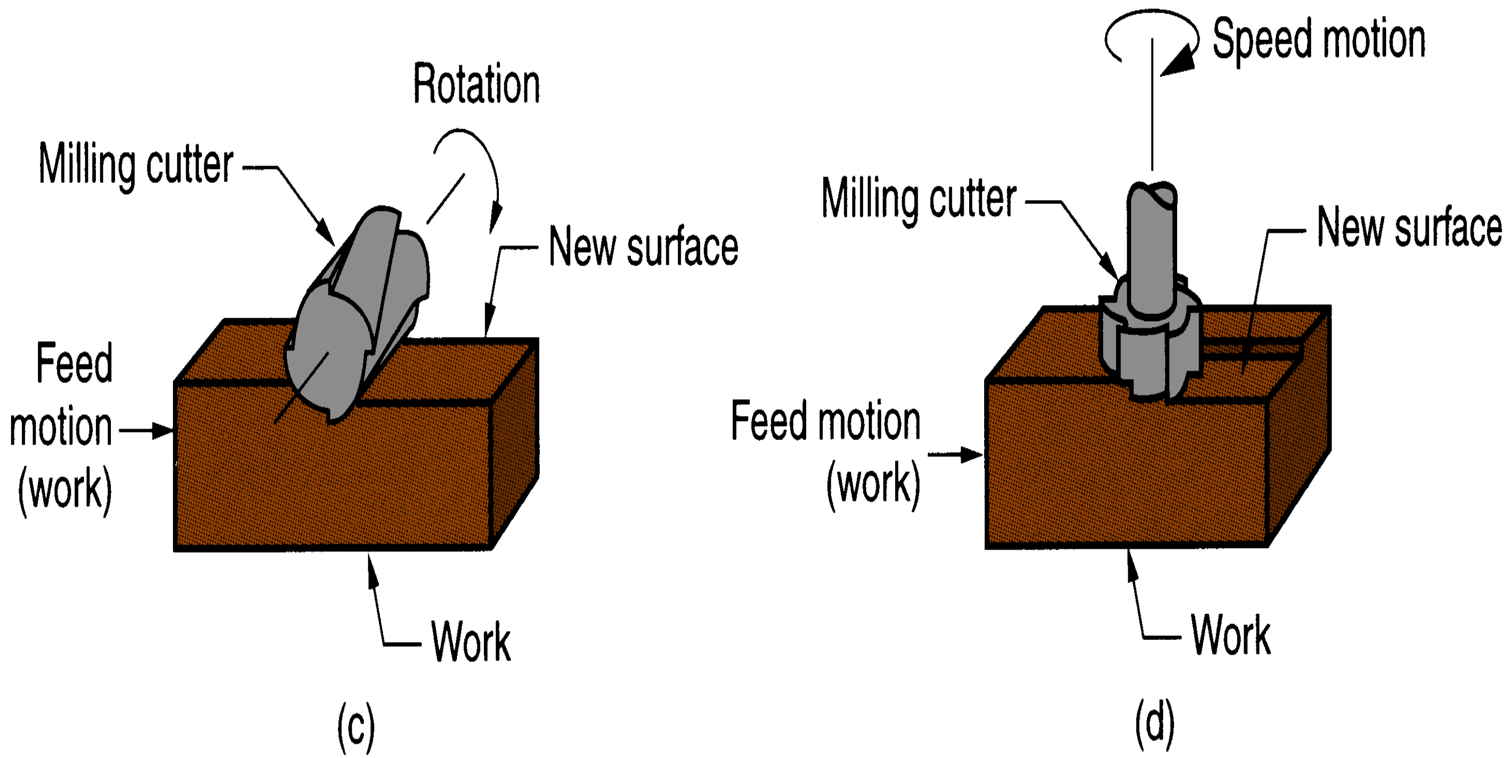
Single point cutting tool removes material from a rotating work piece to form a cylindrical shape

Drilling



Used to create a round hole, usually by means of a rotating tool (drill bit) with two cutting edges

Milling

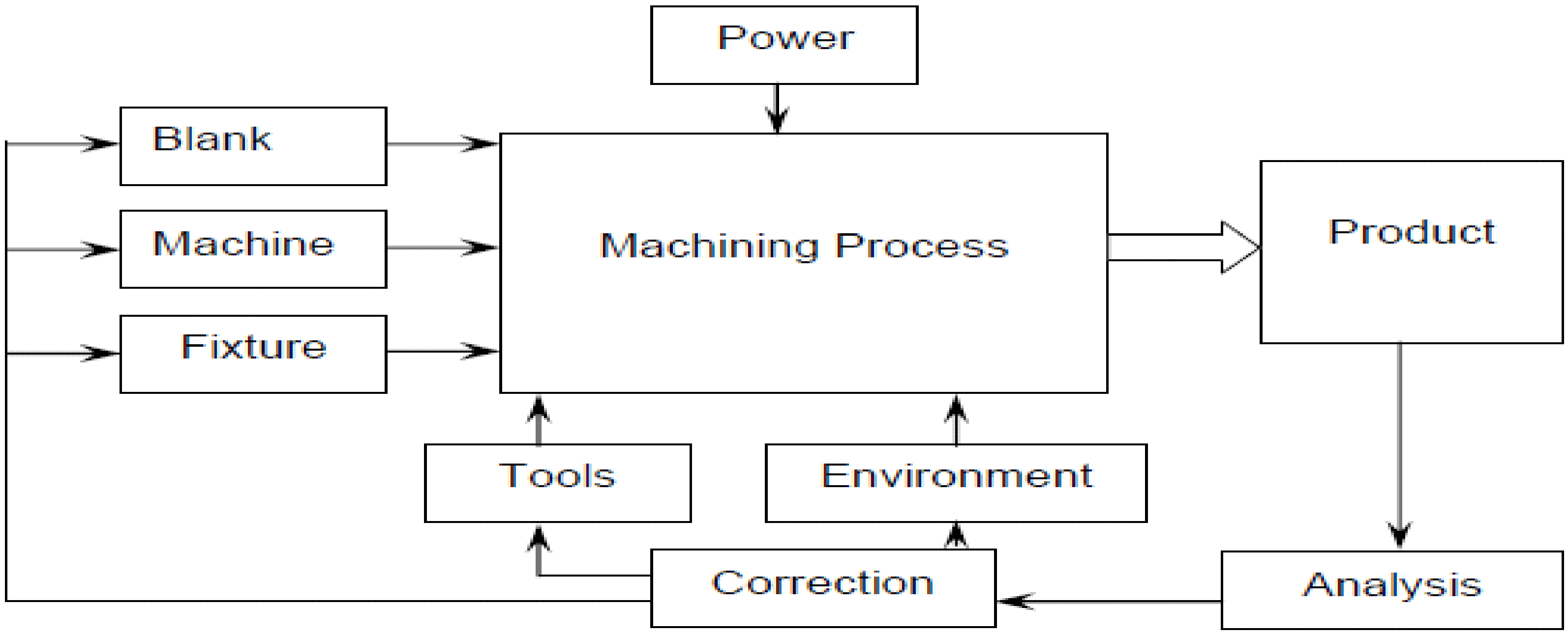


(c) peripheral milling (d) face milling.

Rotating multiple-cutting-edge tool is moved across work to cut a plane or straight surface

Manufacturing Technology

Machining requirements



The blank and the cutting tool are properly mounted (in fixtures) and moved in a powerful device called machine tool enabling gradual removal of layer of material from the work surface resulting in its desired dimensions and surface finish. Additionally some environment called cutting fluid is generally used to ease machining by cooling and lubrication.

Manufacturing Technology

Machine Tool - Definition

- A machine tool is a non-portable power operated and reasonably valued device or system of devices in which energy is expended to produce jobs of desired size, shape and surface finish by removing excess material from the preformed blanks in the form of chips with the help of cutting tools moved past the work surface's.

Basic functions of Machine Tools

- Machine Tools basically produce geometrical surfaces like flat, cylindrical or any contour on the preformed blanks by machining work with the help of cutting tools.

Manufacturing Technology

The physical functions of a Machine Tool in machining are

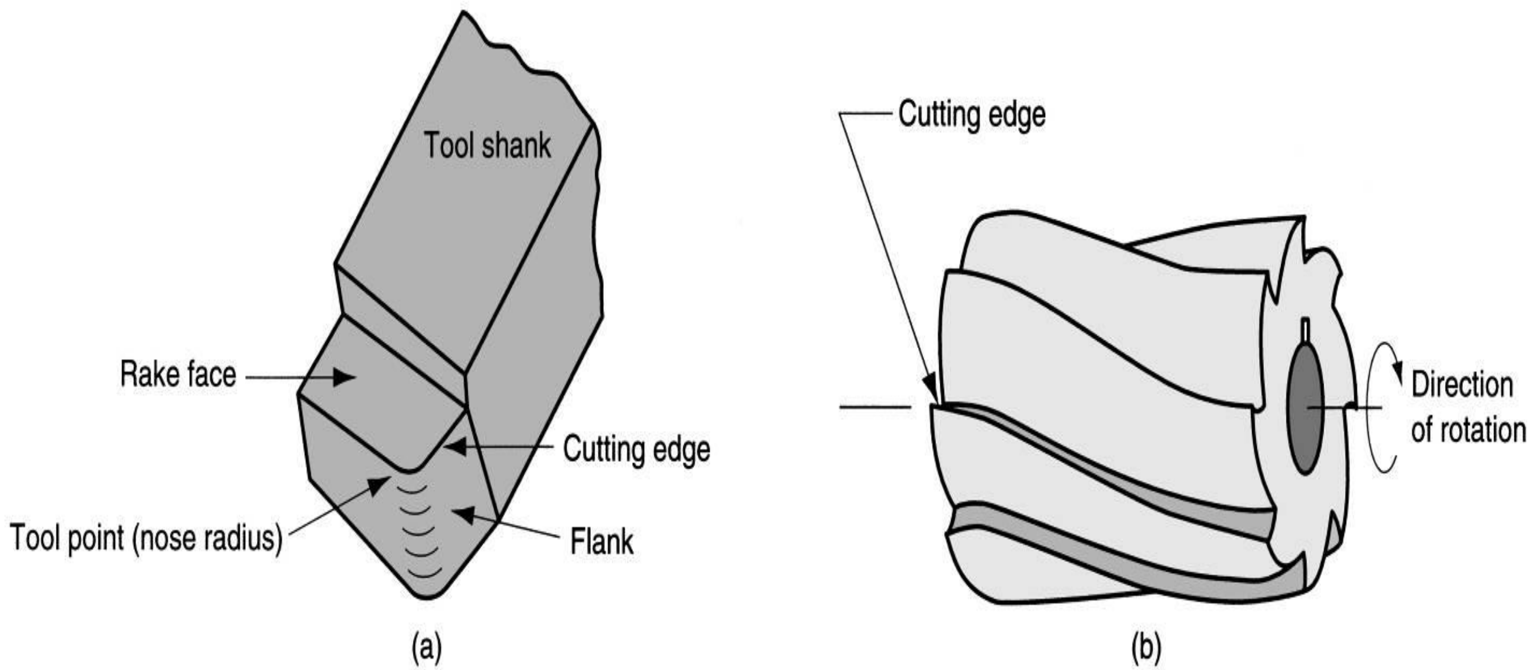
- Firmly holding the blank and the tool
- Transmit motions to the tool and the blank
- Provide power to the tool-work pair for the machining action.
- Control of the machining parameters, (speed, feed and depth of cut).

Manufacturing Technology

Classification of cutting tools

- Single-Point Cutting Edge Tools
  - One dominant cutting edge
  - Point is usually rounded to form a nose radius
  - Turning uses single point tools
- Multiple Point Cutting Edge Tools
  - More than one cutting edge
  - Motion relative to work achieved by rotating
  - Drilling and milling use rotating multiple cutting edge tools

- Cutting Tools



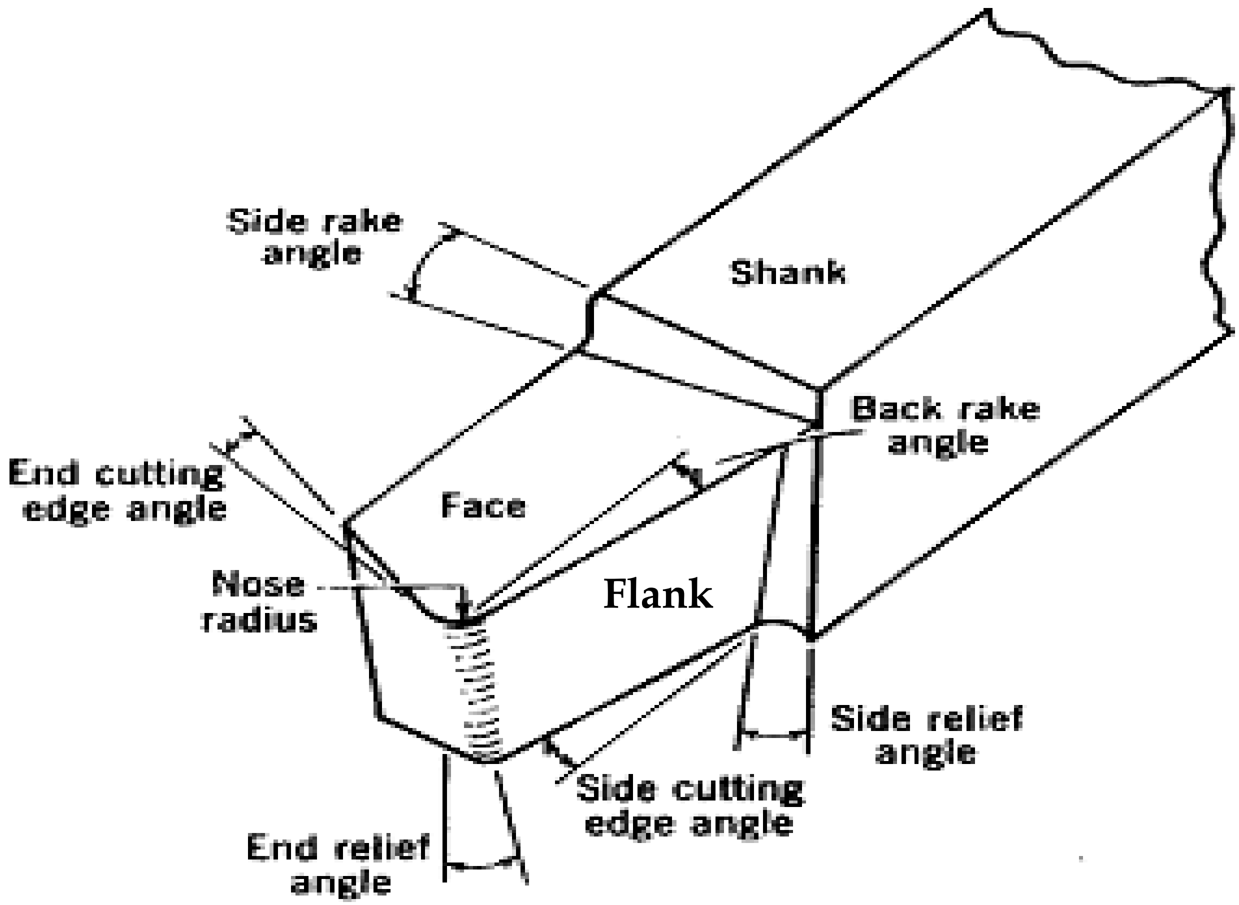
a. Single-Point Cutting Tool

b. Multi-Point Cutting Tool

Figure (a) A single-point tool showing rake face, flank, and tool point; and (b) a helical milling cutter, representative of tools with multiple cutting edges.

Manufacturing Technology

Tool signature for single point cutting tool



Manufacturing Technology

Tool signature for single point cutting tool

- Shank
  - It is the main body of the tool
- Flank
  - The surface of the tool adjacent to the cutting edge
- Face
  - The surface on which the chip slides
- Nose
  - It is the point where the side cutting edge and end cutting edge intersect
- Nose Radius
  - Strengthens finishing point of tool
- Cutting Edge
  - It is the edge on the face of the tool which removes the material from the work piece
- Side cutting edge angle
  - Angle between side cutting edge and the side of the tool shank

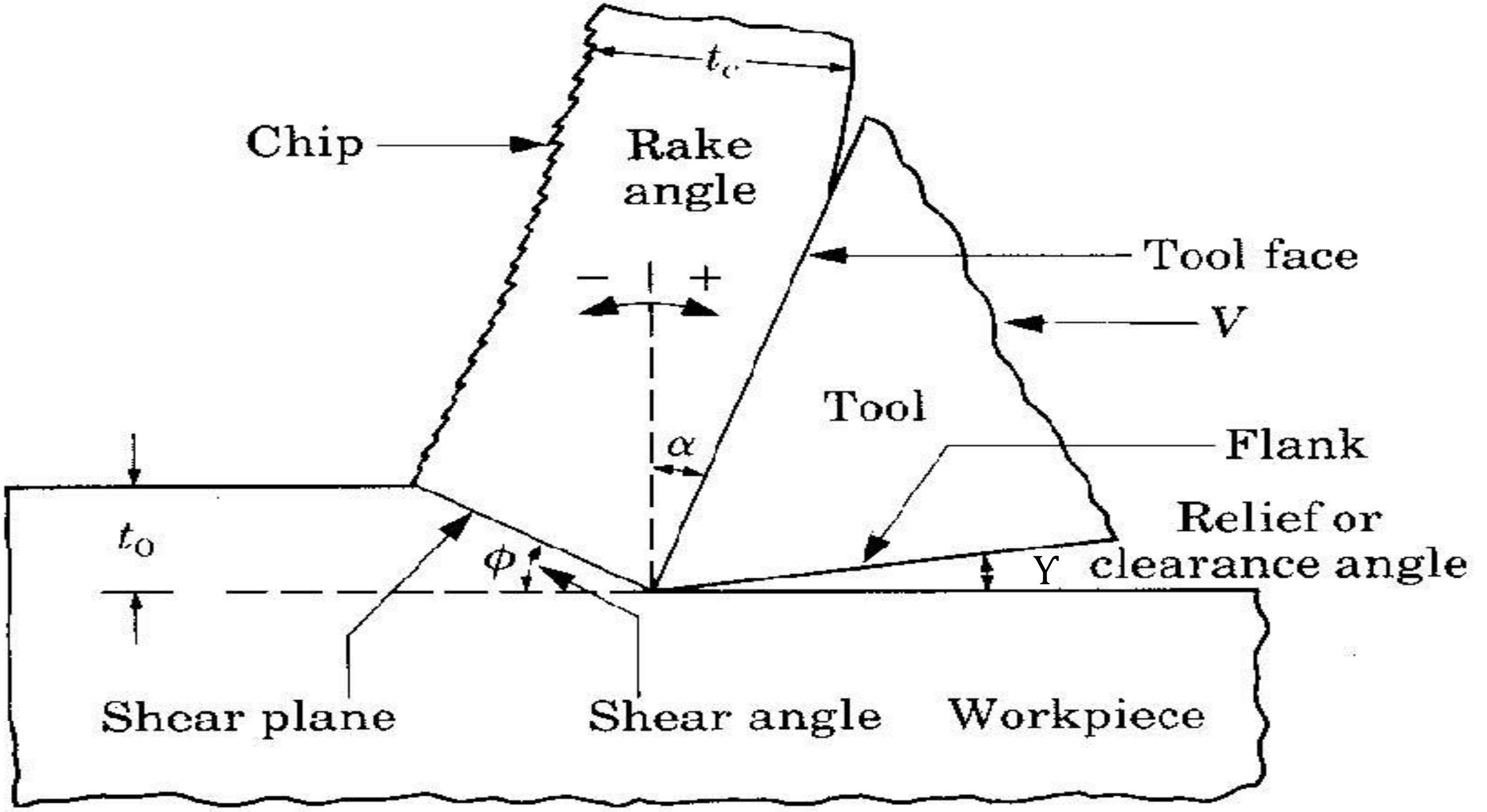
Manufacturing Technology

Tool signature for single point cutting tool

- End cutting edge angle
  - Angle between end cutting edge and the line normal to the tool shank
- Side Relief angle
  - Angle between the portion of the side flank immediately below the side cutting edge and a line perpendicular to the base of the tool, measured at right angle to the side flank
- End Relief angle
  - Angle between the portion of the end flank immediately below the end cutting edge and a line perpendicular to the base of the tool, measured at right angle to the end flank
- Side Rake angle
  - Angle between the tool face and a line parallel to the base of the tool and measured in a plane perpendicular to the base and the side cutting edge
- Back Rake angle
  - Angle between the tool face and a line parallel to the base of the tool and measured in a plane perpendicular to the side cutting edge

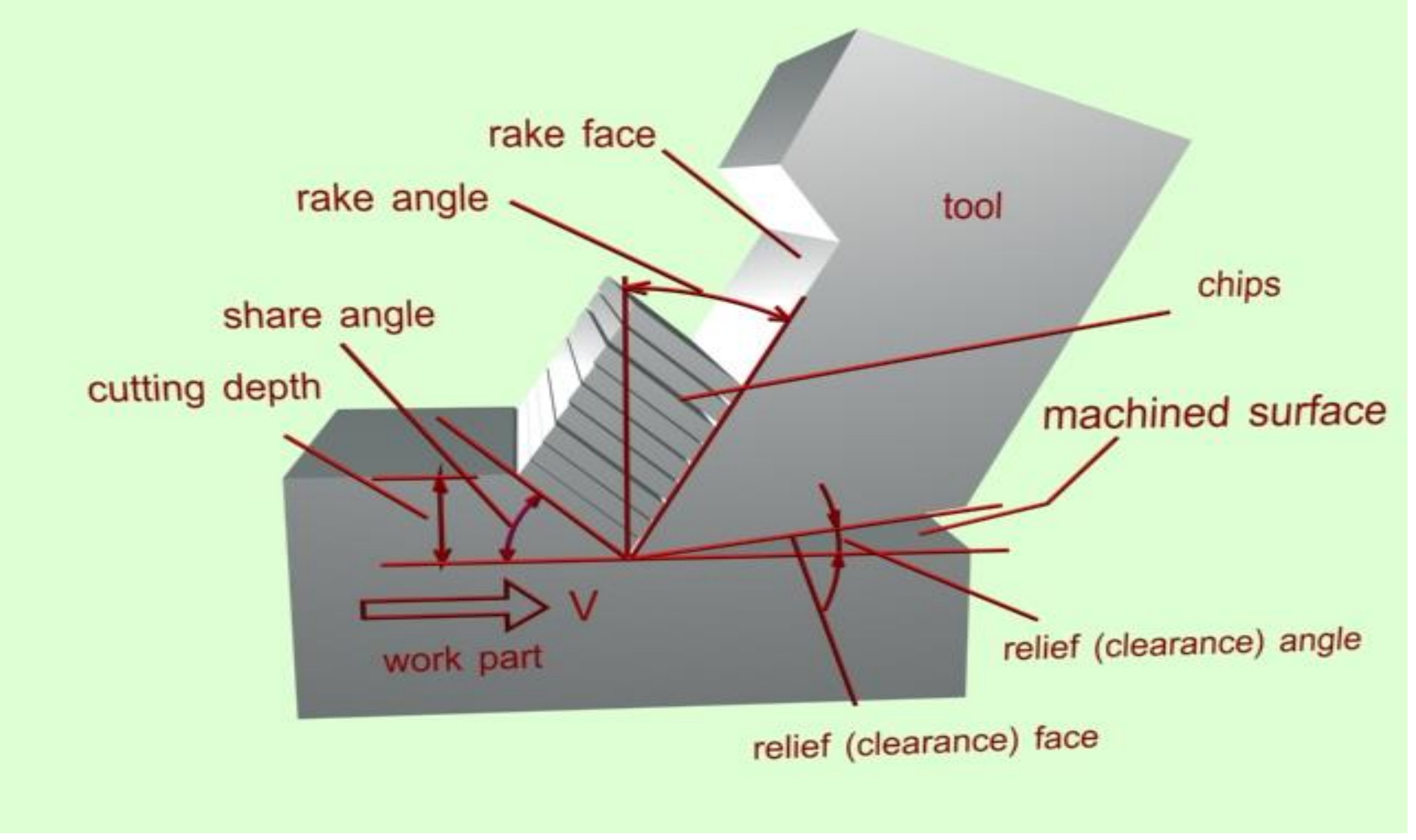
Manufacturing Technology

Single Point Cutting Tool Terminology-2D



Manufacturing Technology

Single Point Cutting Tool Terminology – 3D



Manufacturing Technology

Cutting Tool Materials

- Carbon steels, High-speed steels
- Cast carbides, Cemented carbides, Coated carbides
- Cermets, Ceramic Tools
- Polycrystalline Cubic Boron Nitride (PCBN)
- Polycrystalline Diamond (PCD)

Properties of Cutting Tool Materials

- Harder than work piece.
- High toughness
- High thermal shock resistance
- Low adhesion to work piece material
- Low diffusivity to work piece material

Manufacturing Technology

Theory of Metal Cutting

- Metal cutting or machining is the process of producing a work piece by removing unwanted material from a block of metal, in the form of chips.
- This process is most important since almost all the products get their final shape and size by metal removal, either directly or indirectly.

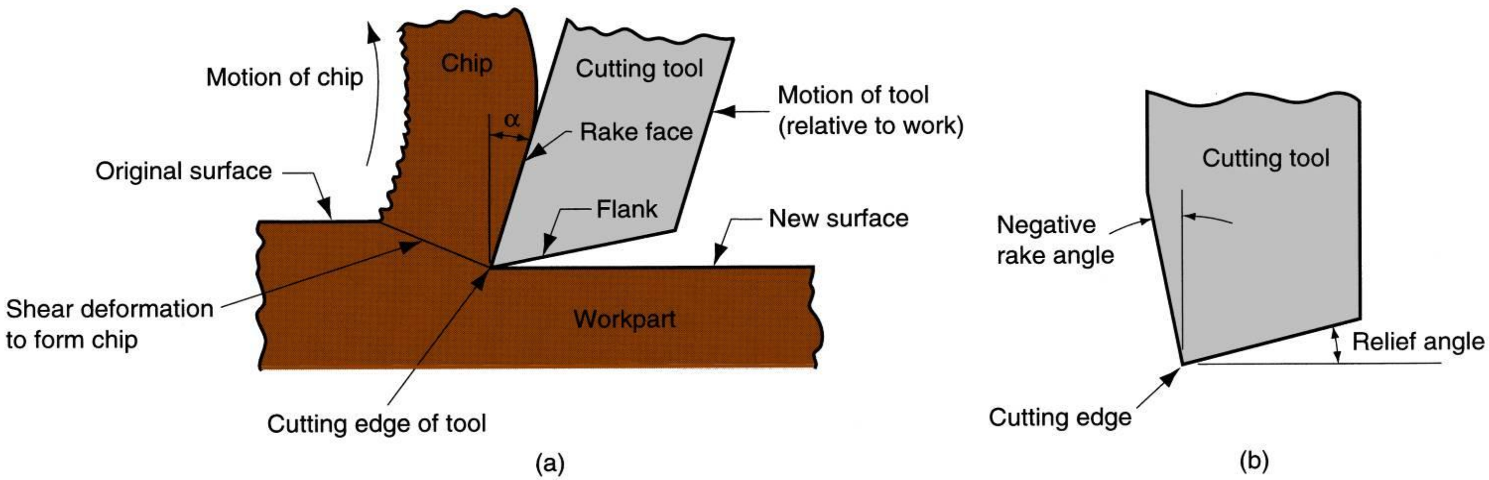
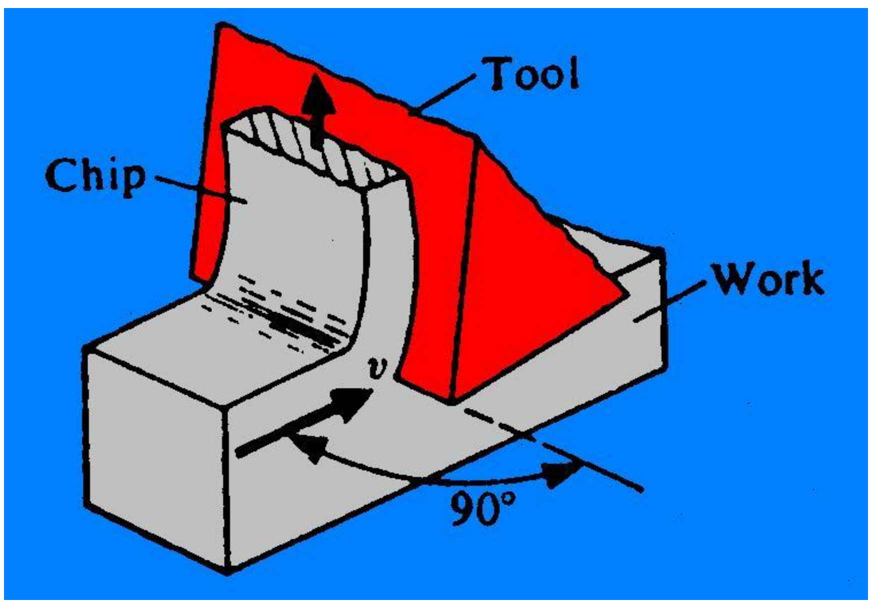


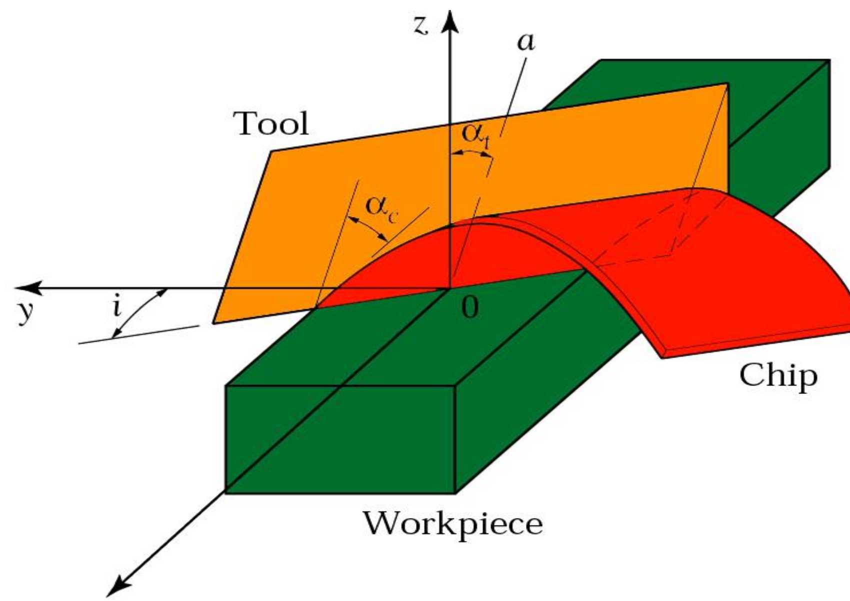
Figure (a) A cross-sectional view of the machining process,
(b) tool with negative rake angle; compare with positive rake angle in (a).

Manufacturing Technology

Orthogonal and oblique cutting

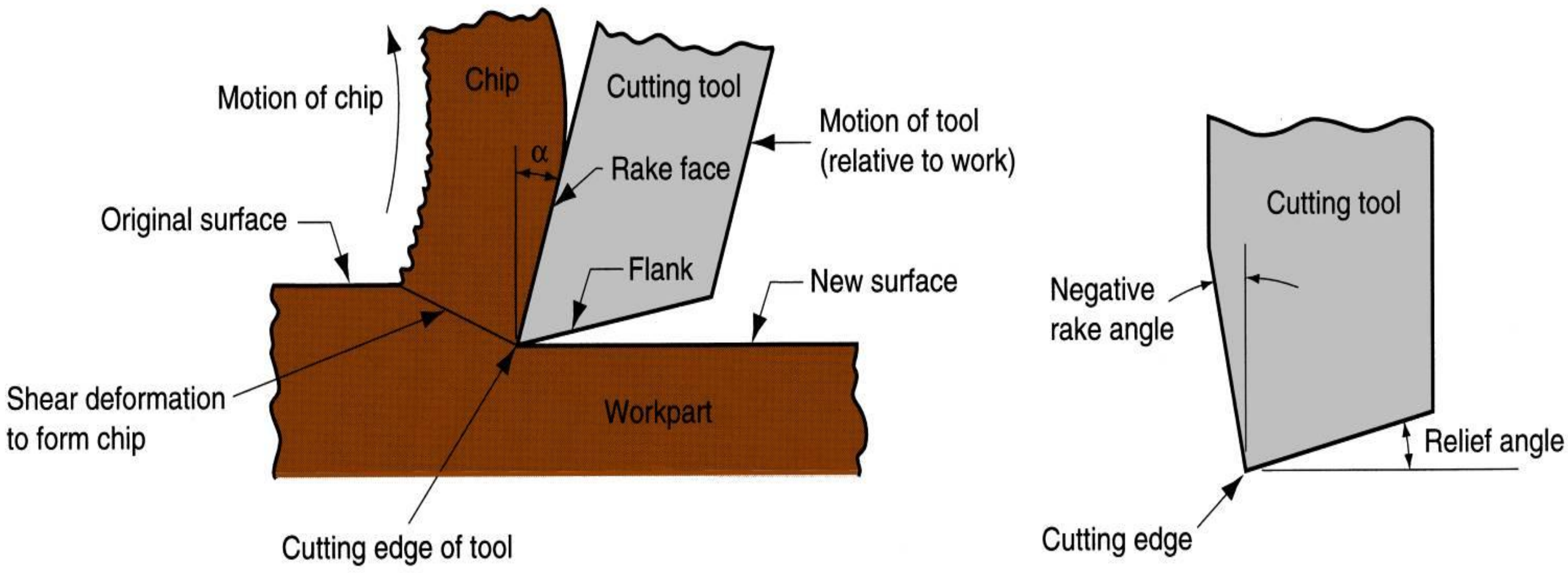
- Orthogonal cutting
  - The cutting edge of the tool is straight and perpendicular to the direction of motion.
- Oblique cutting
  - The cutting edge of the tool is set at an angle to the direction of motion.





The Mechanism of Cutting

- Cutting action involves shear deformation of work material to form a chip. As chip is removed, new surface is exposed
- Orthogonal Cutting - assumes that the cutting edge of the tool is set in a position that is perpendicular to the direction of relative work or tool motion. This allows us to deal with forces that act only in one plane.



(a) A cross-sectional view of the machining process, (b) tool with negative rake angle; compare with positive rake angle in (a).

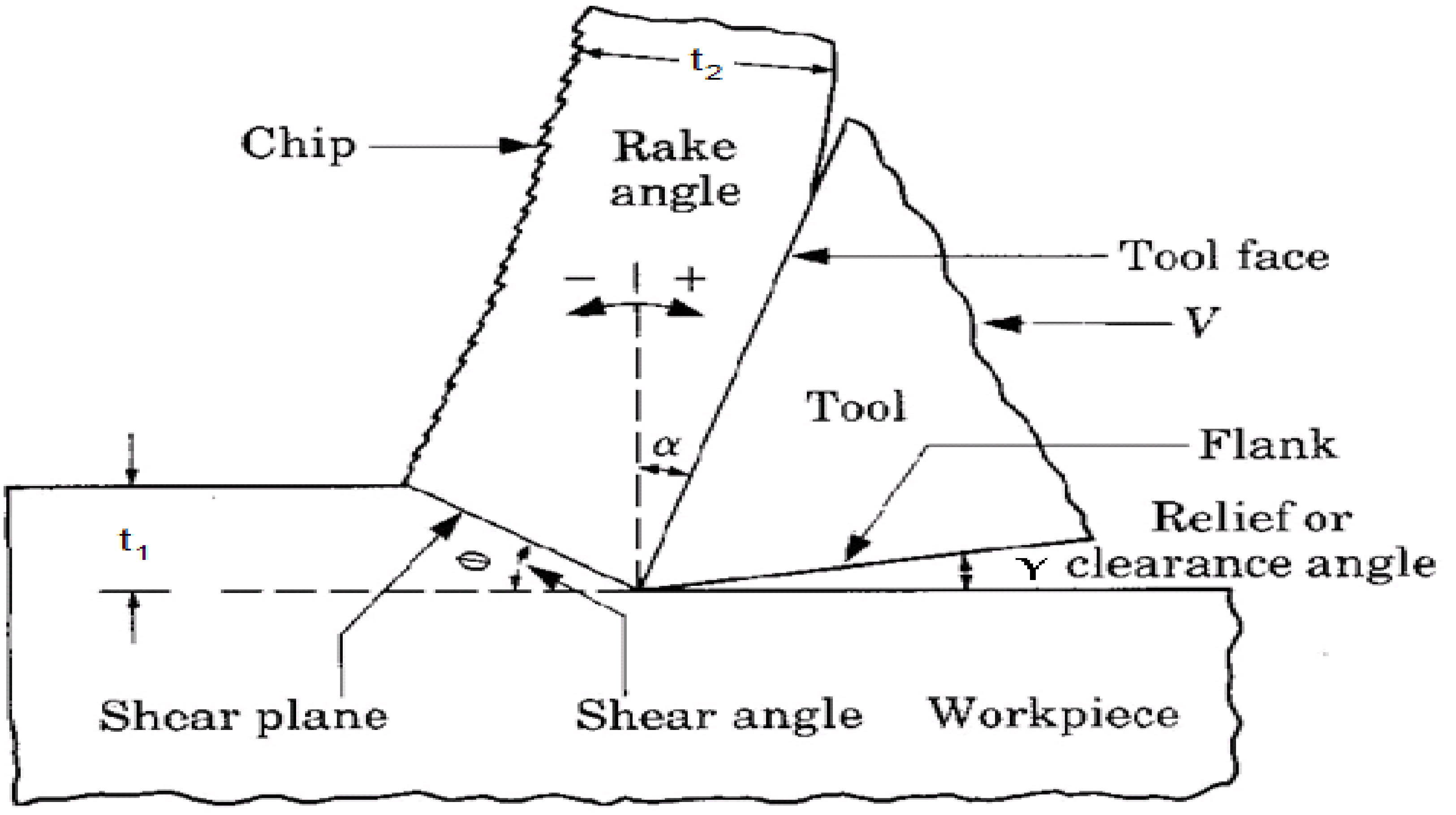
Mechanics of Orthogonal Cutting

Orthogonal Cutting

- Ideal Orthogonal Cutting is when the cutting edge of the tool is straight and perpendicular to the direction of motion.
- During machining, the material is removed in form of chips, which are generated by shear deformation along a plane called the shear plane.
- The surface the chip flows across is called the face or rake face.
- The surface that forms the other boundary of the wedge is called the flank.
- The rake angle is the angle between the tool face and a line perpendicular to the cutting point of the work piece surface.

Mechanics of Orthogonal Cutting

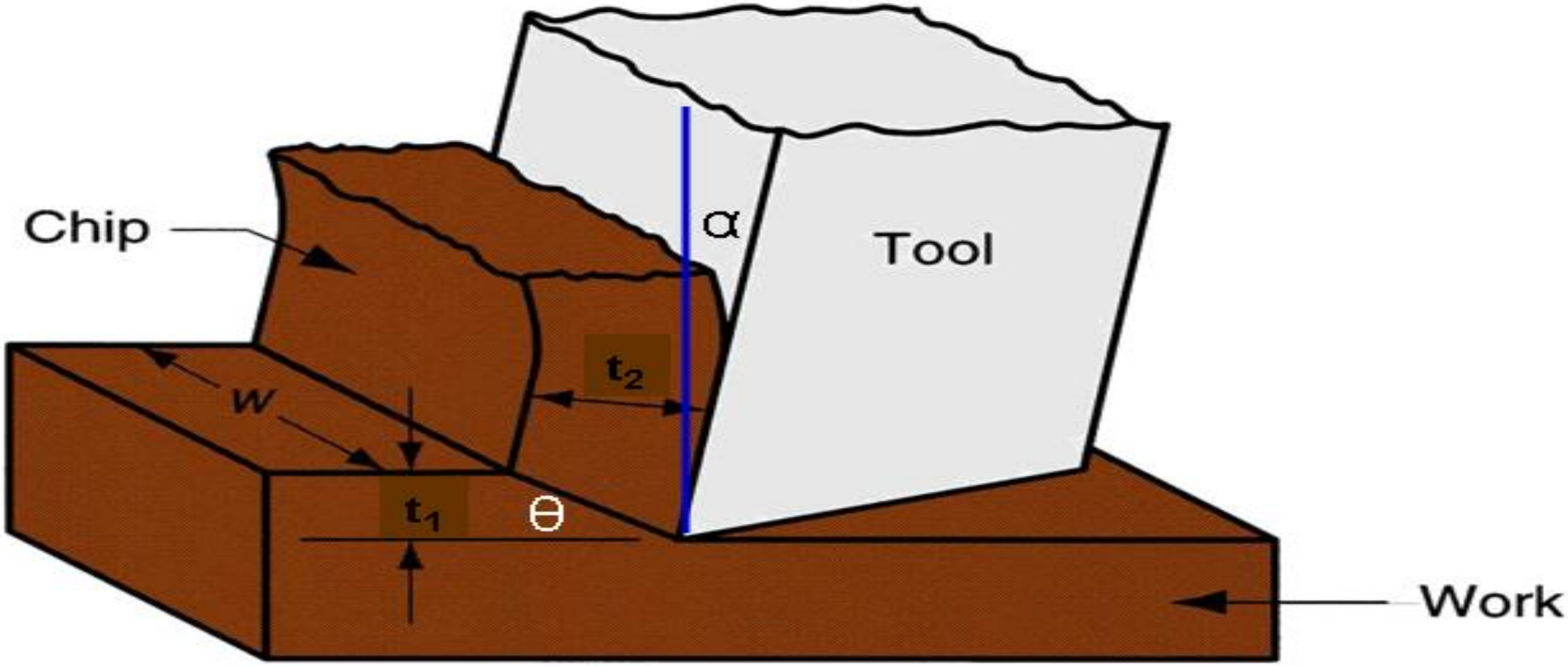
- The relief or clearance angle is the angle between the tool flank and the newly formed surface of the work piece angle.



Mechanics of Orthogonal Cutting

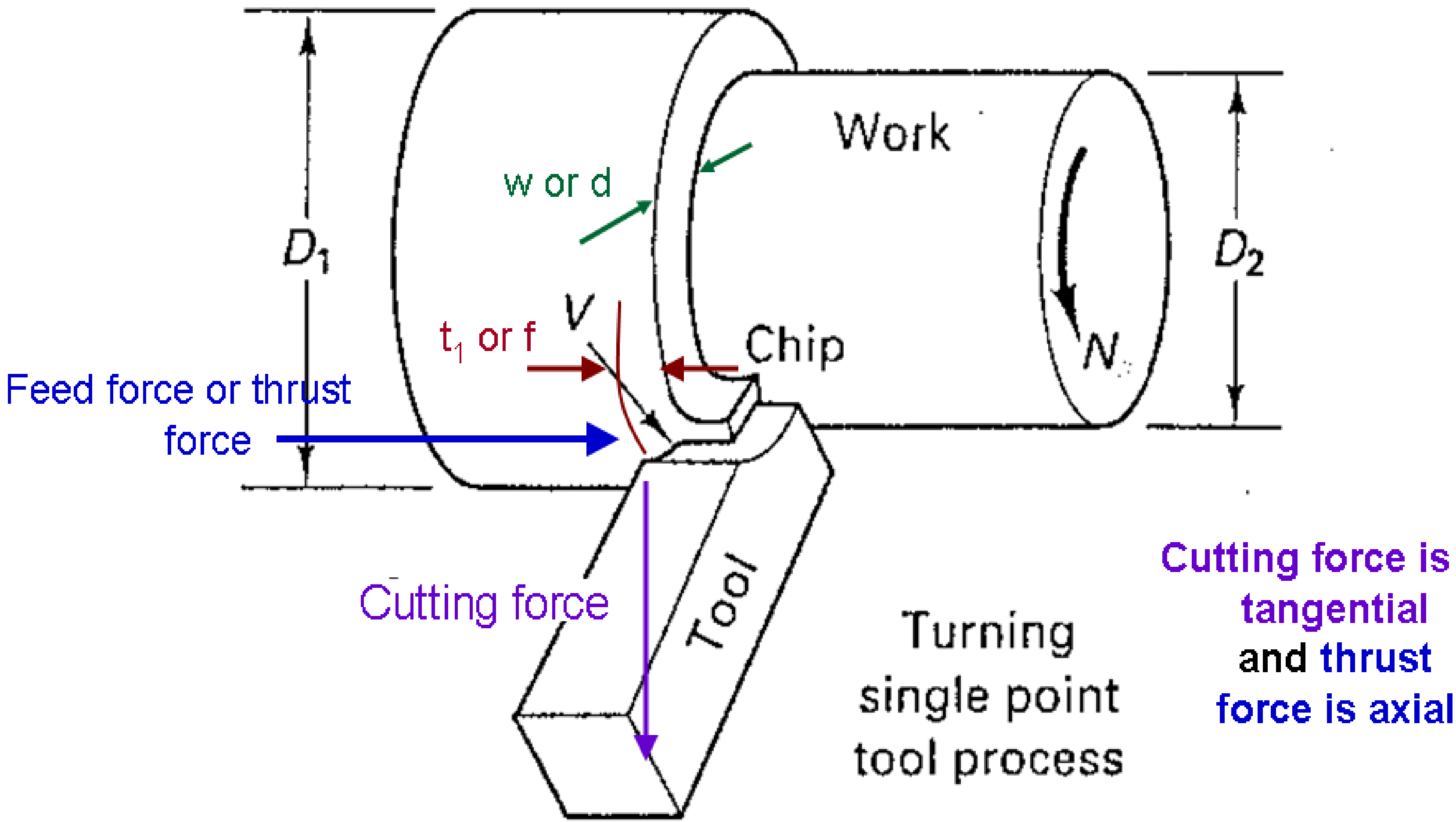
Orthogonal cutting model:

- t_1 = un deformed chip thickness
- t_2 = deformed chip thickness (usually $t_2 > t_1$)
- α = rake angle
- If we are using a lathe, t_1 is the feed per revolution.

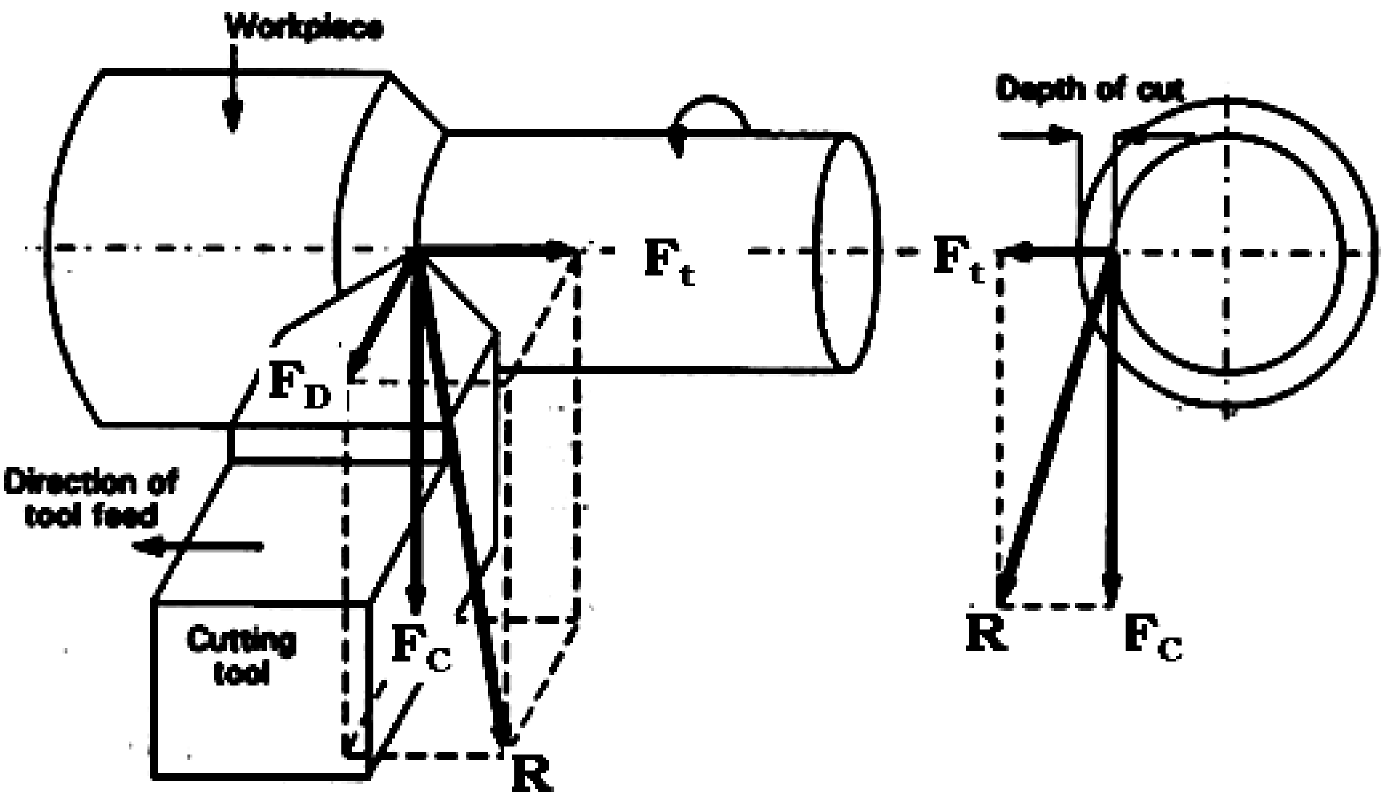


The Mechanism of Cutting

- In turning, w = depth of cut and t_1= feed



The Mechanism of Cutting



Cutting force (Fc) is tangential and Thrust force is axial (Ft)

Cutting forces in a turning operation

Mechanics of Orthogonal Cutting

Chip thickness ratio (or) cutting ratio

$$\boxed{\text{Cutting ratio} = r = \frac{t_1}{t_2}}$$

where

- r = *chip thickness ratio or cutting ratio*;
- t_1 = thickness of the chip prior to chip formation;
- t_2 = chip thickness after separation

Which one is more correct?

- $r \geq 1$
- $r \leq 1$
- Chip thickness after cut always greater than before, so chip ratio always less than 1.0

Mechanics of Orthogonal Cutting

Shear Plane Angle

- Based on the geometric parameters of the orthogonal model, the shear plane angle θ can be determined as:

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

where

- r = *chip thickness ratio or cutting ratio*;
- α = Rake angle
- θ = *Shear angle*

Mechanics of Orthogonal Cutting

Shear Plane Angle Proof

$$t_1 = h\sin\theta, \qquad t_2 = h\cos(\theta-\alpha)$$

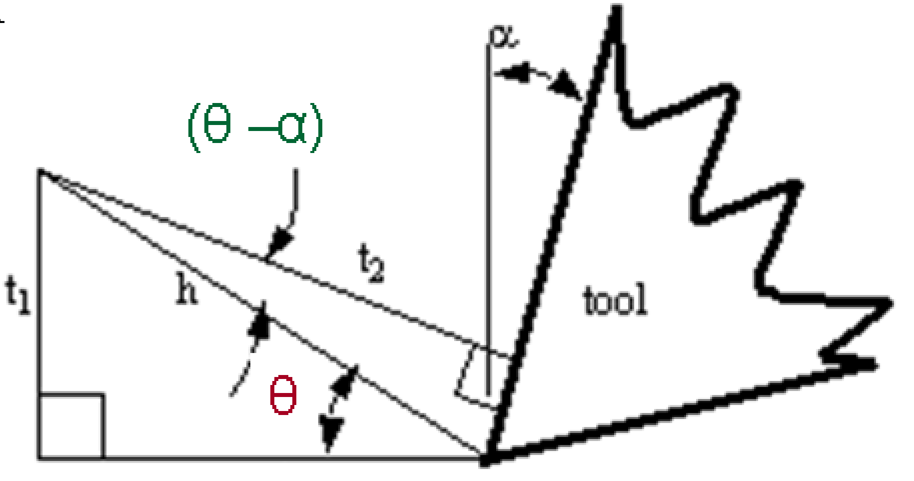
$$r = \frac{t_1}{t_2} = \frac{h\sin\theta}{h\cos(\theta-\alpha)} = \frac{\sin\theta}{\cos\theta\cos\alpha+\sin\theta\sin\alpha}$$

$$r\cos\theta\cos\alpha + r\sin\theta\sin\alpha = \sin\theta$$

$$\frac{r\cos\theta\cos\alpha}{\sin\theta} + \frac{r\sin\theta\sin\alpha}{\sin\theta} = 1$$

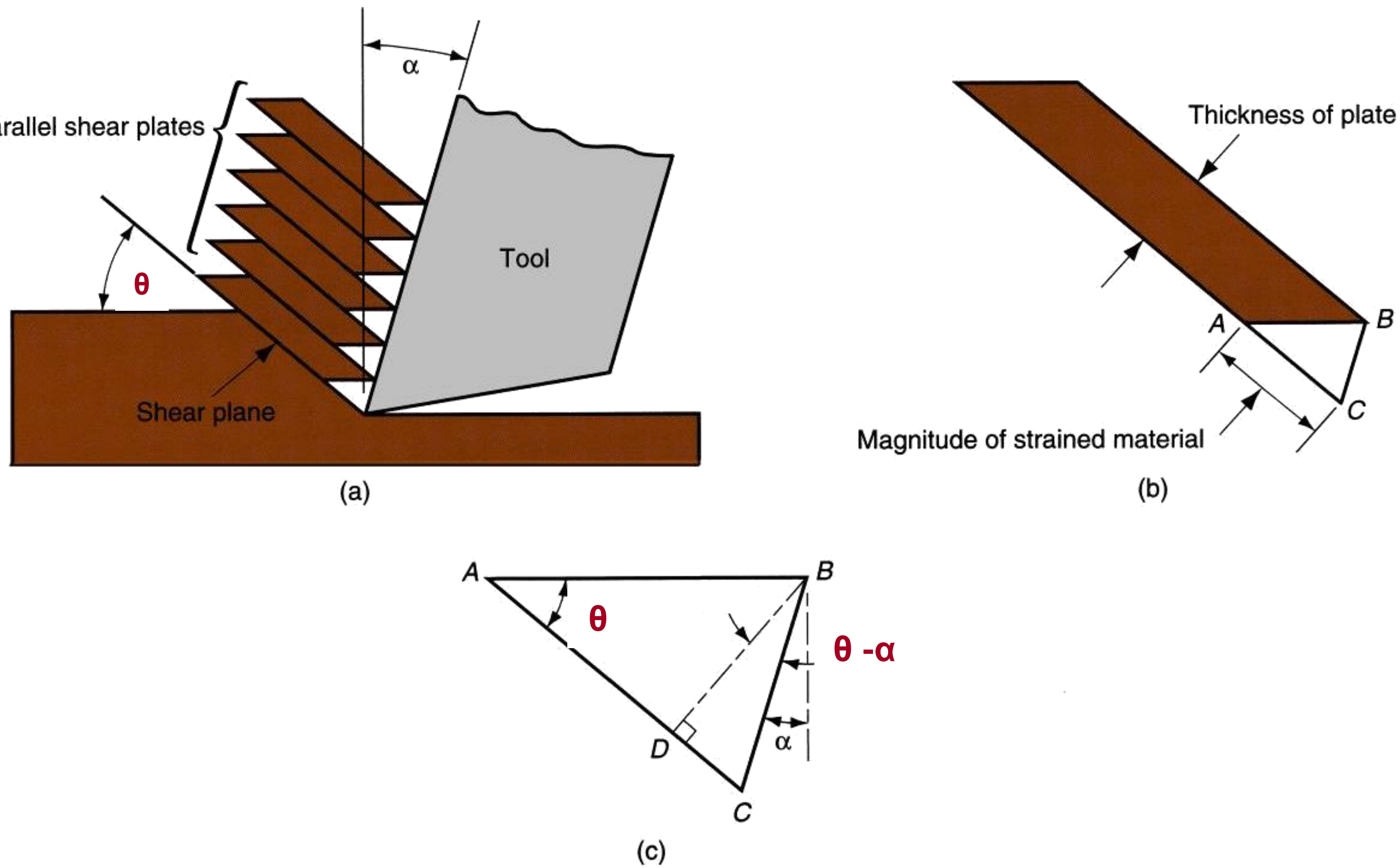
$$\frac{r\cos\alpha}{\tan\theta} + r\sin\alpha = 1$$

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



Mechanics of Orthogonal Cutting

Shear Strain in chip formation



(a) chip formation depicted as a series of parallel plates sliding relative to each other, (b) one of the plates isolated to show shear strain, and (c) shear strain triangle used to derive strain equation.

Mechanics of Orthogonal Cutting

Shear Strain in chip formation

- Shear strain in machining can be computed from the following equation, based on the preceding parallel plate model:
  - $\gamma = \tan(\theta - \alpha) + \cot\theta$

where

- γ = shear strain
- θ = shear angle
- α = rake angle of cutting tool

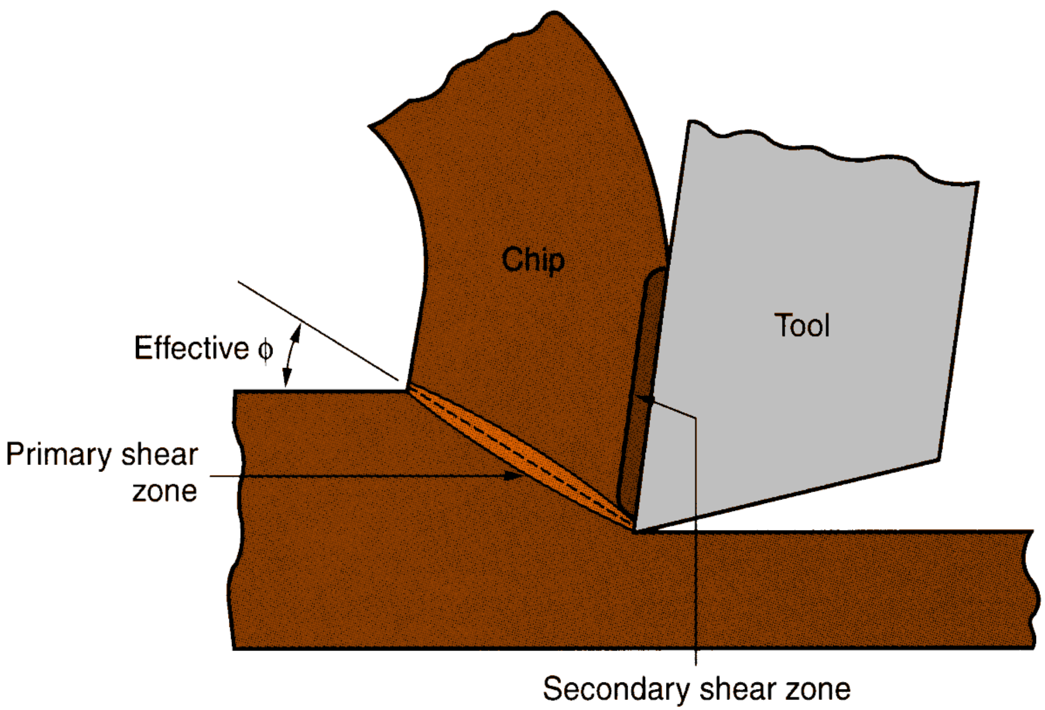
Mechanics of Orthogonal Cutting

Shear Strain Proof

- From the shear strain triangle (image c –slide 35)
  - γ = AC/DB= (AD+DC)/DB
  - γ = AD/DB + DC/DB
  - AD/DB = Cot θ
  - DC/DB = tan (θ - α)
  - Therefore γ = Cot θ + tan (θ - α)
    - $\gamma = \tan(\theta - \alpha) + \cot\theta$

Chip formation

- Mechanics of metal cutting is greatly depend on the shape and size of the chips formed.



More realistic view of chip formation, showing shear zone rather than shear plane. Also shown is the secondary shear zone resulting from tool-chip friction.

Four Basic Type of Chips in Machining are

- Discontinuous chip
- Continuous chip
- Continuous chip with Built-up Edge (BUE)
- Serrated chip

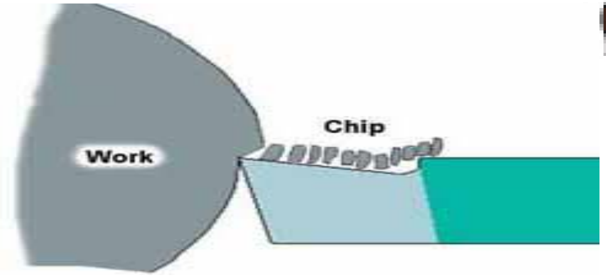
Manufacturing Technology

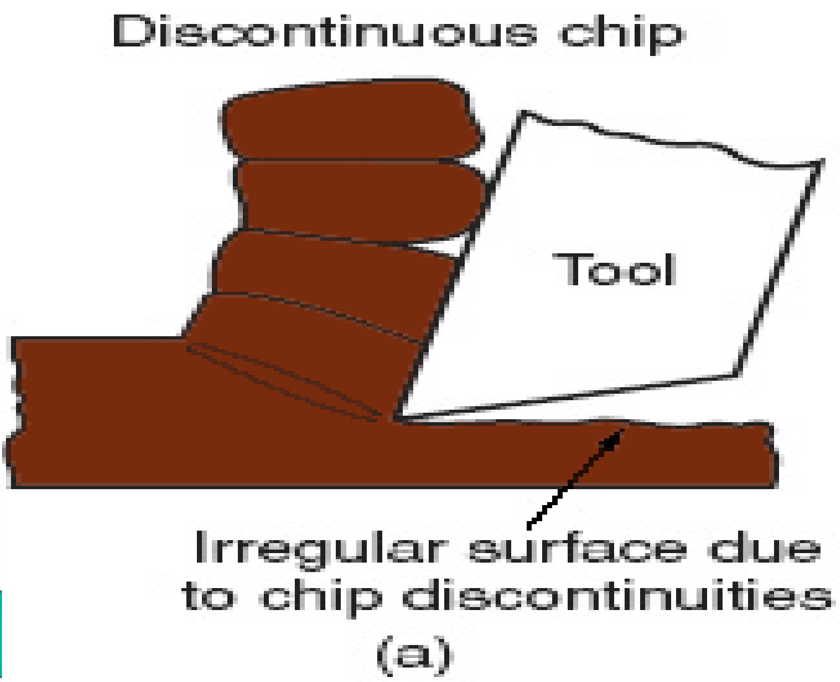
Discontinuous chip

- When brittle materials like cast iron are cut, the deformed material gets fractured very easily and thus the Chip produced is in the form of discontinuous segments

Reasons

- Brittle work materials
- Low cutting speeds
- Large feed and depth of cut
- High tool-chip friction





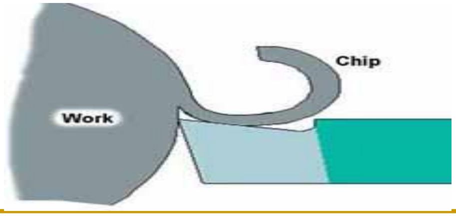
Manufacturing Technology

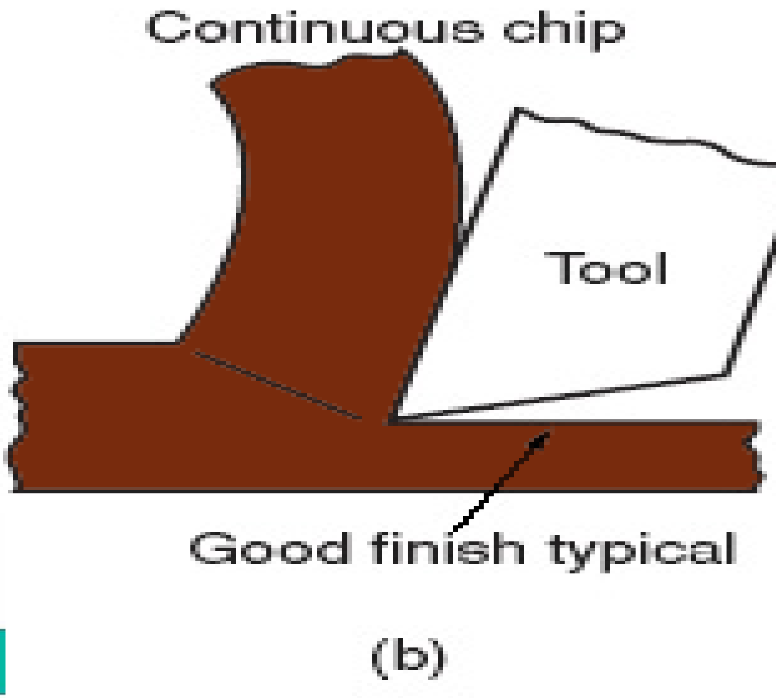
Continuous chip

- Continuous chips are normally produced when machining steel or ductile materials at high cutting speeds. The continuous chip which is like a ribbon flows along the rake face.

Reasons

- Ductile work materials
- High cutting speeds
- Small feeds and depths
- Sharp cutting edge
- Low tool-chip friction





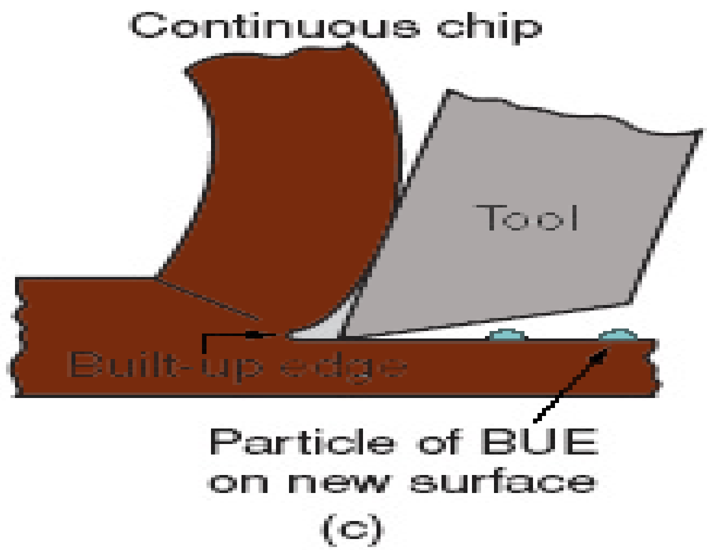
Manufacturing Technology

Continuous chip with Built-up Edge (BUE)

- When the friction between tool and chip is high while machining ductile materials, some particles of chip adhere to the tool rake face near the tool tip. When such sizeable material piles upon the rake face, it acts as a cutting edge in place of the actual cutting edge is termed as built up edge (BUE). By virtue of work hardening, BUE is harder than the parent work material

Reasons

- Ductile materials
- Low-to-medium cutting speeds
- Tool-chip friction causes portions of chip to adhere to rake face
- BUE forms, then breaks off, cyclically



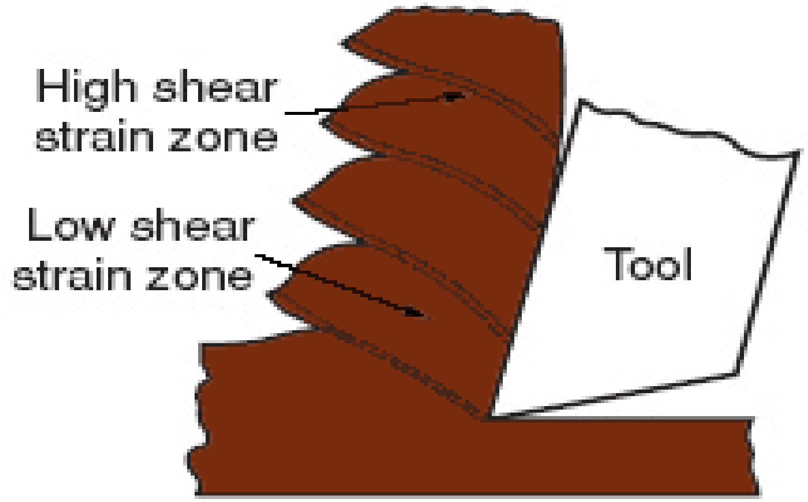
Manufacturing Technology

Serrated chip

- Semi Continuous (saw tooth appearance) chips produced when machining tool steels or Harden materials at high cutting speeds.

Reasons

- Ductile materials
- Low-to-medium cutting speeds
- Tool-chip friction causes portions of chip to adhere to rake face
- BUE forms, then breaks off, cyclically



(d)

Manufacturing Technology

Chip Breakers

- Long continuous chip are undesirable
- Chip breaker is a piece of metal clamped to the rake surface of the tool which bends the chip and breaks it
- Chips can also be broken by changing the tool geometry, thereby controlling the chip flow

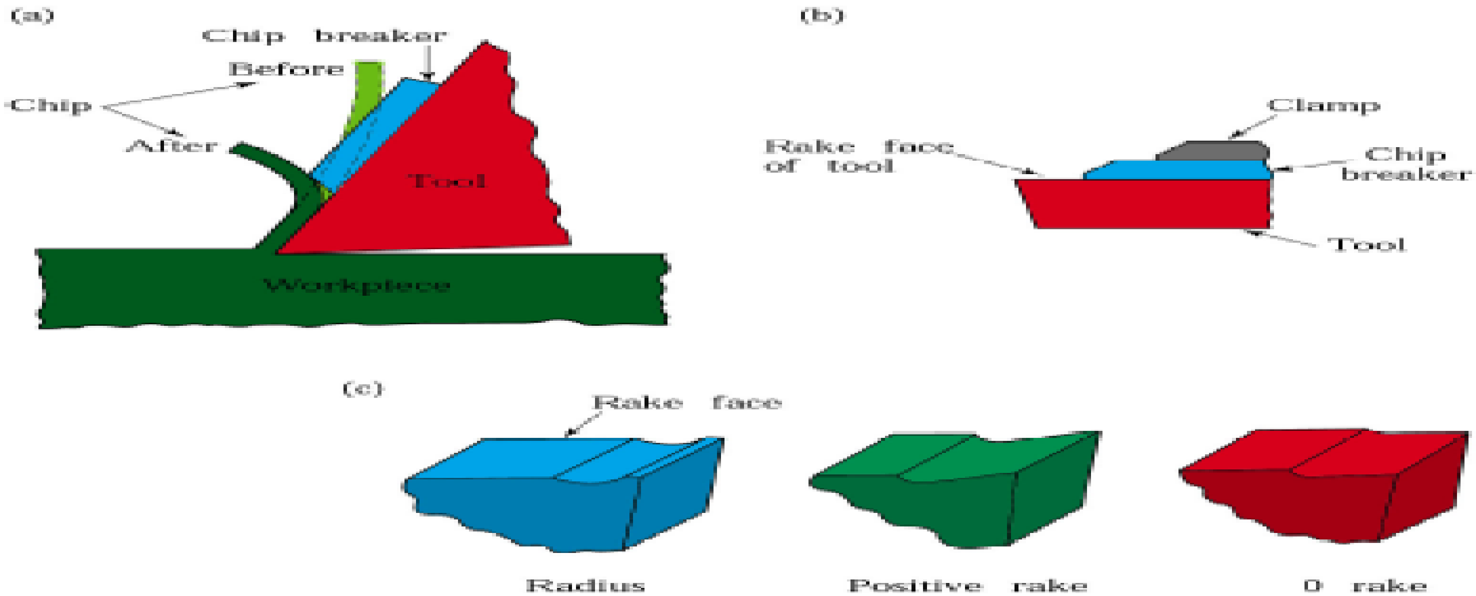


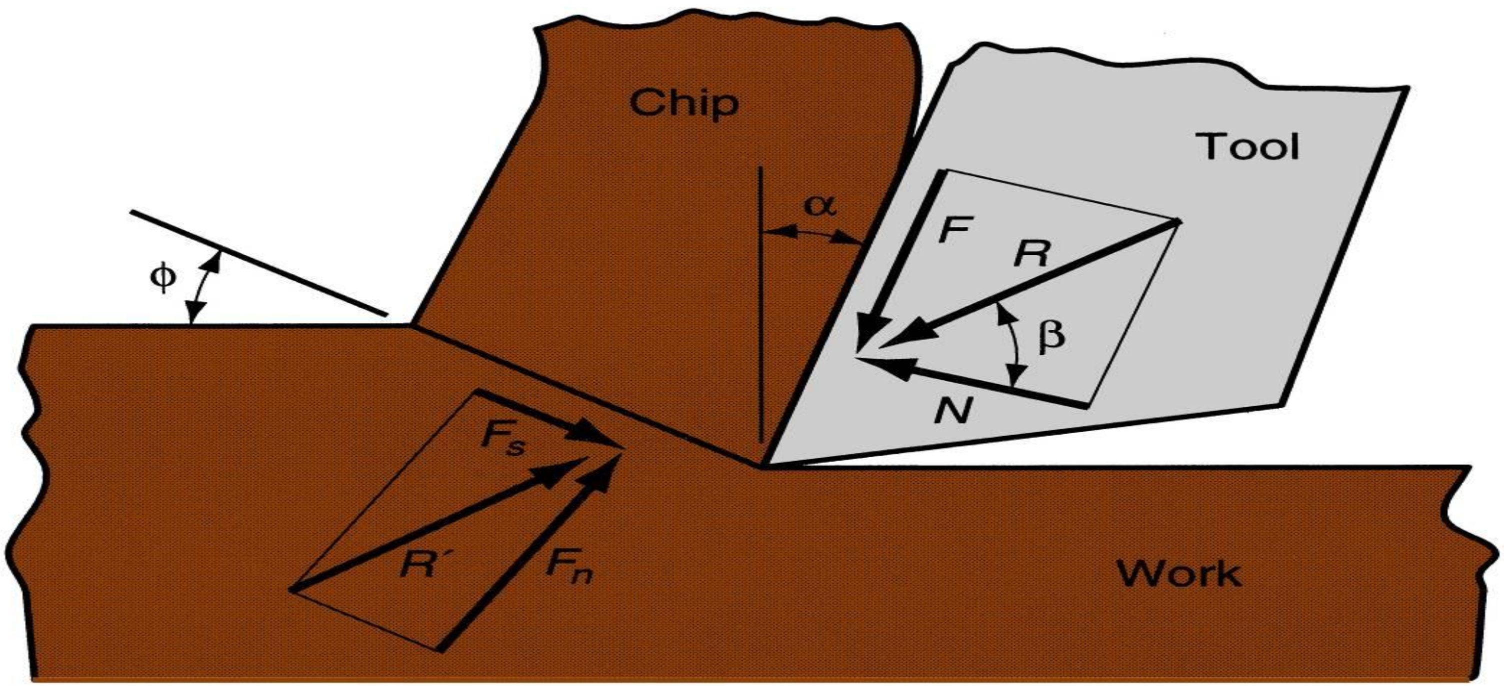
Fig. (a) Schematic illustration of the action of a chip breaker .(b) Chip breaker Clamped on the rake of a cutting tool. (c) Grooves in cutting tools acting as chip breakers

Force & Velocity Relationships and the Merchant Equation

Manufacturing Technology

Forces Acting on Chip

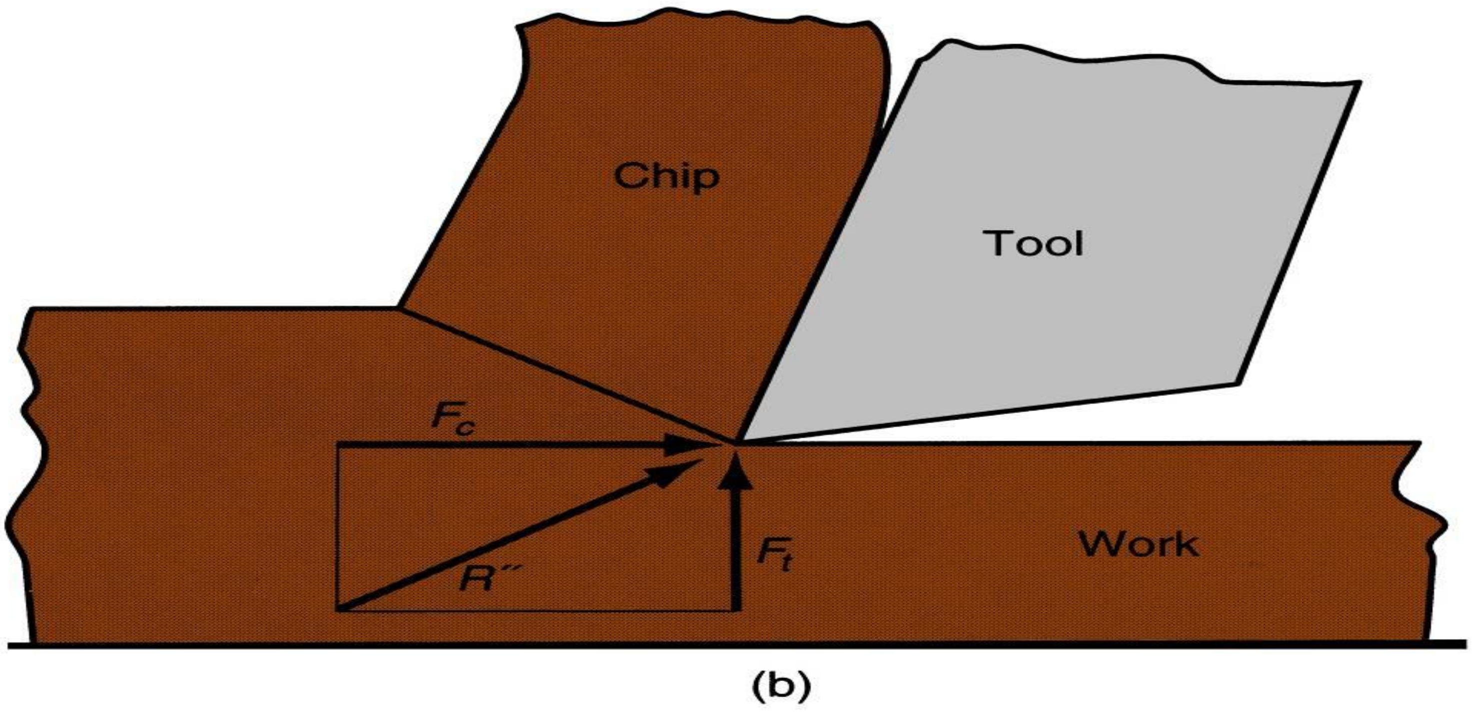
- Friction force F and Normal force to friction N
- Shear force F_s and Normal force to shear F_n



Forces in metal cutting: (a) forces acting on the chip in orthogonal cutting

Cutting Force and Thrust Force

- F, N, F_s and F_n cannot be measured directly, in order to measure these forces the forces acting on the tool to be measured initially
  - Cutting force F_c and Thrust force F_t



Forces in metal cutting: (b) forces acting on the tool that can be measured

Resultant Forces

- Vector addition of F and N = resultant R
- Vector addition of F_s and F_n = resultant R'
- Forces acting on the chip must be in balance:
  - R' must be equal in magnitude to R
  - R′ must be opposite in direction to R
  - R′ must be collinear with R

Manufacturing Technology

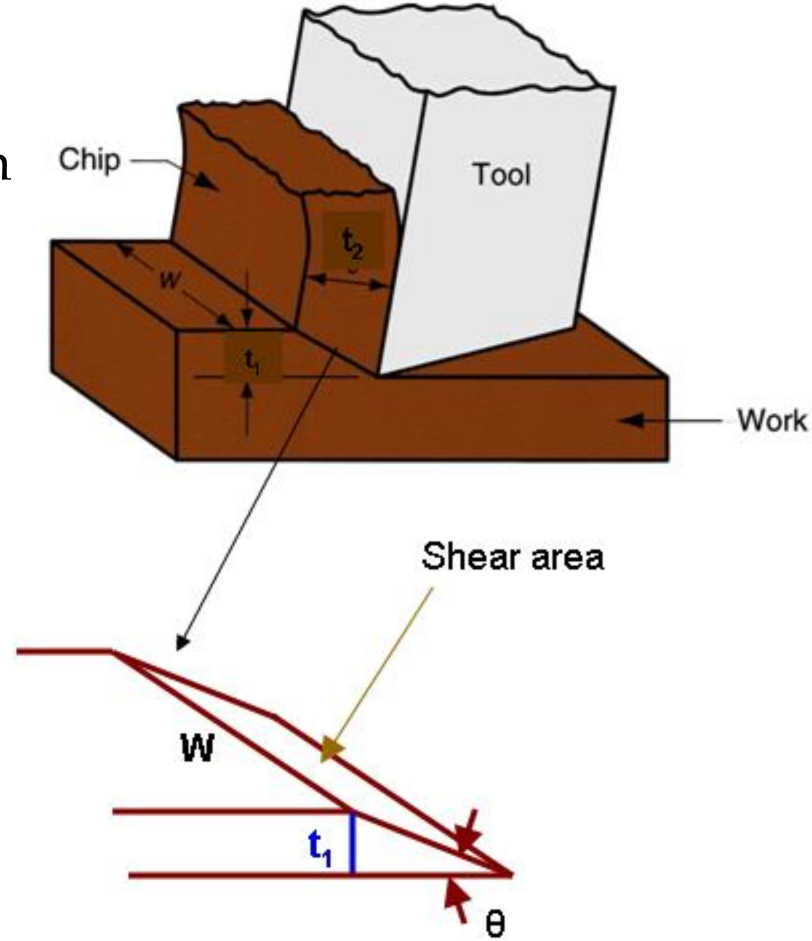
Shear Stress

- Shear stress acting along the shear plan

$$S = \frac{F_s}{A_s}$$

- where As = area of the shear plane

$$A_s = \frac{t_1 w}{\sin\theta}$$



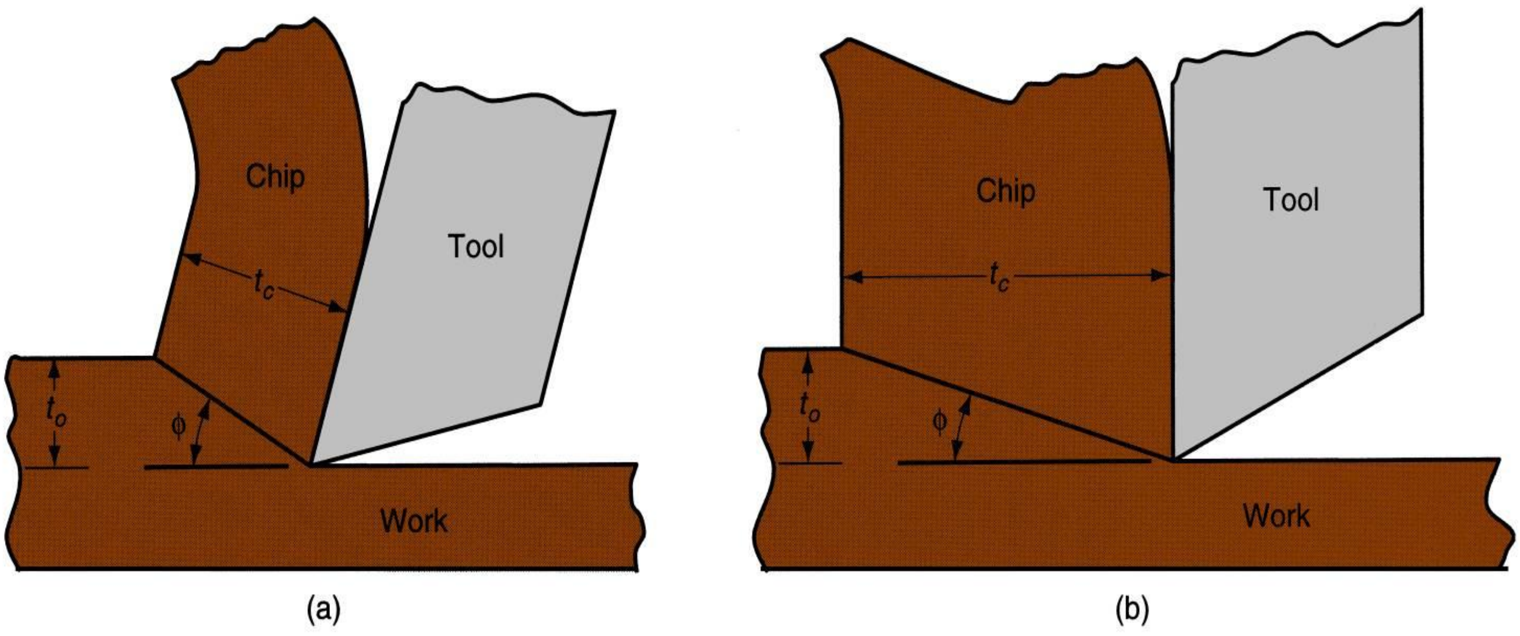
- Shear stress = shear strength of work material during cutting

Shear Stress- Effect of Higher Shear Plane Angle

Shear angle and its significance

Effect of Higher Shear Plane Angle

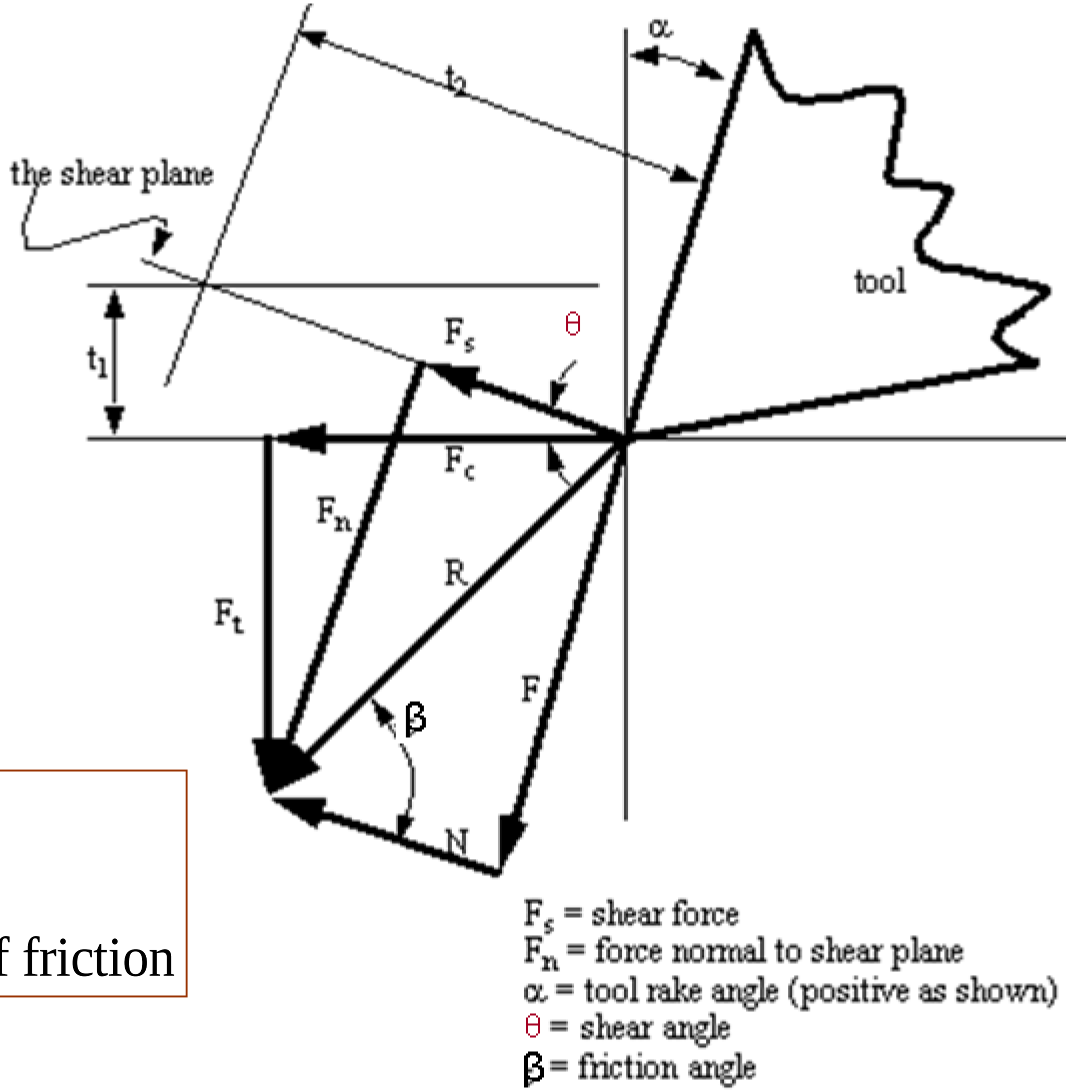
- Higher shear plane angle means smaller shear plane which means lower shear force, cutting forces, power, and temperature



Effect of shear plane angle ϕ : (a) higher θ with a resulting lower shear plane area; (b) smaller θ with a corresponding larger shear plane area. Note that the rake angle is larger in (a), which tends to increase shear angle according to the Merchant equation

Force Calculations

- The forces and angles involved in cutting are drawn here,
- Having seen the vector based determination of the cutting forces, we can now look at equivalent calculations:



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

Where $\mu =$ The coefficient of friction

Force Calculations

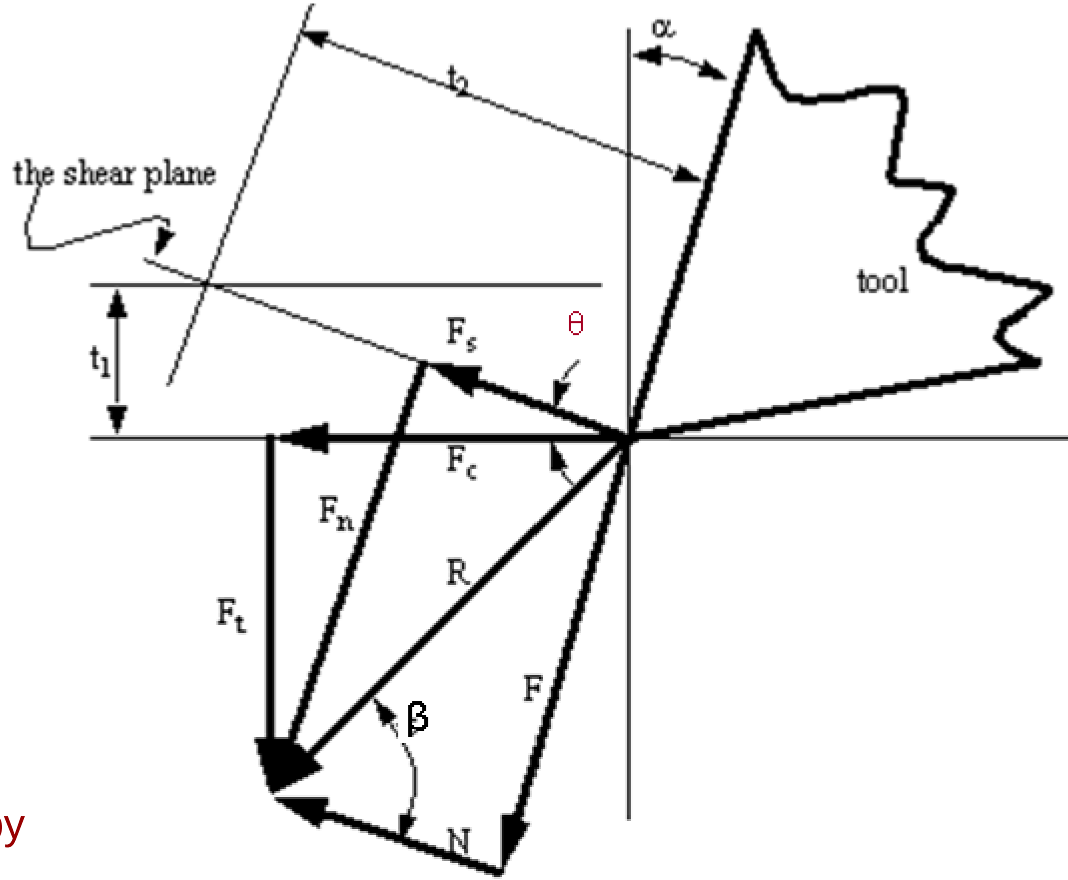
And, by trigonometry:

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

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

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

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



Where the Resultant force R is Given by

$$R = \sqrt{F_c^2 + F_t^2} = \sqrt{F_s^2 + F_n^2} = \sqrt{F^2 + N^2}$$

F_s = shear force
F_n = force normal to shear plane
α = tool rake angle (positive as shown)
θ = shear angle
β = friction angle

Force Calculations

- We can write the cutting and thrust forces in terms of the shear force:

$$R = \left(F_c^2 + F_t^2\right)^{1/2} = \left(F_s^2 + F_n^2\right)^{1/2} = \left(F^2 + N^2\right)^{1/2}$$

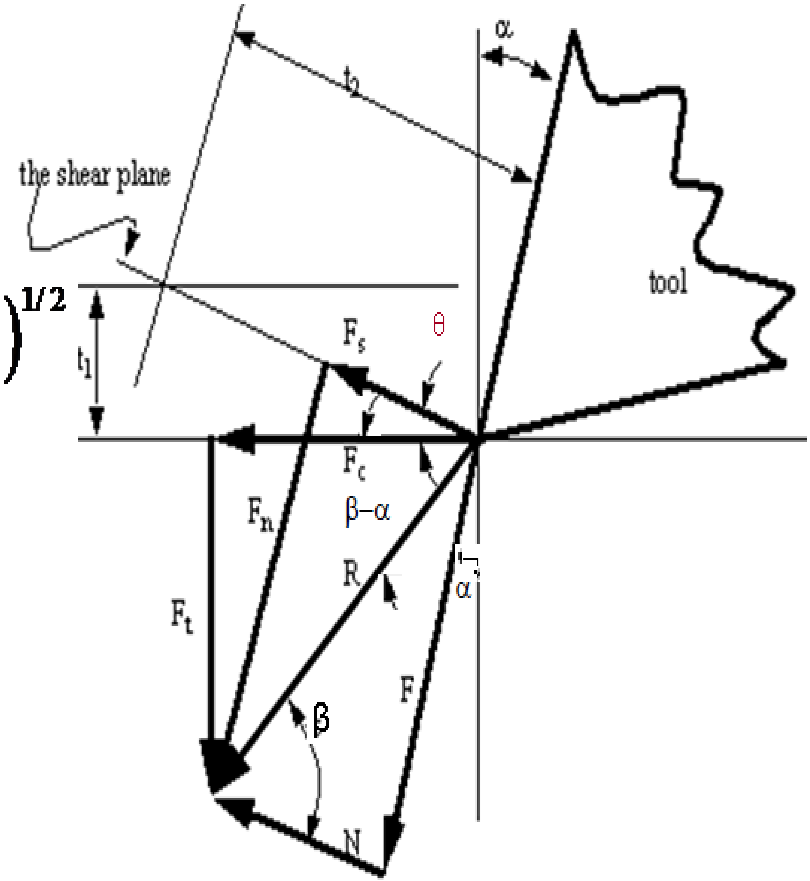
$$F_c = R\cos(\beta - \alpha)$$

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

$$F_s = R\cos(\theta + \beta - \alpha)$$

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

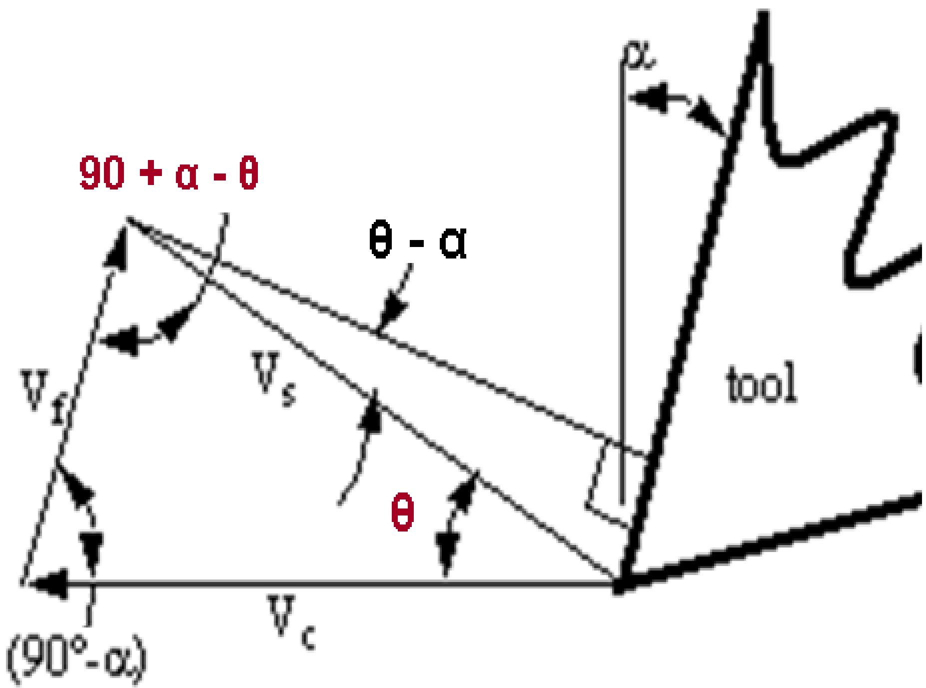
$$\boxed{F_c = \frac{F_s\cos(\beta - \alpha)}{\cos(\theta + \beta - \alpha)} \qquad F_t = \frac{F_s\sin(\beta - \alpha)}{\cos(\theta + \beta - \alpha)}}$$



F_s = shear force
F_n = force normal to shear plane
α = tool rake angle (positive as shown)
θ = shear angle
β = friction angle

Velocity Calculations

- Having seen the vector based determination of the cutting forces, we can now look at equivalent calculations:
- V_c= Cutting velocity (ft/min) as set or measured on the machine
- V_s= Shearing velocity
- V_f= Frictional velocity



Using the sign rules:

$$\frac{V_s}{\sin\left(90^o - \alpha\right)} = \frac{V_c}{\sin\left(90^o + \alpha - \theta\right)}$$

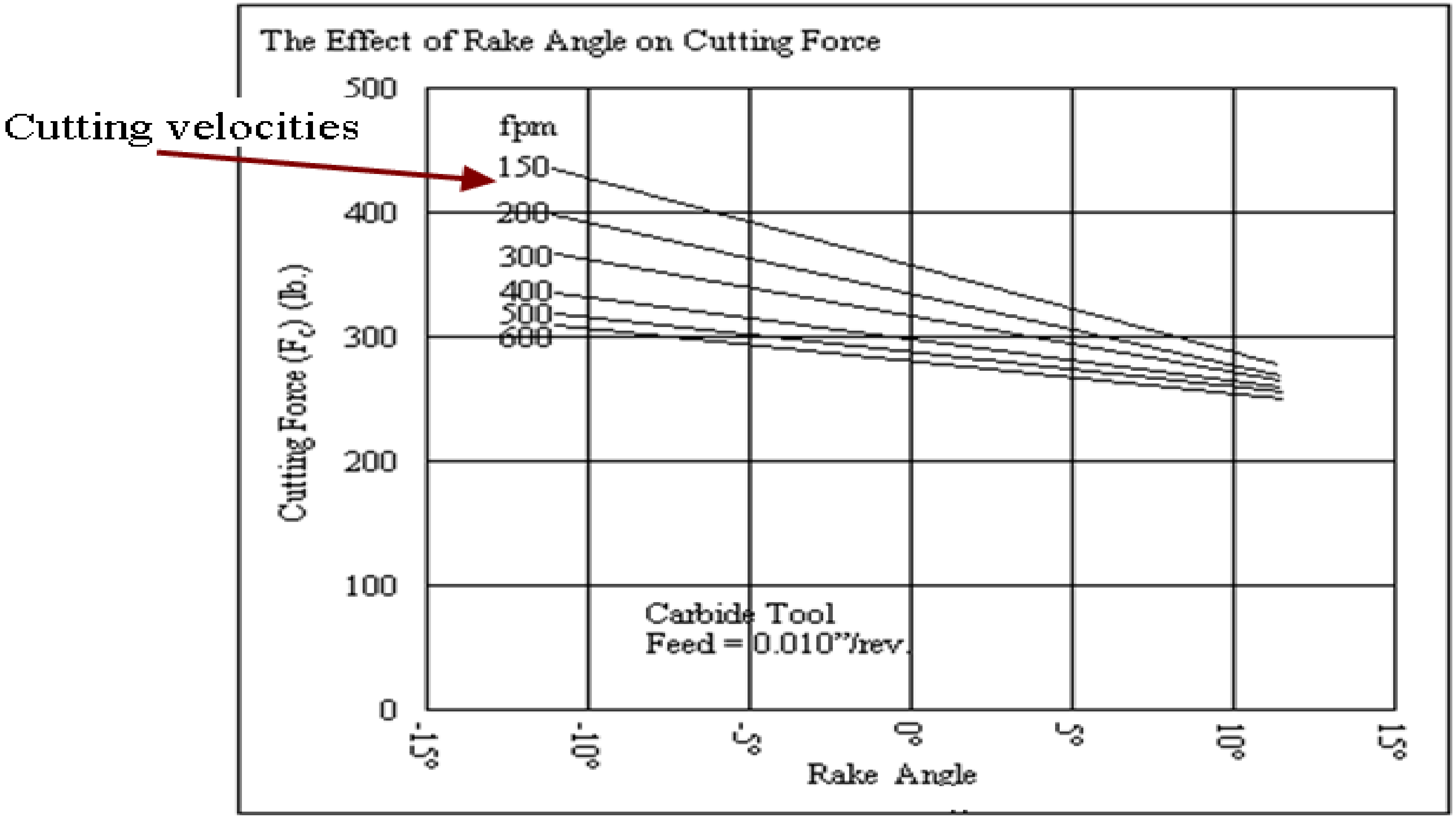
$$V_s = \frac{V_c \sin\left(90^o - \alpha\right)}{\sin\left(90^o + \alpha - \theta\right)} = \frac{V_c \cos\alpha}{\cos\left(\theta - \alpha\right)}$$

Also,

$$V_f = \frac{V_c \sin\theta}{\cos\left(\theta - \alpha\right)}$$

Cutting Force Vs Rake Angle α

- The effects of rake angle on cutting force are shown in the graph below,



The Merchant Equation

- To determine θ he assumed the minimum energy principle applied in metal cutting so that the deformation process adjusted itself to a minimum energy condition.
- Of all the possible angles at which shear deformation can occur, the work material will select a shear plane angle θ that minimizes energy, given by

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

  - Derived by Eugene Merchant

What the Merchant Equation Tells Us

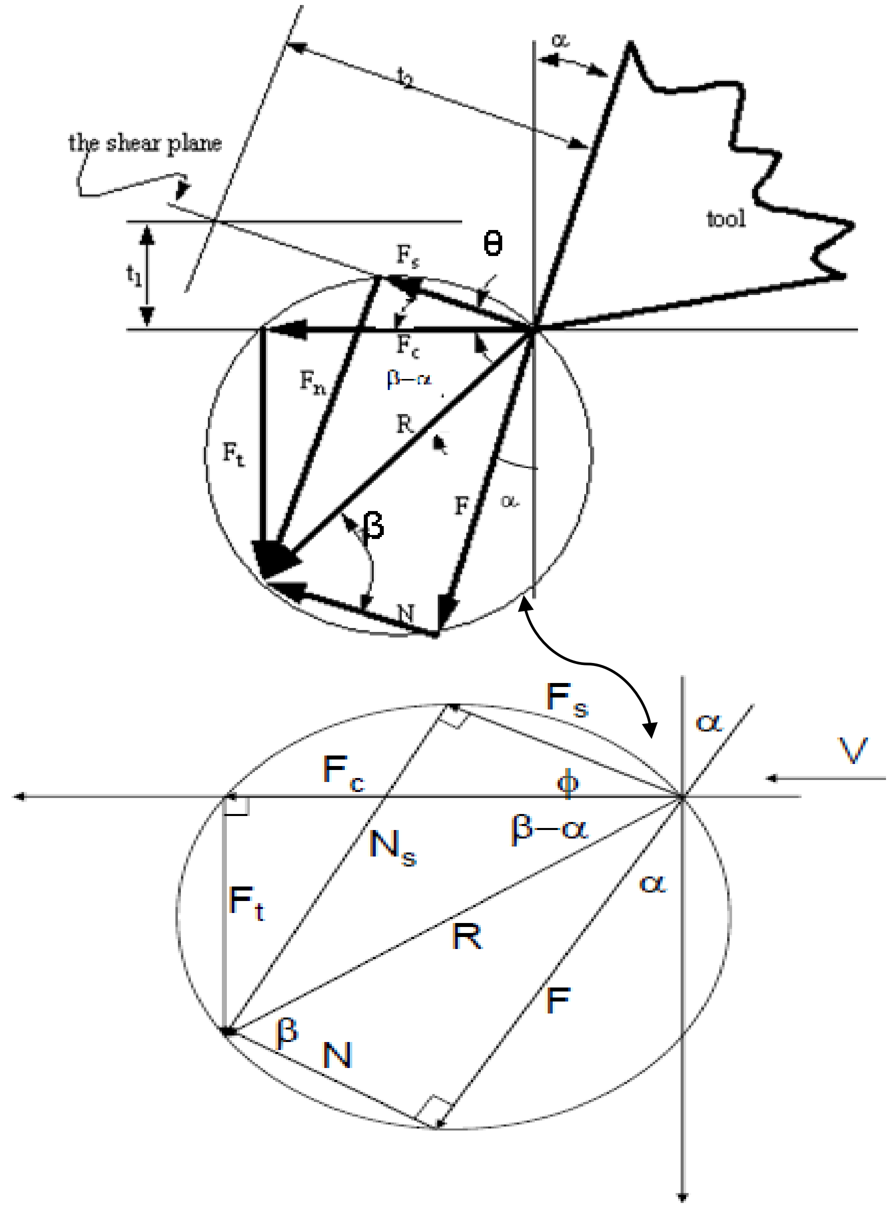
- To increase shear plane angle
  - Increase the rake angle (α)
  - Reduce the friction angle (β) or coefficient of friction

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

Merchant's Force Circle

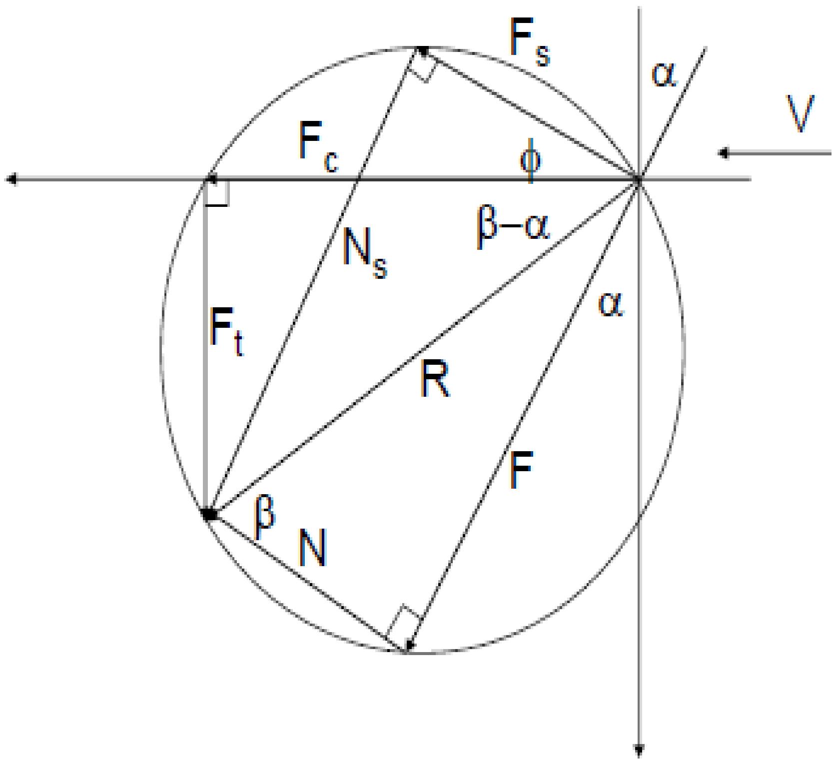
- Merchant's Force Circle is a method for calculating the various forces involved in the cutting process.

1. Set up x-y axis labeled with forces, and the origin in the centre of the page. The scale should be enough to include both the measured forces. The cutting force (F_c) is drawn horizontally, and the tangential force (F_t) is drawn vertically. (These forces will all be in the lower left hand quadrant).



Merchant's Force Circle

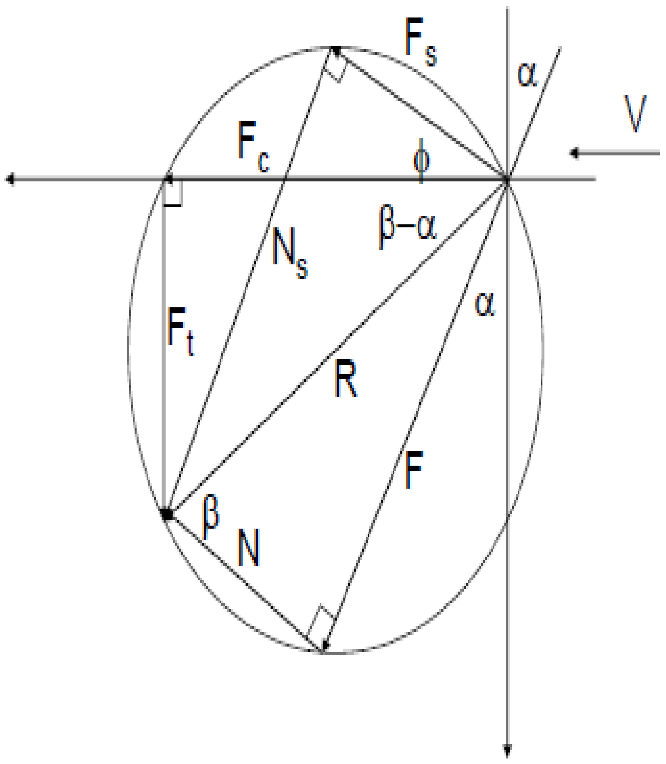
2. Draw in the resultant (R) of Fc and Ft.
3. Locate the centre of R, and draw a circle that encloses vector R. If done correctly, the heads and tails of all 3 vectors will lie on this circle.
4. Draw in the cutting tool in the upper right hand quadrant, taking care to draw the correct rake angle (α) from the vertical axis.
5. 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).



Merchant's Force Circle

Merchant's Force Circle

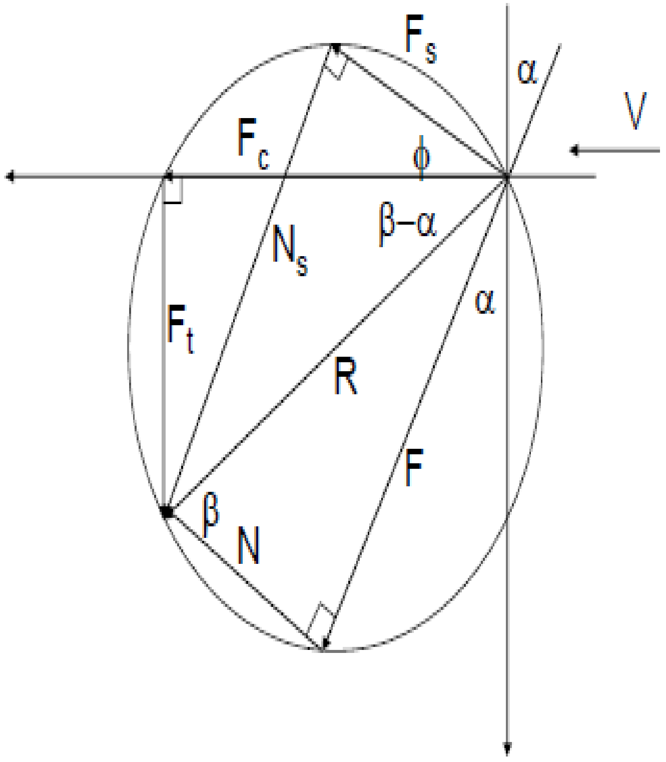
6. A line can now be drawn from the head of the friction vector, to the head of the resultant vector (R). This gives the normal vector (N). Also add a friction angle (β) between vectors R and N. As a side note recall that any vector can be broken down into components. Therefore, mathematically, R = Fc + Ft = F + N.
7. We next use the chip thickness, compared to the cut depth to find the shear force. To do this, the chip is drawn on before and after cut. Before drawing, select some magnification factor (e.g., 200 times) to multiply both values by. Draw a feed thickness line (t_1) parallel to the horizontal axis. Next draw a chip thickness line parallel to the tool cutting face.



Merchant's Force Circle

Merchant's Force Circle

8. 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 F_s and F_c.
9. Finally add the shear force normal (F_n) from the head of F_s to the head of R.
10. Use a scale and protractor to measure off all distances (forces) and angles.



Merchant's Force Circle

Power and Energy Relationships

- There are a number of reasons for wanting to calculate the power consumed in cutting. These numbers can tell us how fast we can cut, or how large the motor on a machine must be. Having both the forces and velocities found with the Merchant for Circle, we are able to calculate the power,
- The power to perform machining can be computed from:

$$Pc = Fc \cdot Vc \text{ in kw}$$

$$Pc = Fc \cdot Vc / 33{,}000 \text{ in HP}$$

where

- P_c = cutting power in KW
- F_c = cutting force in KN
- Vc = cutting speed in m/min

Manufacturing Technology

Power and Energy Relationships

- There are a number of reasons for wanting to calculate the power consumed in cutting. These numbers can tell us how fast we can cut, or how large the motor on a machine must be. Having both the forces and velocities found with the Merchant for Circle, we are able to calculate the power,
- The power to perform machining can be computed from:

$$Pc = Fc \cdot Vc \quad \text{in kw}$$

$$Pc = Fc \cdot Vc / 33{,}000 \quad \text{in HP}$$

where

- P_c = cutting power in KW
- F_c = cutting force in KN
- Vc = cutting speed in m/min

Manufacturing Technology

Power and Energy Relationships

- Gross power to operate the machine tool P_g or HP_g is given by

$$\boxed{P_g = \frac{P_c}{E}} \quad \text{or} \quad \boxed{HP_g = \frac{HP_c}{E}}$$

where

- E = mechanical efficiency of machine tool
- Typical E for machine tools ~ 90%

- There are losses in the machine that must be considered when estimating the size of the electric motor required:

$$\boxed{P_g = \frac{P_c}{E} + P_t}$$

Where

- Pt = power required to run the machine at no-load conditions (hp or kW)

Manufacturing Technology

Power and Energy Relationships

- Useful to convert power into power per unit volume rate of metal cut (power to cut one cubic inch per minute)
- Called *unit power*, P_u or *unit horsepower*, HP_u

$$\boxed{P_U = \frac{P_c}{R_{MR}}}$$

or

$$\boxed{HP_U = \frac{HP_c}{R_{MR}}}$$

- where R_{MR} = material removal rate

Manufacturing Technology

Power and Energy Relationships

- Unit power is also known as the *specific energy U*

$$U = P_u = \frac{P_c}{R_{MR}} = \frac{F_c \cdot V_c}{V_c \cdot t_1 \cdot w} = \frac{F_c}{t_1 \cdot w}$$

- Units for specific energy are typically N-m/mm3 or J/mm3 (in-lb/in3)
- Specific energy is in fact pressure and sometimes is called specific cutting pressure:

$$U = \frac{F_c}{A}$$

Manufacturing Technology

Cutting Temperature

- Approximately 98% of the energy in machining is converted into heat
- This can cause temperatures to be very high at the tool-chip
- The remaining energy (about 2%) is retained as elastic energy in the chip

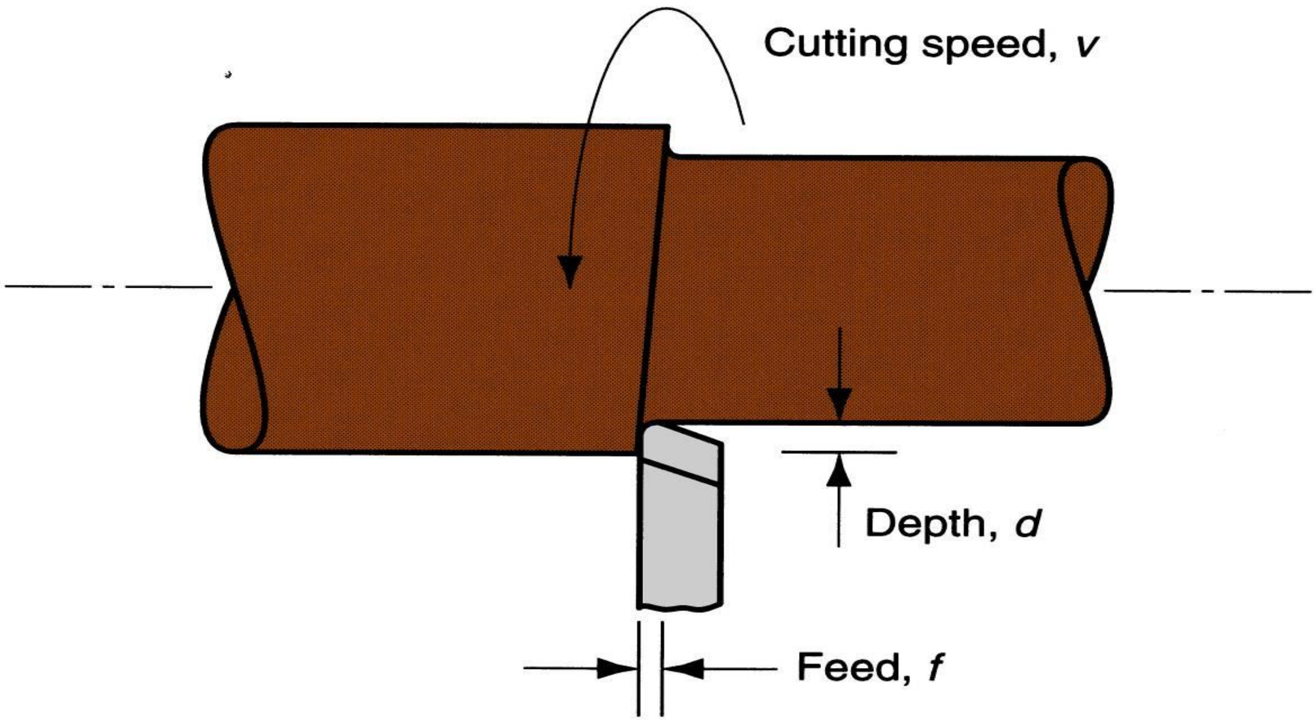
High cutting temperatures

- Reduce tool life
- Produce hot chips that pose safety hazards to the machine operator
- Can cause inaccuracies in part dimensions due to thermal expansion of work material

Manufacturing Technology

Process Parameters

- Speed (v), Feed (f), Depth of Cut (d)
- Material Removal Rate (MRR) = f x d x v



Shear angle and its significance

- Shear angle(θ) is the angle made by the shear plane with the cutting speed vector.
- Shear angle is very important parameter I metal cutting. Higher the shear angle, better is the cutting performance.
- In metal cutting it is observed that a higher rake angles give rise to higher shear angles

Manufacturing Technology

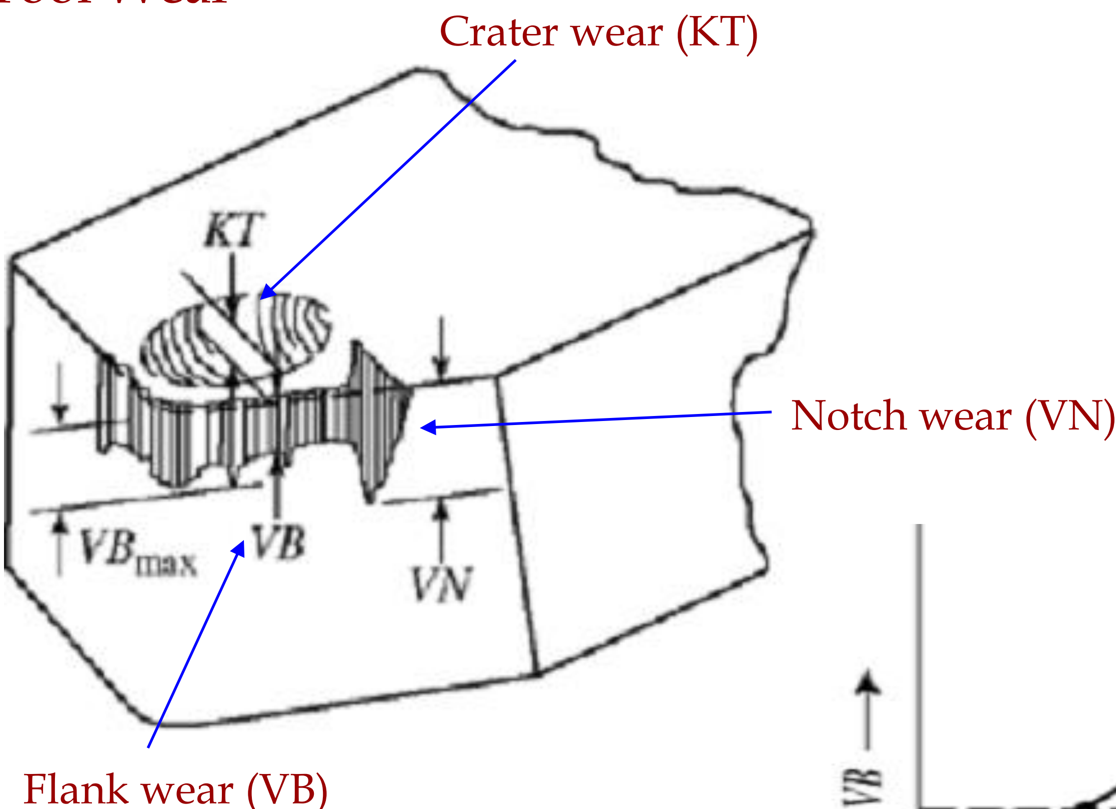
Tool Wear

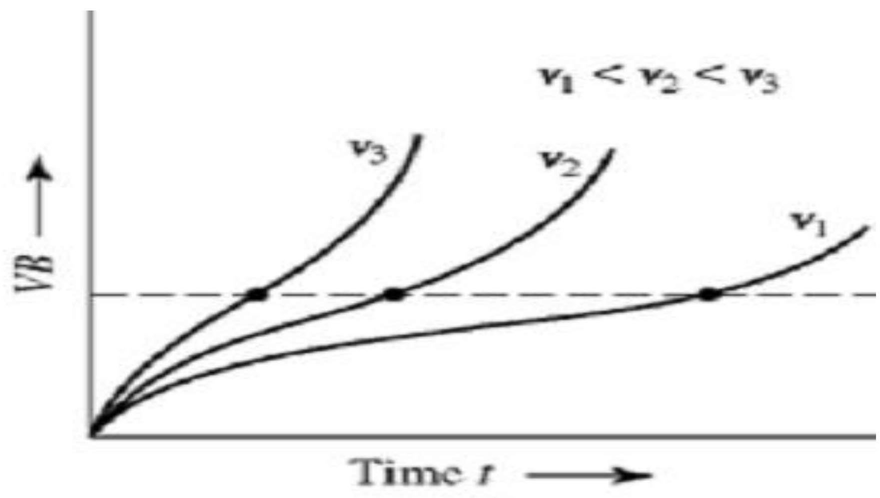
- Tools get worn out due to long term usage

Types of Tool Wear

- Flank wear (VB)
  - It occurs on the relief face of the tool and the side relief angle.
- Crater wear (KT)
  - It occurs on the rake face of the tool.
- Notch wear or Chipping (VN)
  - Breaking away of a small piece from the cutting edge of the tool

Tool Wear





Flank wear rate based on cutting speed

Manufacturing Technology

Tool Wear

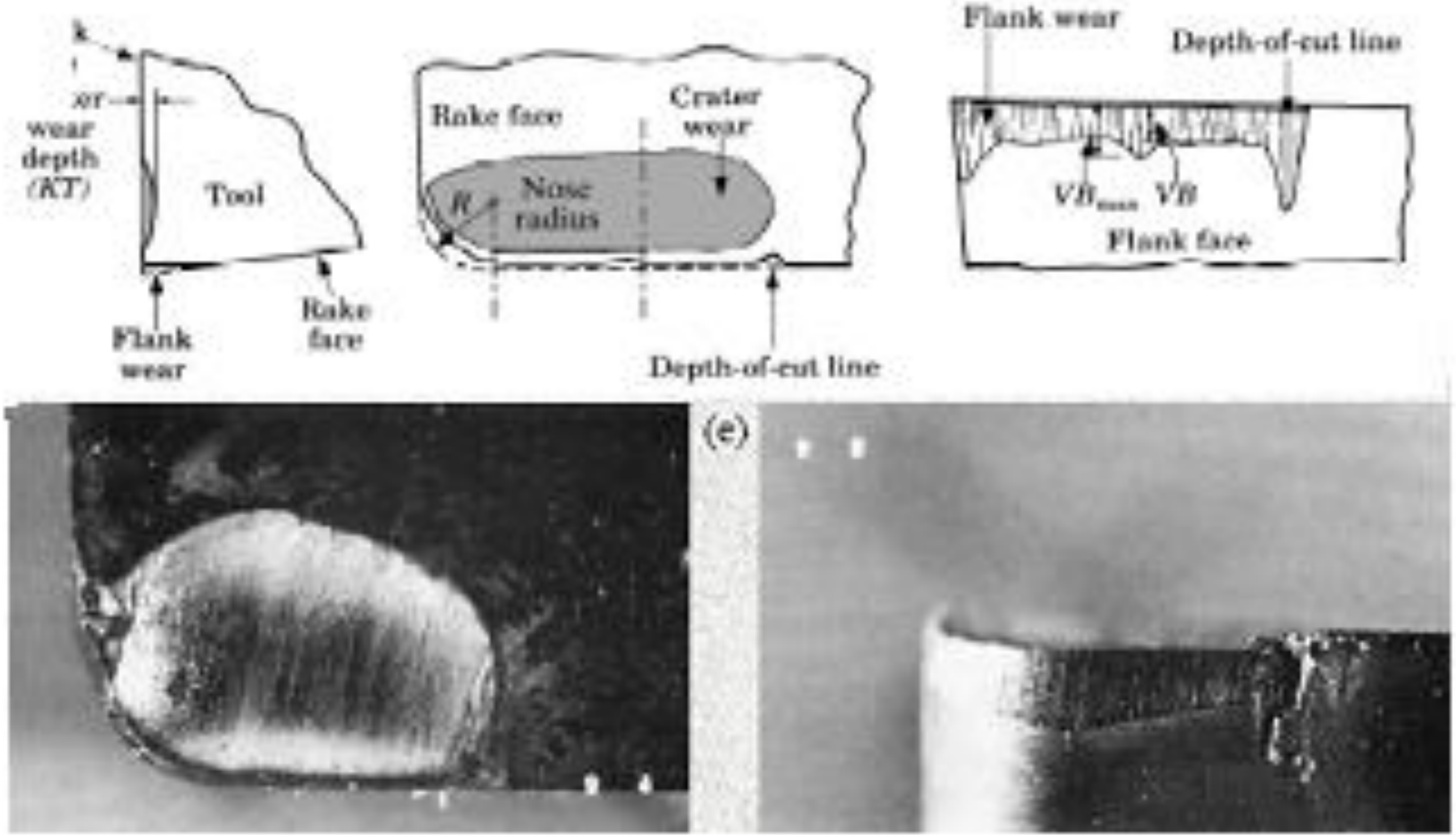


Fig (a) Flank and crater wear in a cutting tool. tool moves to the left. (b) View of the rake of a turning tool, showing nose radius R and crater wear pattern on the rake face of the tool c) View of the flank face of a turning tool, sowing the average flank wear land VB and the depth-of-cut line (wear notch)

Manufacturing Technology

Tool Life

- Tool life represents the useful life of the tool, expressed generally in time units from the start of cut to some end point defined by a failure criterion.

Tool Life Prediction

- Taylor's tool life equation predicts tool failure based on flank wear of the tool

$$Vt^n = C$$

where

- V is the cutting speed, t is the tool life,
- n is Taylor exponent.
  - n=0.125 for HSS
  - n=0.25 for Carbide
  - n=0.5 for Coated Carbide/Ceramic
  - C is a constant given for work piece material

Manufacturing Technology

Machinability

- Machinability is a system property that indicates how easy a material can be machined at low cost.
- Good machinabililty may mean one or more of the following: cutting with minimum energy, minimum tool wear, good surface finish, etc.

Quantitative measures of machinability

- Machinability index: an average rating stated in comparison with reference materials. This measure can be misleading.
- Tool life: service time in minutes or seconds to total failure by chipping or cracking of the tool at certain cutting speed, or the volume of material removed before total failure.
- Surface finish produced at standardized cutting speeds and feeds.
- Others based on cutting force, power, temperature, or chip formation.

Manufacturing Technology

Machinable Materials

Good machinable materials should have the following properties

- Low ductility, low strain-hardening exponent (n), low fracture toughness.
- Low shear strength (low TS), low hardness.
- A strong metallurgical bond (adhesion) between tool and work piece is undesirable when it weakens the tool material.
- Very hard compounds, such as some oxides, all carbides, many inter metallic compounds, and elements such as silicon, embedded in the work piece material accelerate tool wear, thus should be avoided.
- Inclusions that soften at high temperatures are beneficial.
- High thermal conductivity is helpful.

Manufacturing Technology

Machinable Materials

- Ferrous materials
  - Carbon steels: annealed, heat-treated (spheroidized), cold worked
  - Free-machining steels: special inclusions
  - Alloy steels: hard
  - Stainless steels: high strength, low thermal conductivity, high strain hardening rate
  - Cast iron: white, gray, nodular cast iron
- Non-ferrous materials
  - Zinc, Magnesium, Aluminum alloys, Beryllium, Copper-based alloys, Nickel-based alloys and super alloys,
  - Titanium, Plastics, composites.

Manufacturing Technology

Factors Affecting Machining

TABLE

Parameter	Influence and interrelationship
Cutting speed, depth of cut, feed, cutting fluids	Forces, power, temperature rise, tool life, type of chip, surface finish
Tool angles	As above; influence on chip flow direction; resistance to tool chipping
Continuous chip	Good surface finish; steady cutting forces; undesirable in automated machinery.
Built-up edge chip	Poor surface finish; thin stable edge can protect tool surfaces.
Discontinuous chip	Desirable for ease of chip disposal; fluctuating cutting forces; can affect surface finish and cause vibration and chatter.
Temperature rise	Influences tool life, particularly crater wear, and dimensional accuracy of workpiece; may cause thermal damage to workpiece surface.
Tool wear	Influences surface finish, dimensional accuracy, temperature rise, forces and power.
Machinability	Related to tool life, surface finish, forces and power.

Manufacturing Technology

Cutting Fluids

- A fluid which is used in machining as well as abrasive machining processes to reduce friction and tool wear

Function of cutting fluids

- Lubrication
- Cooling
- Chip removal

Types

- Straight Oil (Petroleum based oils)
- Soluble Oil (water based oils)

Manufacturing Technology

Problems

- Refer P.C. Sharma volume-II book
- Page No – 33 to 46

END