MANUFACTURING TECHNOLOGY-II

MEC3442

UNIT 1

UNIT 1

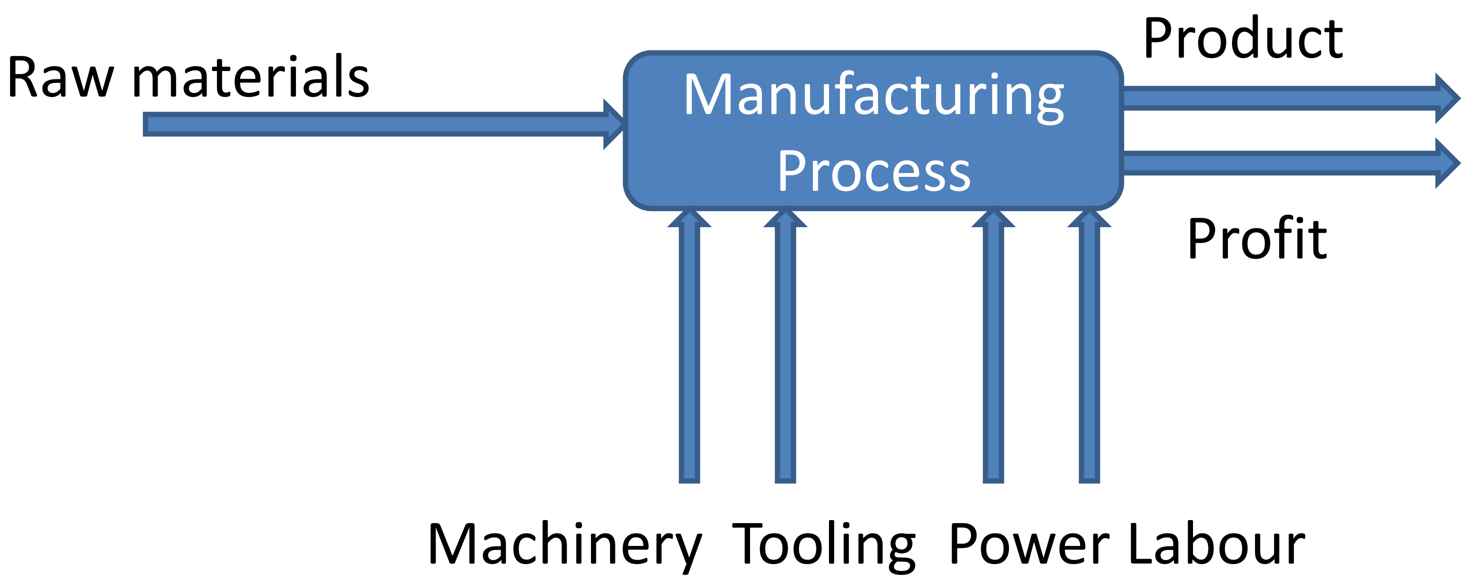
Mechanics of metal cutting:

- Chip formation
- Signature of single and multi-point cutting tools
- Tool geometry and materials,
- Temperature in cutting,
- Cutting Fluids,
- Tool life and wear
- Economics of machining

Manufacturing:

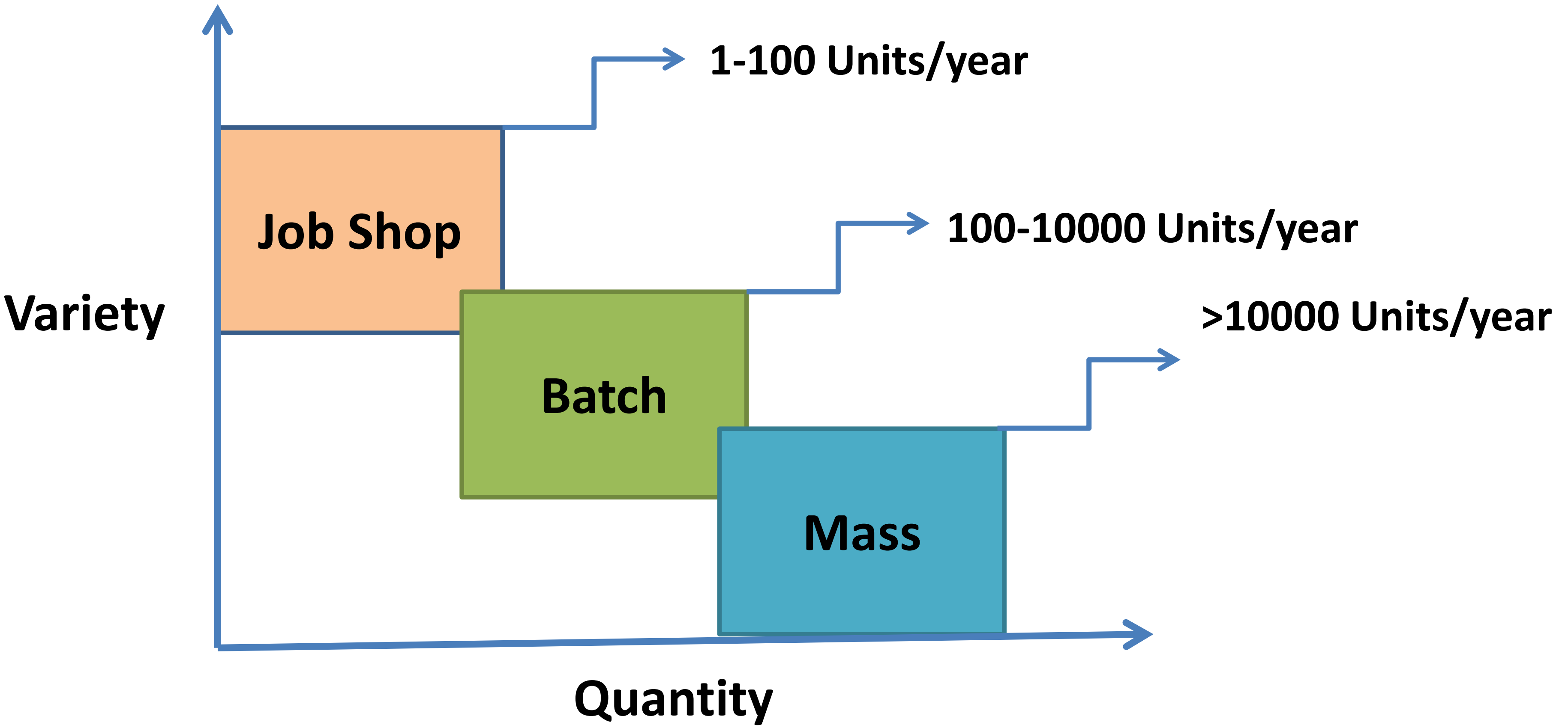
Derived from Latin word Manu (hand) and factus (making)

Manufacturing is the process of **converting** raw materials and into finished goods.
Manufacturing involves a **combination** of machinery, tools, power and manual labour.
Manufacturing is the **transformation** of materials into items of **greater value** by means of one or more processing involved.

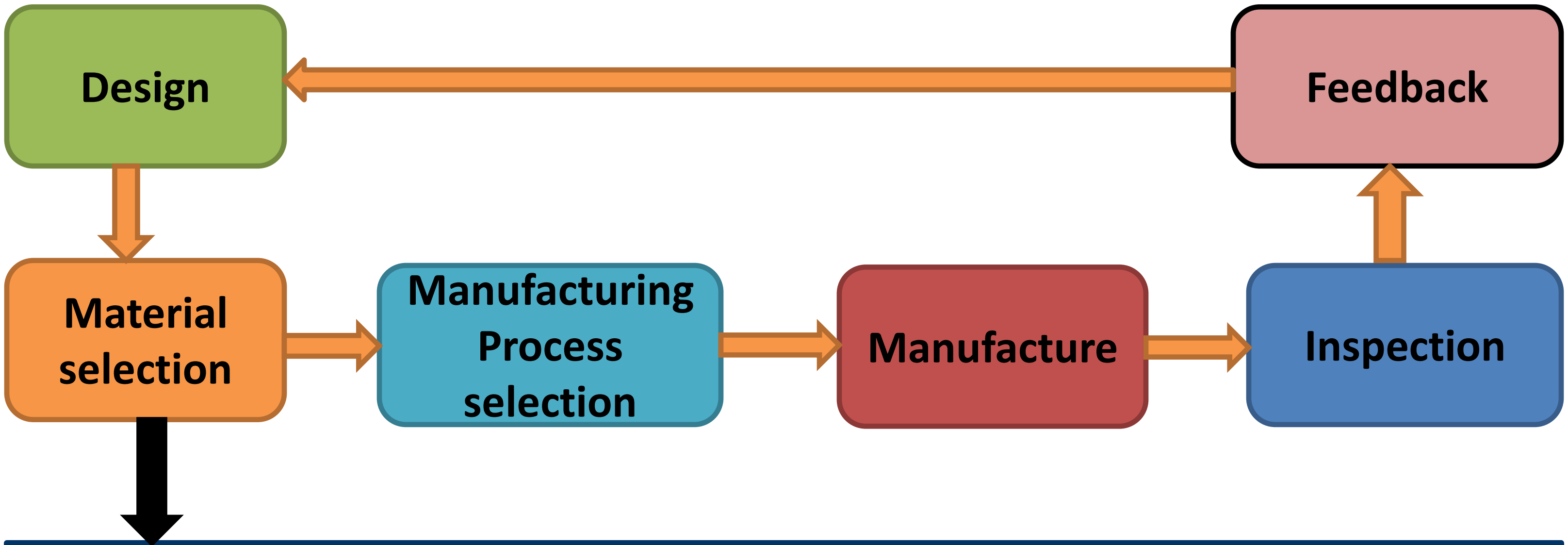


1st Industrial Revolution	2nd Industrial Revolution	3rd Industrial Revolution	4th Industrial Revolution	5th Industrial Revolution
Mechanisation	Electrification	Automation and Globalisation	Digitalisation	Personalisation
Occurred during the 18th centuries, mainly in Europe and North America	From the late 1800s to the start of the First World War	The digital revolution occurred around the 1980s	Start of the 21st century	2nd decade of the 21st century
Steam engines replacing horse and human power	Production of steel, electricity and combustion engines.	Computers, digitisation and the internet,	AI, robotics, IoT, blockchain and crypto.	Innovation purpose and inclusivity.
Introduction of mechanical production facilities driven by water and steam power	Division of labour and mass production, enabled by electricity.	Automation of production through electronic and IT systems	Robotics, artificial intelligence, augmented reality, virtual reality	Deep, multi-level cooperation between people and machines. Consciousness.

Manufacturing Environment



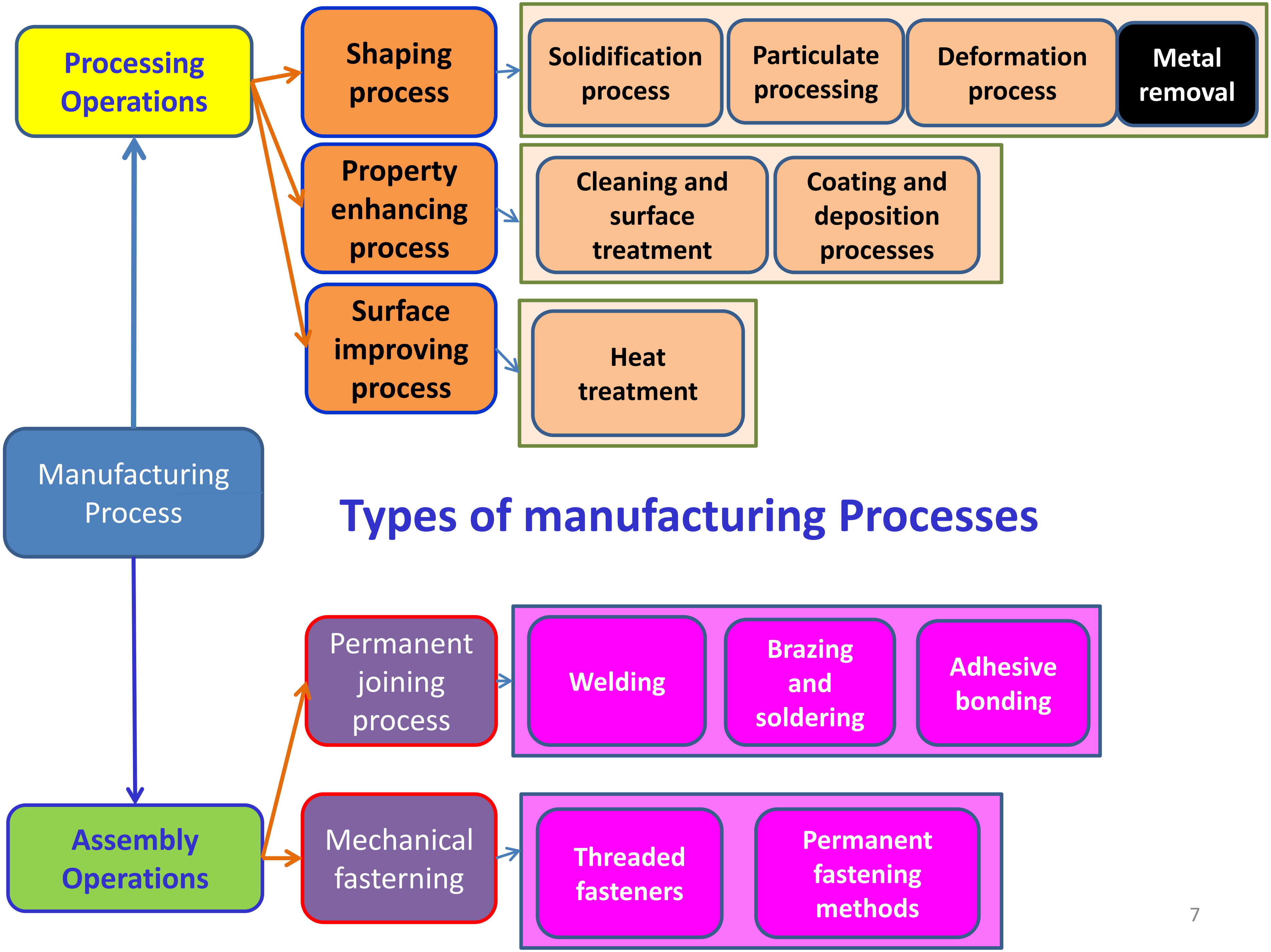
Product creation cycle



Most **engineering materials** can classified into one of the following three categories:

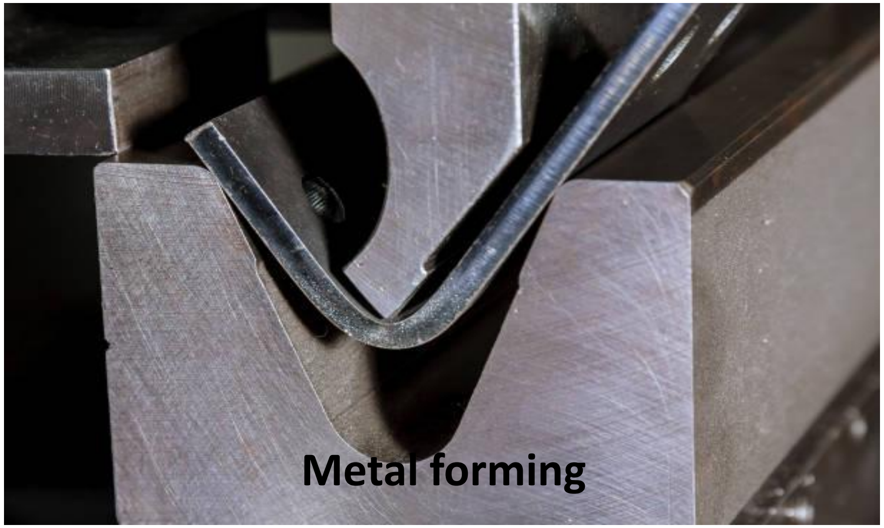
- **Metals**
- **Ceramics**
- **Polymers**
- **Composites**

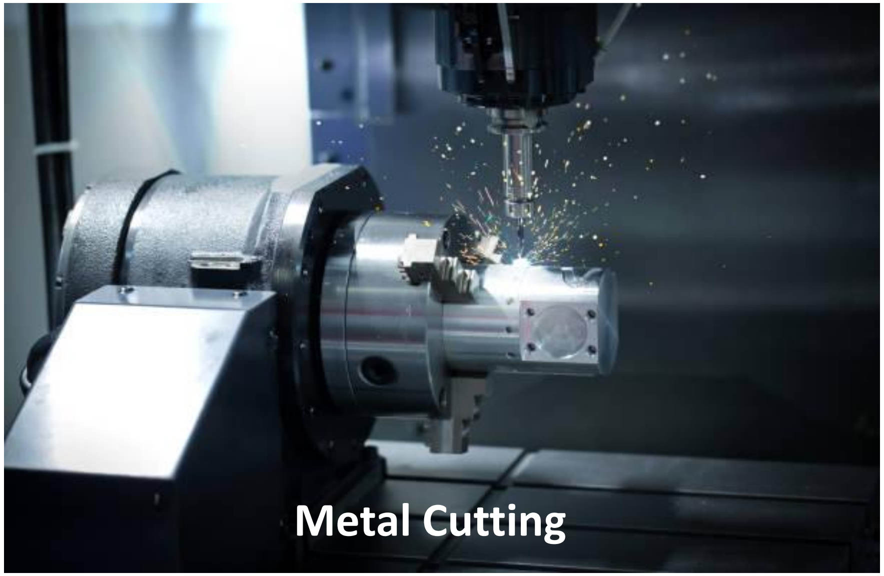
Their physical and mechanical properties are different.
These differences affect the selection of manufacturing process that can be used to produce products out of them.

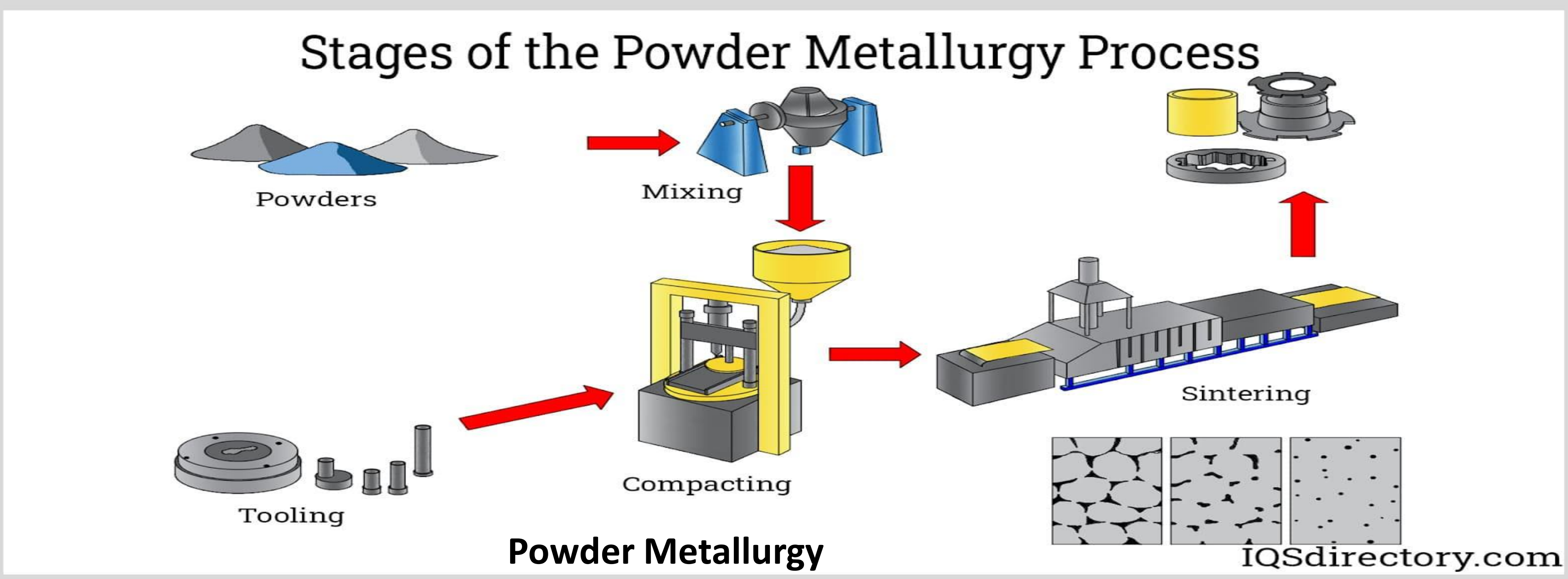

Processing Operations
Shaping process
Solidification process
Particulate processing
Deformation process
Metal removal
Property enhancing process
Cleaning and surface treatment
Coating and deposition processes
Surface improving process
Heat treatment
Manufacturing Process
Types of manufacturing Processes
Permanent joining process
Welding
Brazing and soldering
Adhesive bonding
Assembly Operations
Mechanical fasterning
Threaded fasteners
Permanent fastening methods

Types of Manufacturing Processes

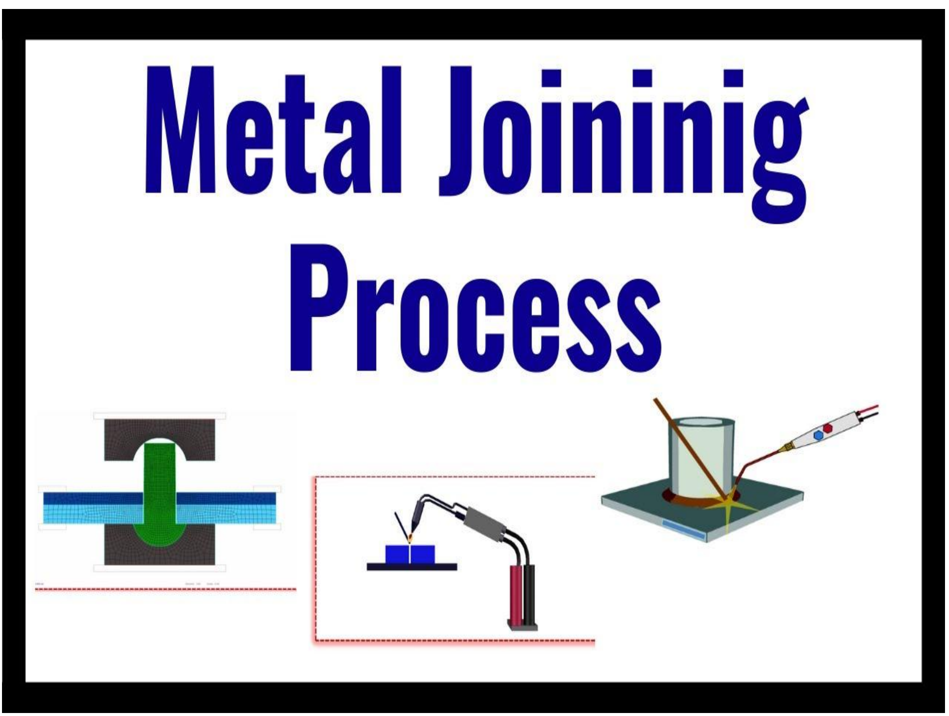
Basic Manufacturing Processes:

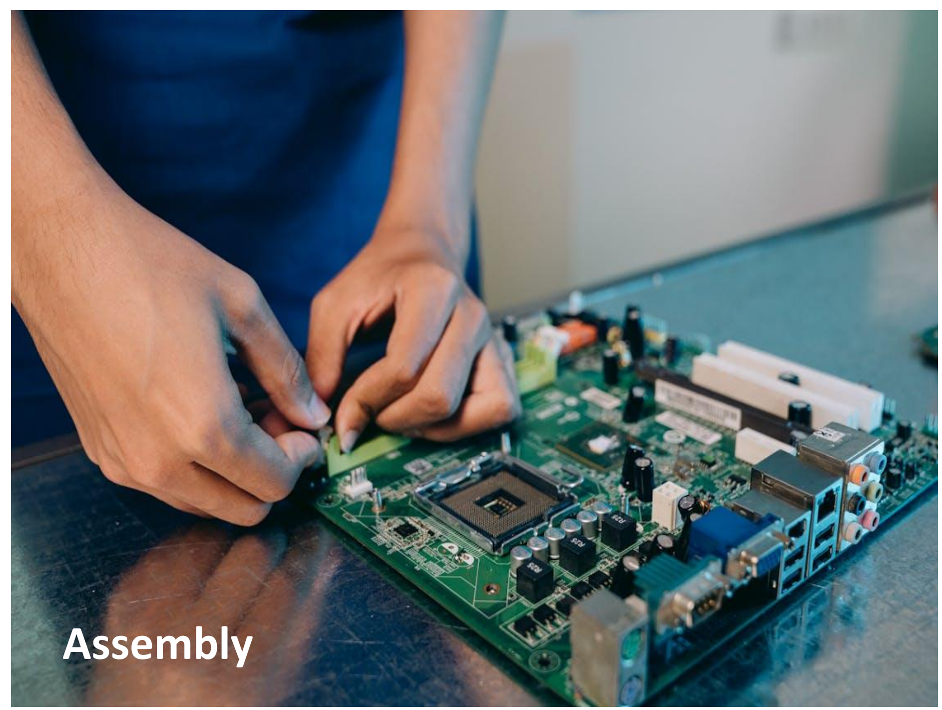






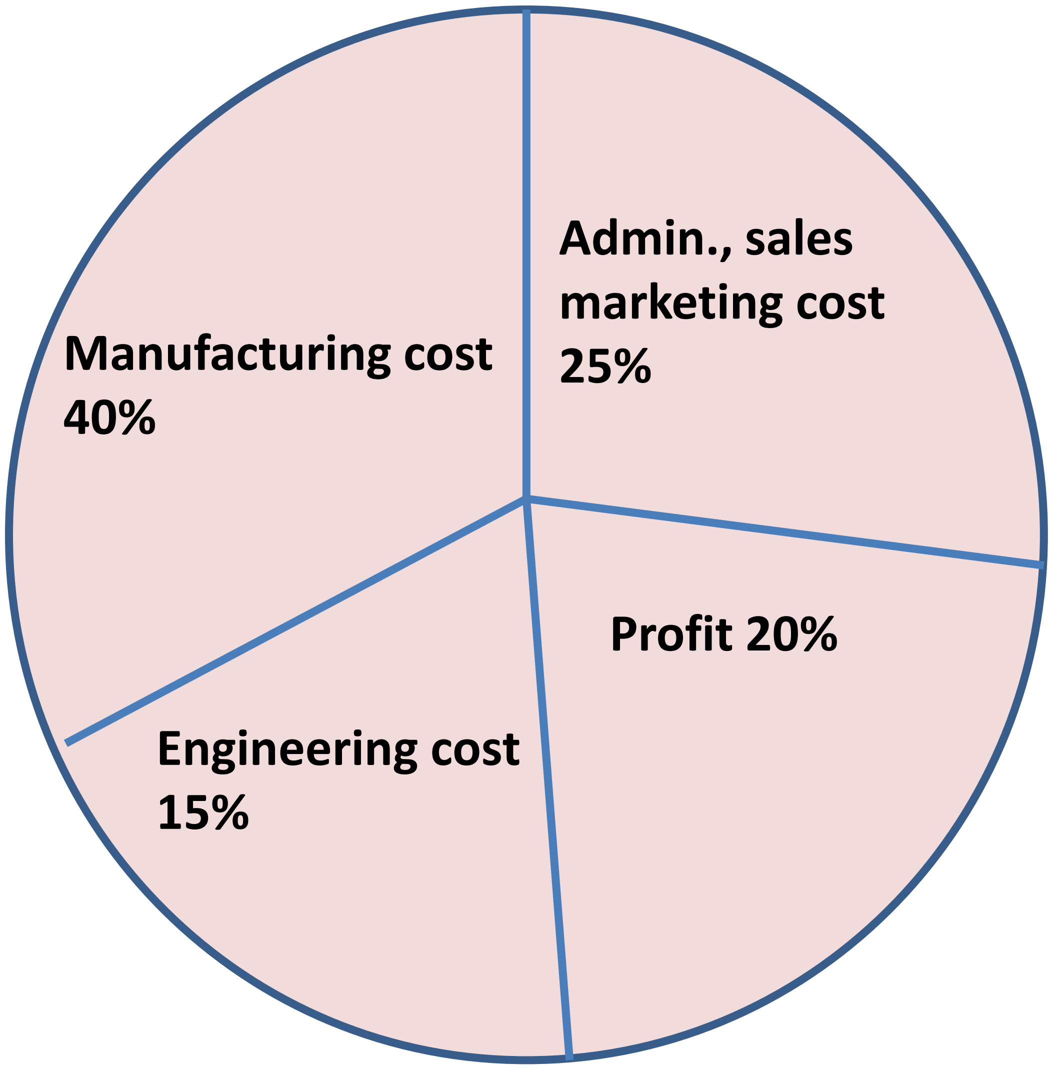
Powder Metallurgy





Assembly

Typical product cost breakdown

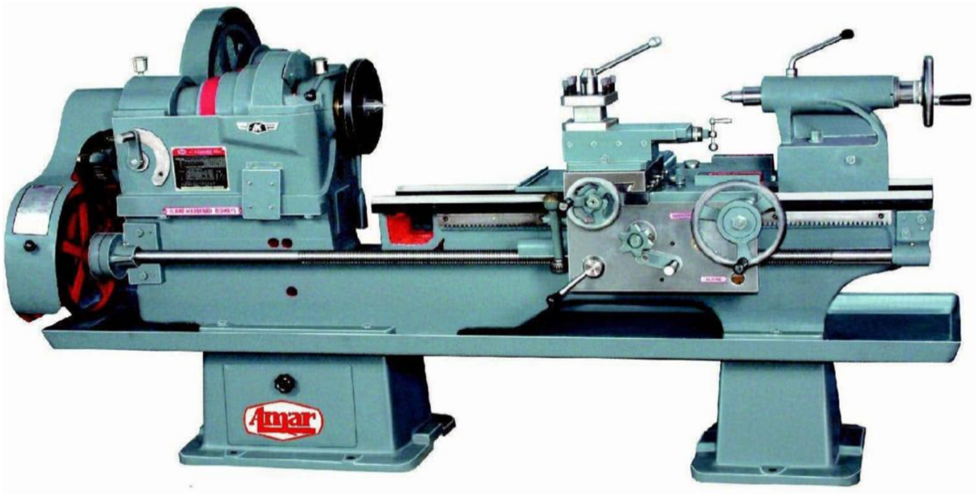


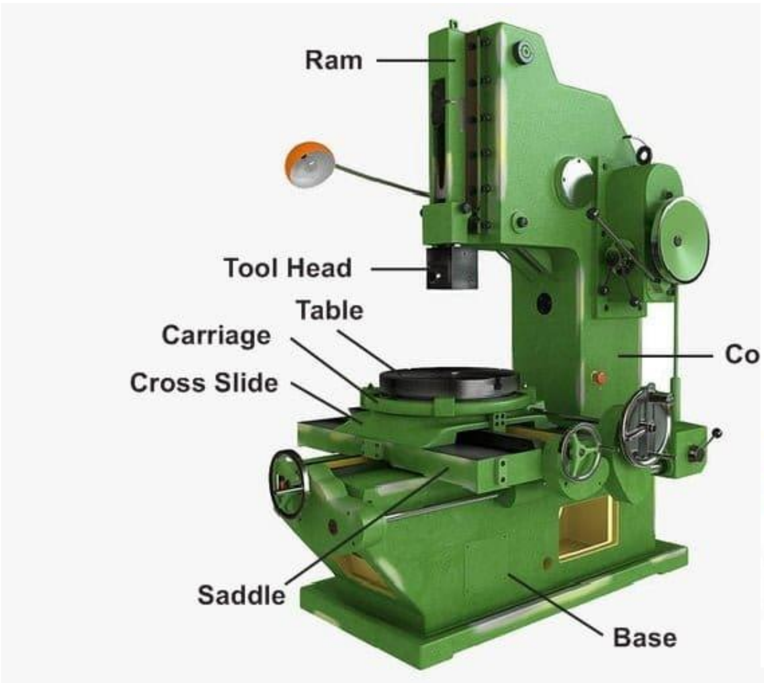
Machine Tools

Machine tools, any stationary power-driven machine that is used to shape or form parts made of metal or other materials.

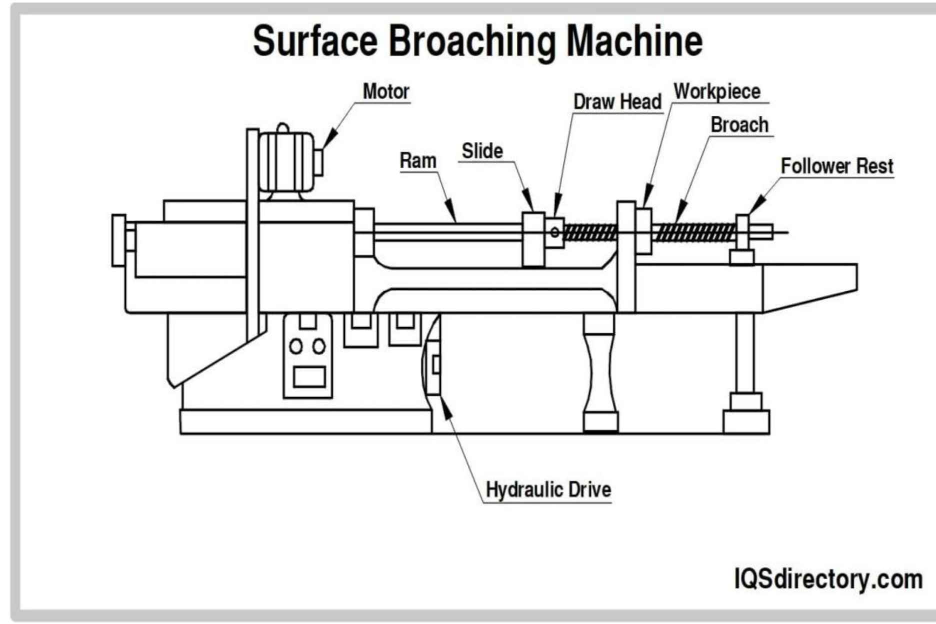
- **by cutting excess material in the form of chips from the part:** lathes, shapers and planers, drilling machines, milling machines, grinders, and power saws.
- **by shearing the material:** cold forming of metal parts, such as cooking utensils, automobile bodies, and similar items, is done on punch presses, while the hot forming of white-hot blanks into appropriately shaped dies is done on forging presses
- **by applying electricity, ultrasound, or corrosive chemicals to the material** : Electrical-discharge machining (EDM) , Electrochemical machining (ECM, Plasma arc machining (PAM), Ultrasonic machining (USM),Water-jet machining (WJM) etc.

Machine Tools





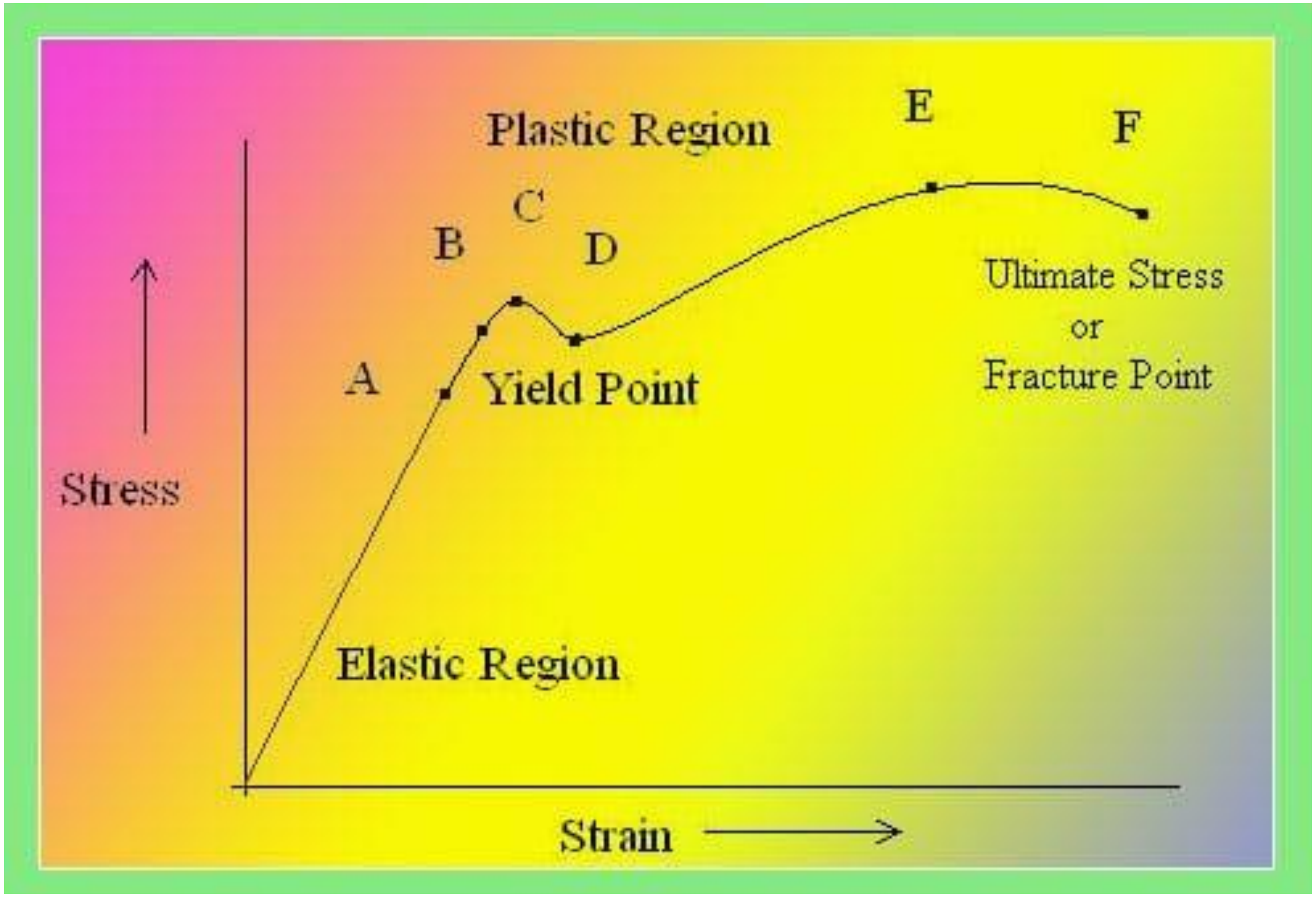

gettyimages
Credit: Phynart Studio
1348571044


Surface Broaching Machine
Motor
Draw Head
Workpiece
Broach
Ram
Slide
Follower Rest
Hydraulic Drive
IQSdirectory.com

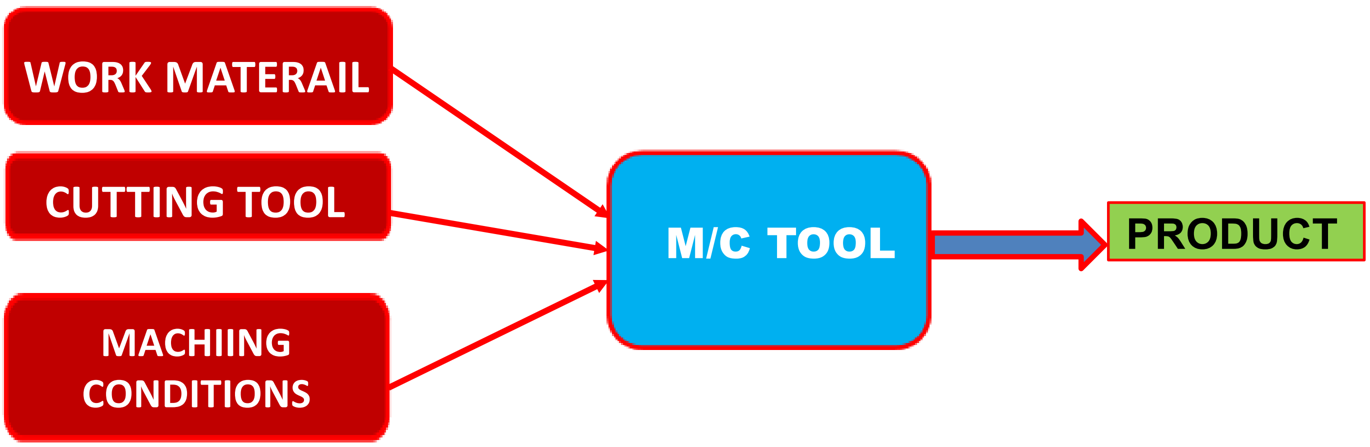

Adobe Stock | #251386765

Machining Processes

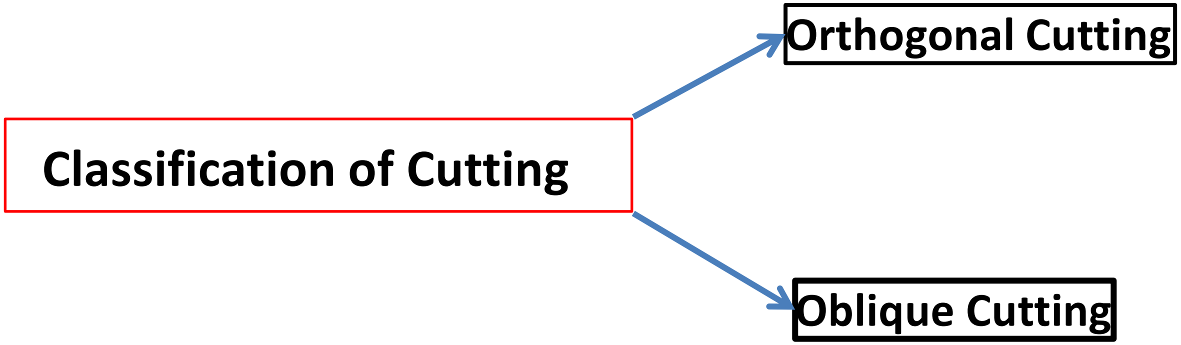
- The materail fails by:
    - **PLASITC DEFORMATION**
    - **SHEARING**



Metal Cutting Process



Metal Cutting Plastic Deformation/Shearing



Metal Cutting Process

Metal cutting process are desirable beacuse:

- Close dimensional accuracy.
- Complex intricate proile can be obtained which can not be obtained by other methods of manufacturing.
- Finishing operations.
- Economical for low production rate.
- Special surace characteristics (mirror made by dimond cutting tool).

Metal cutting process are undesirable beacuse:

- Removal process waste maaterials and require more materials, energy, capital than other methods of manufacturing.
- Unless carried out properly metal cutting processes can have adverse effects on the surface quality and properties of the product.
- Removing a volume of material from work piece generally takes longer than it does to shape it by other processes.

Metal Cutting Process

- In machining the workpiece materials should be **softer** than the tool materials and the desired shape, size and finish are obtained through the removal of excess materials in the form of small **chips.**

- The body which removes the excess material through a direct mechanical contact is called the **cutting tool** and the machines which provides the necessary relative motion between the work and the tool is called the **machine tool.**

- The relative motion between the tool and the work responsible for **cutting action** is called **primary or cutting motion**, and that responsible for gradually **feeding the uncut portion** is termed as the **secondary or feed motion.**

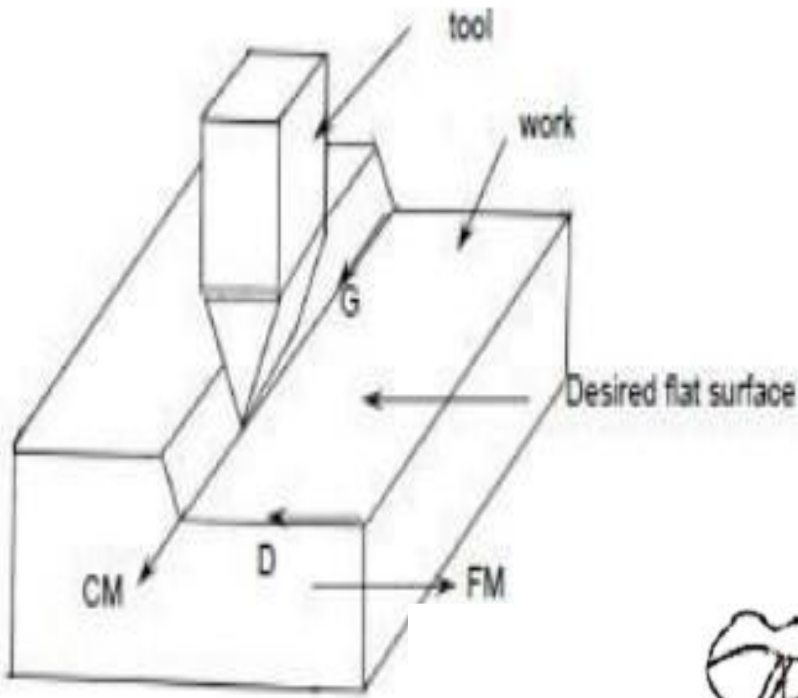
Metal Cutting Process

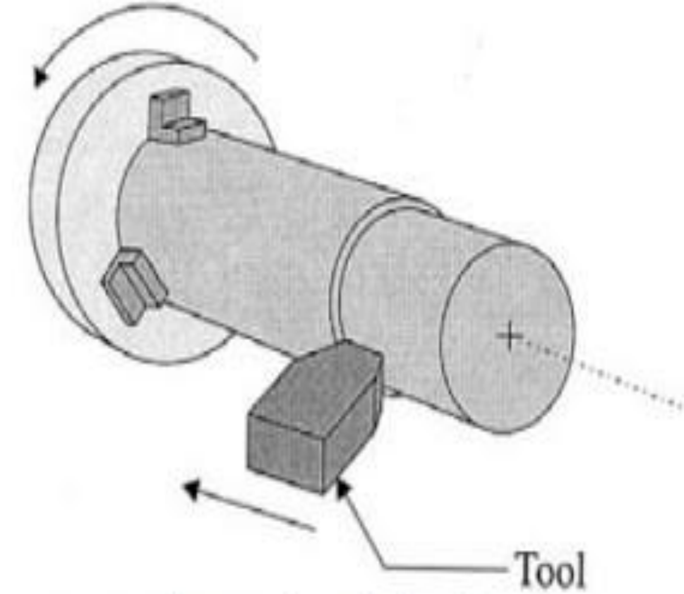
- Depending on the nature of the two relative motions, various types of surfaces can be produced.

- The line generated by the cutting motion is called **GENERATRIX.**

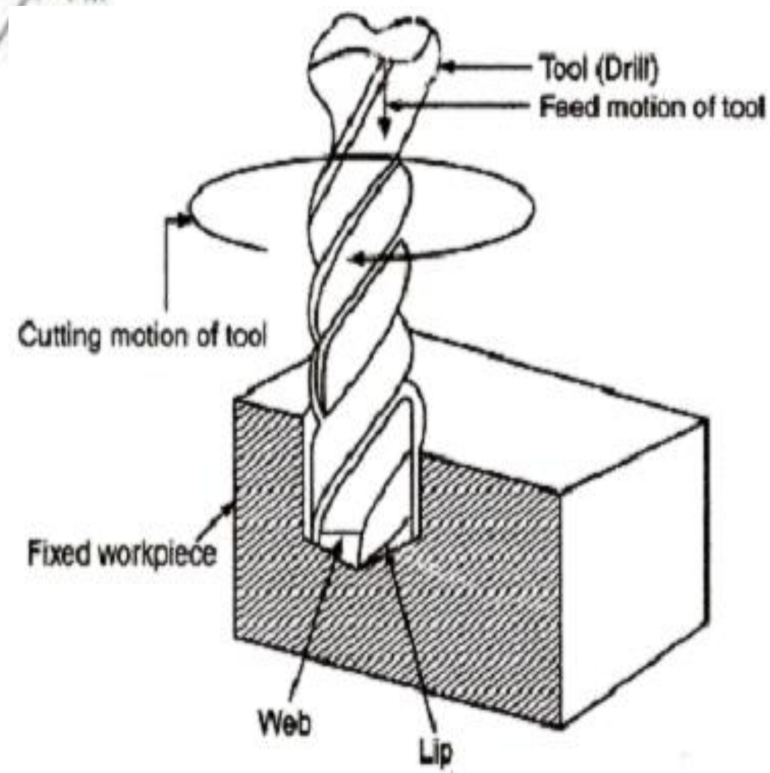
- The line generated by feed motion is called **DIRECTRIX.**

- Various geometries can be obtained depending on the shape of the Generatrix and Directrix.





one-dimensional turning



Mechanics of Cutting

- ***Independent variables*** in cutting are:

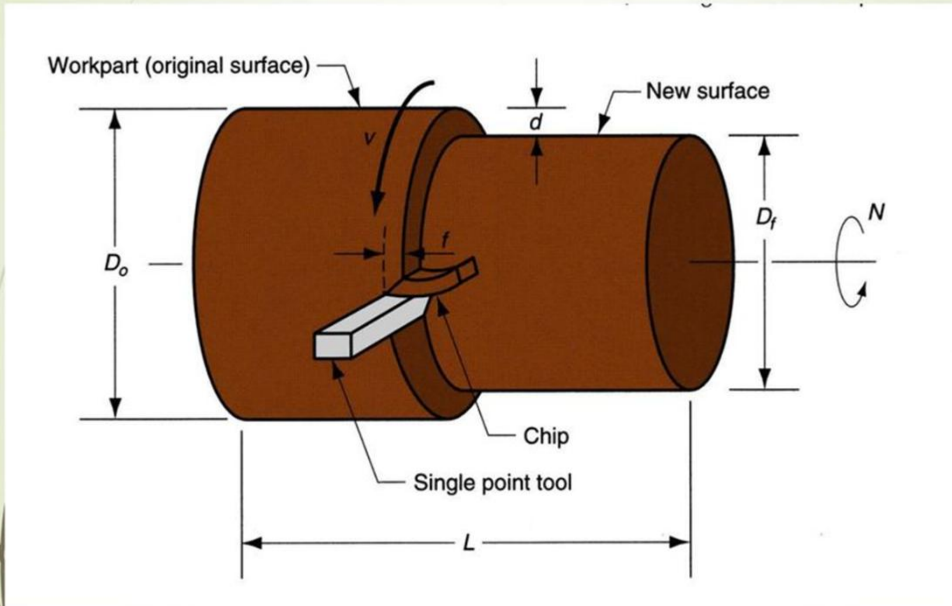
1. Tool material and coatings (Coatings increase the hardness on the surface of the tool (**TiN - TITANIUM NITRIDE, TiCN - TITANIUM CARBONITRID**
2. Tool shape, surface finish, and sharpness
3. Work piece material and condition
4. Cutting speed, feed, and depth of cut
5. Cutting fluids
6. Characteristics of the machine tool
7. Work holding and fixturing

Mechanics of Cutting

- ***Dependent variables*** in cutting are:

1. Type of chip produced
2. Force and energy dissipated during cutting
3. Temperature rise in the work piece, the tool and the chip
4. Tool wear and failure
5. Surface finish and surface integrity of the work piece

Turning Operation



For metal cutting processes it necessary to distinguish between w.r.t **TURNING.**

SPEED (V) is the primary cutting motion which relates the velocity of the cutting tool relative to workpiece. It is generally given in terms of m/min, m/sec etc.

FEED (f) is the amount of material removed per revolution or per pass of the tool over the work piece.

Depth of Cut (DOC) is the distance the tool is plunged into the surface. It is half the difference in the initial diameter and final diameter. DOC= (D-d)/2

Orthogonal and oblique cutting

Orthogonal/Oblique cutting

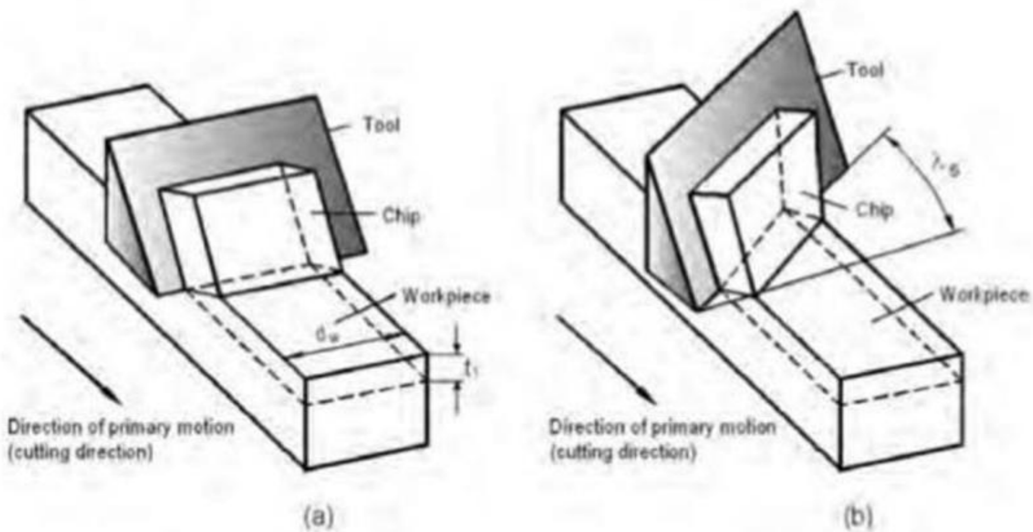
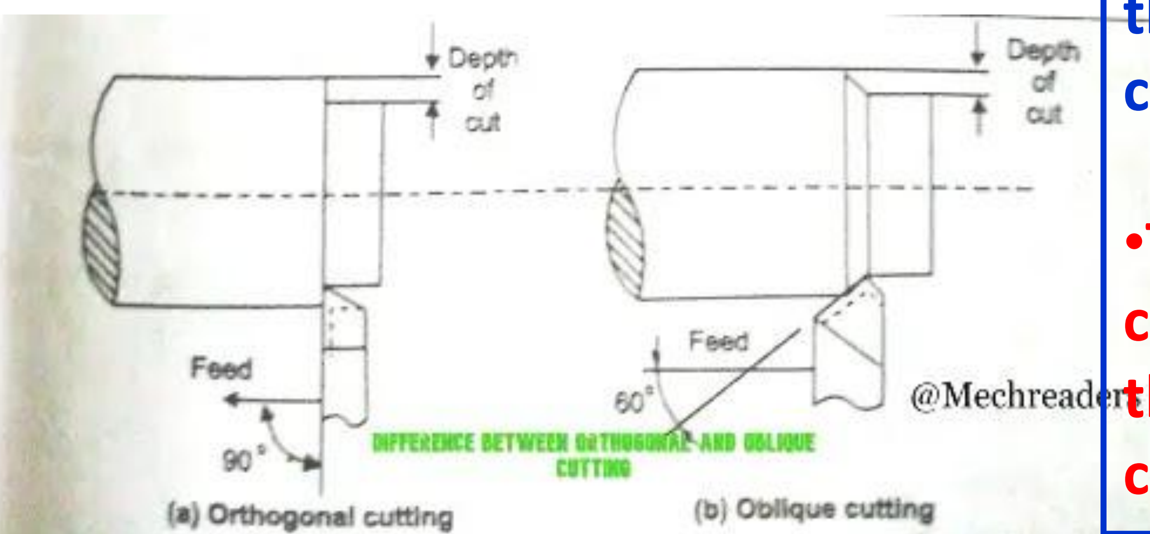


Fig. 2.3. Orthogonal (a) and oblique (b) cutting



Orthogonal & Oblique

- The cutting edge of the tool is perpendicular to the direction of the feed motion.
- The cutting edge of the tool is inclined to the direction of the feed motion.
- Only two components of cutting forces are acting on the tool, hence it is called 2D cutting.
- Three components of cutting forces are acting on the tool, hence it is called 3D cutting.

Orthogonal/Oblique cutting

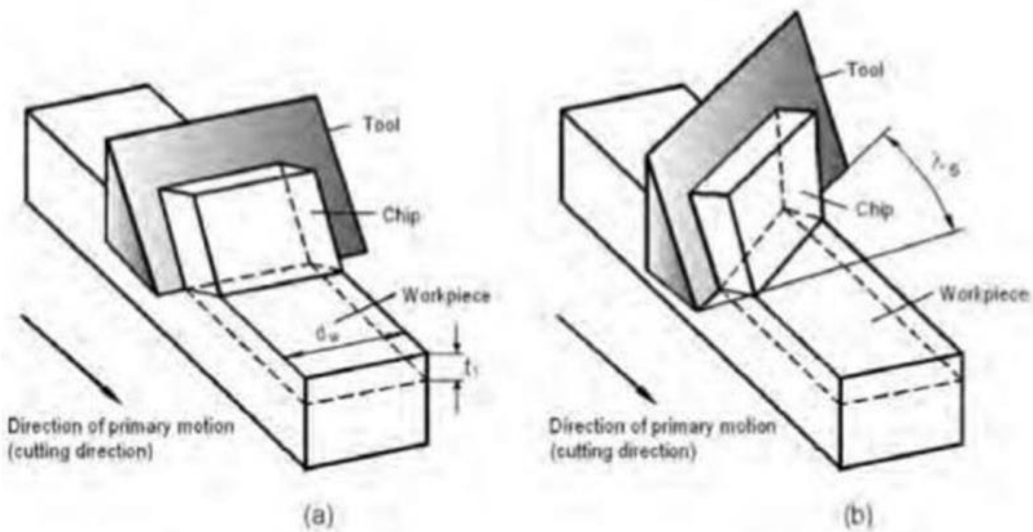
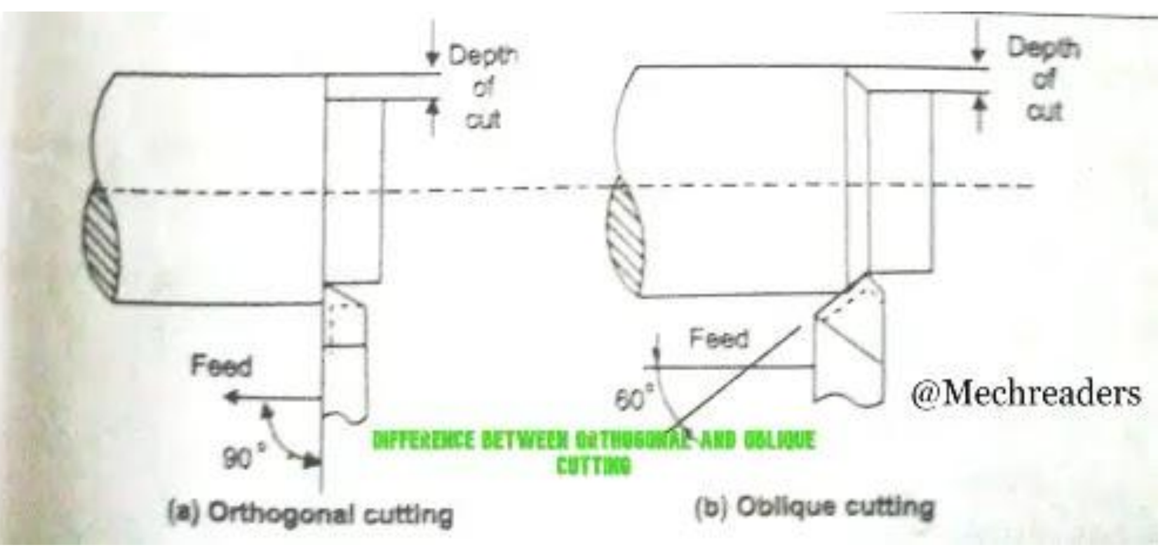


Fig. 2.3. Orthogonal (a) and oblique (b) cutting



Orthogonal & Oblique

- The chips flows over the tool face and the direction of the flow velocity is normal to the cutting edge.
- The chips flows over the tool face making an angle with the normal on the cutting edge.
- The cutting edge is larger than the cutting width.
- The cutting edge is may or may not be larger than the cutting width.

Orthogonal/Oblique cutting

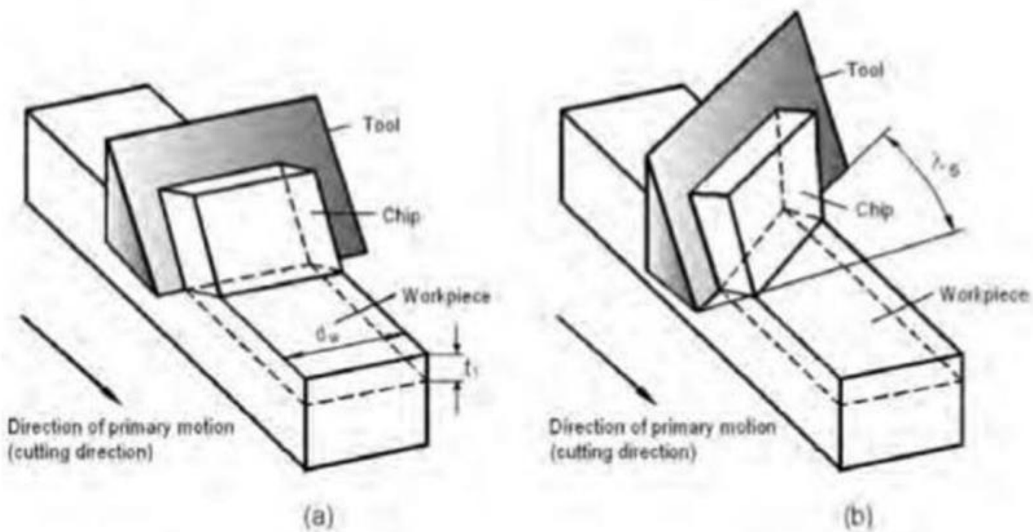
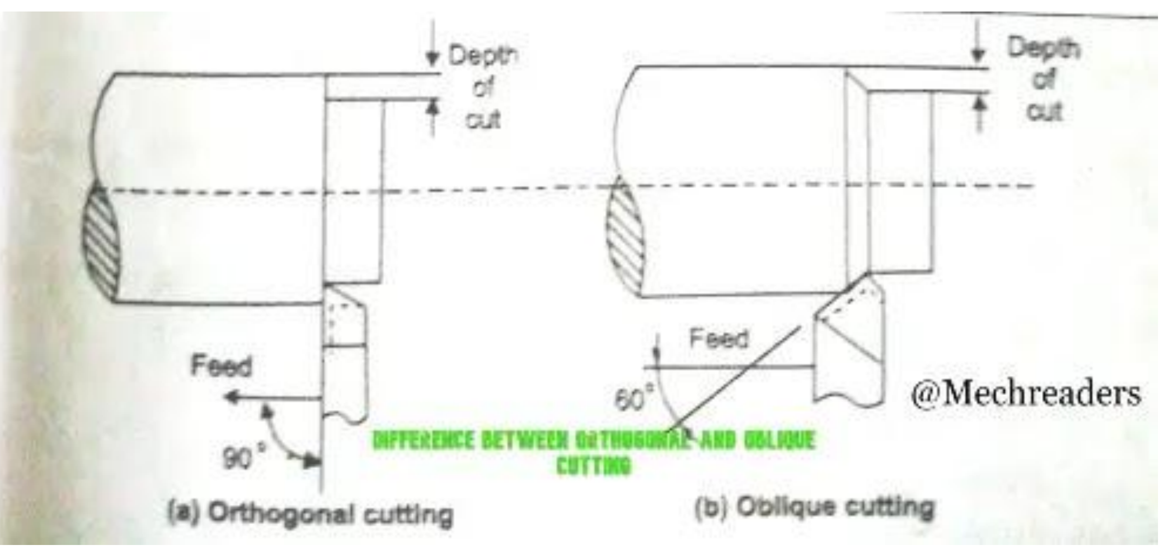


Fig. 2.3. Orthogonal (a) and oblique (b) cutting



Orthogonal & Oblique

- The shear force per unit area is high which increases the heat per unit area.

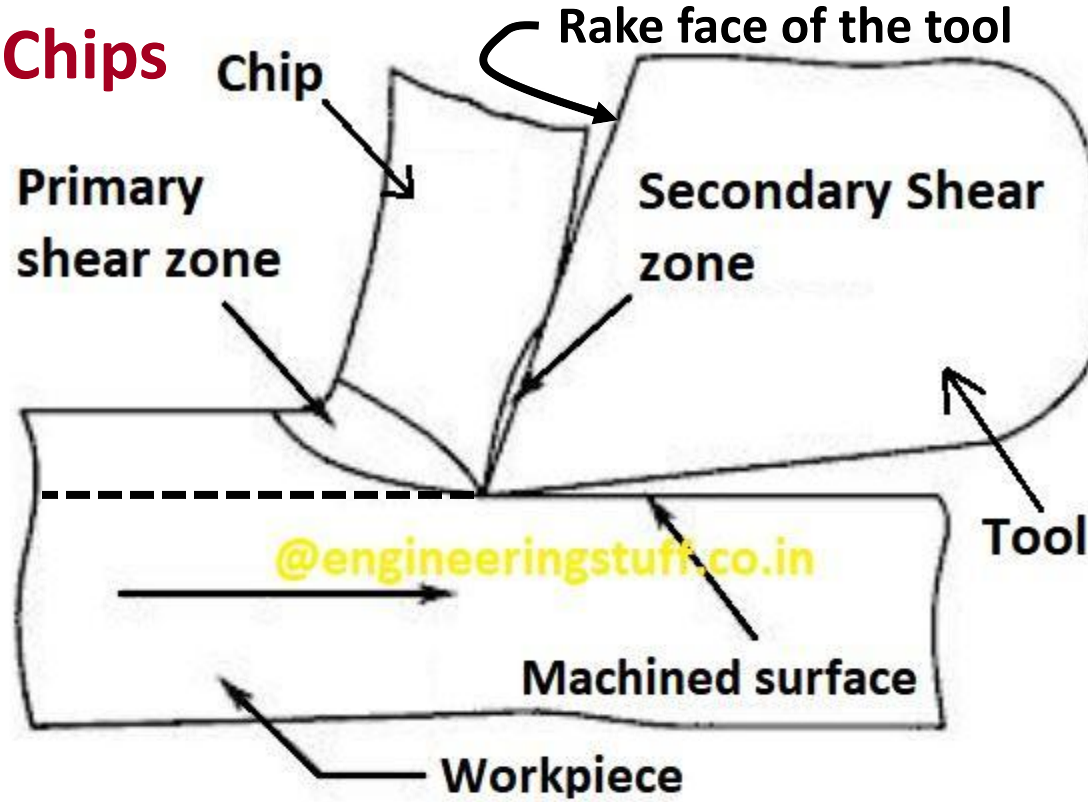
- The shear force per unit area is low which decreases the heat per unit area.

- Tool life is less and surface finish of the work piece is poor.

- Tool life is more and surface finish of the work piece is good.

Types of Chips

Formation of Chips



- The uncut layer deforms into a chip after it goes through a severe plastic deformation in the **PRIMARY SHEAR ZONE.**
- Chips are produced due to shearing and tearing of the materials.
- The metal in front of the tools gets compressed very severely causing **SHEAR STRESS.**
- The shear is maximum along the plane called **SHEAR PLANE.**
- The chips flow along the rake surface of the tool and the newly formed chips surface results in further plastic deformation since, despite sticking, it flows, This zone is called **SECONDARY SHEAR ZONE.**

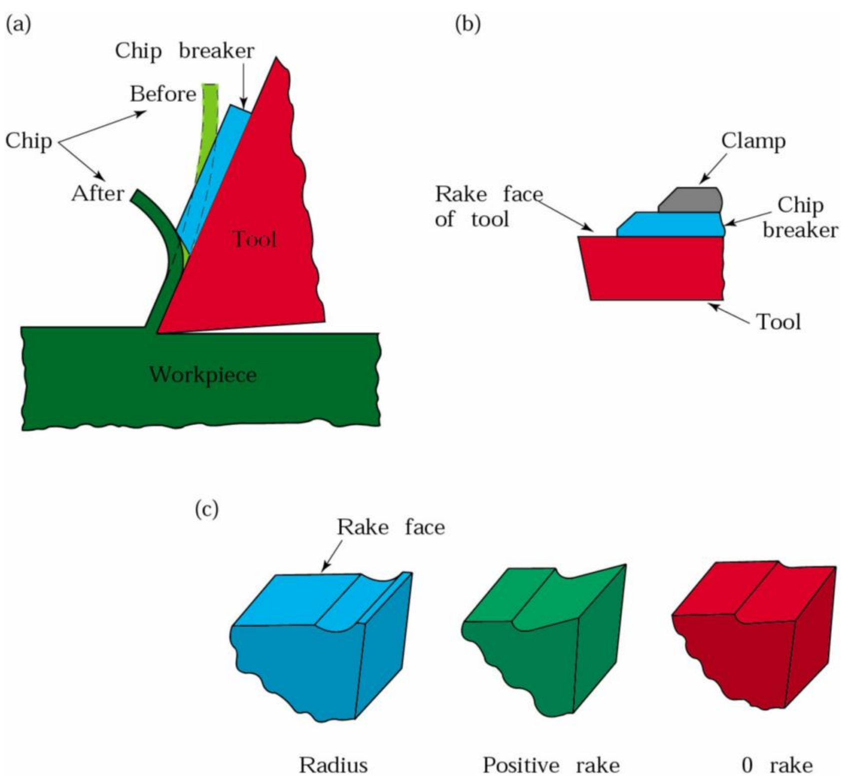
Four basic types of chips in Machining

1. Continuous chips

2. Discontinuous chips

3. Continuous with built up edge (BUE)

4. Serrated chips



- Long continuous ribbon like chips are formed.
- Formed with
- **ductile materials (mild steel, copper, Al)**
- **high cutting speeds, low friction**
- **positive rake angles, sharp cutting dge**
- **small uncut thickness**
- **feed and DOC is low**

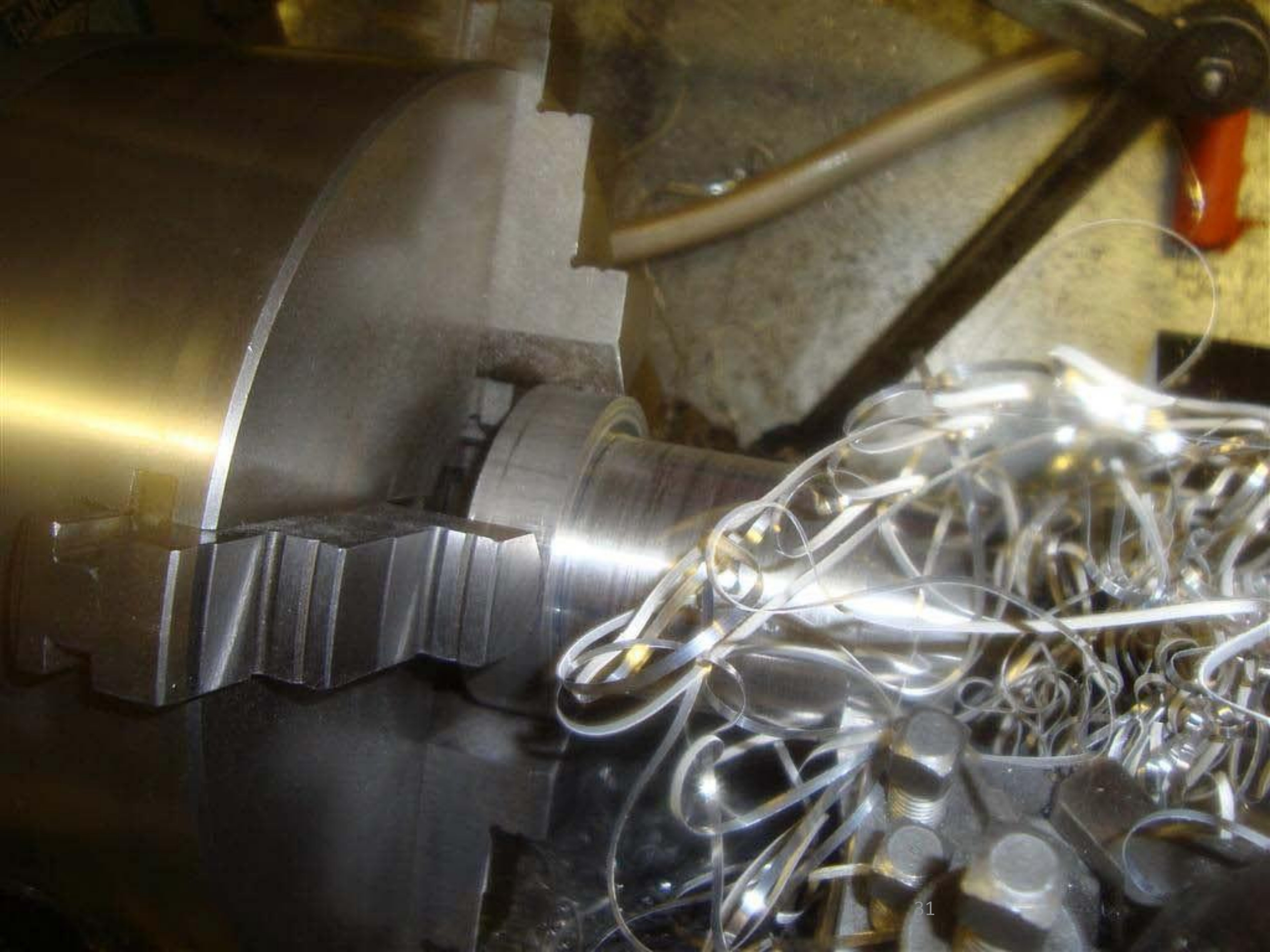
Advantages:

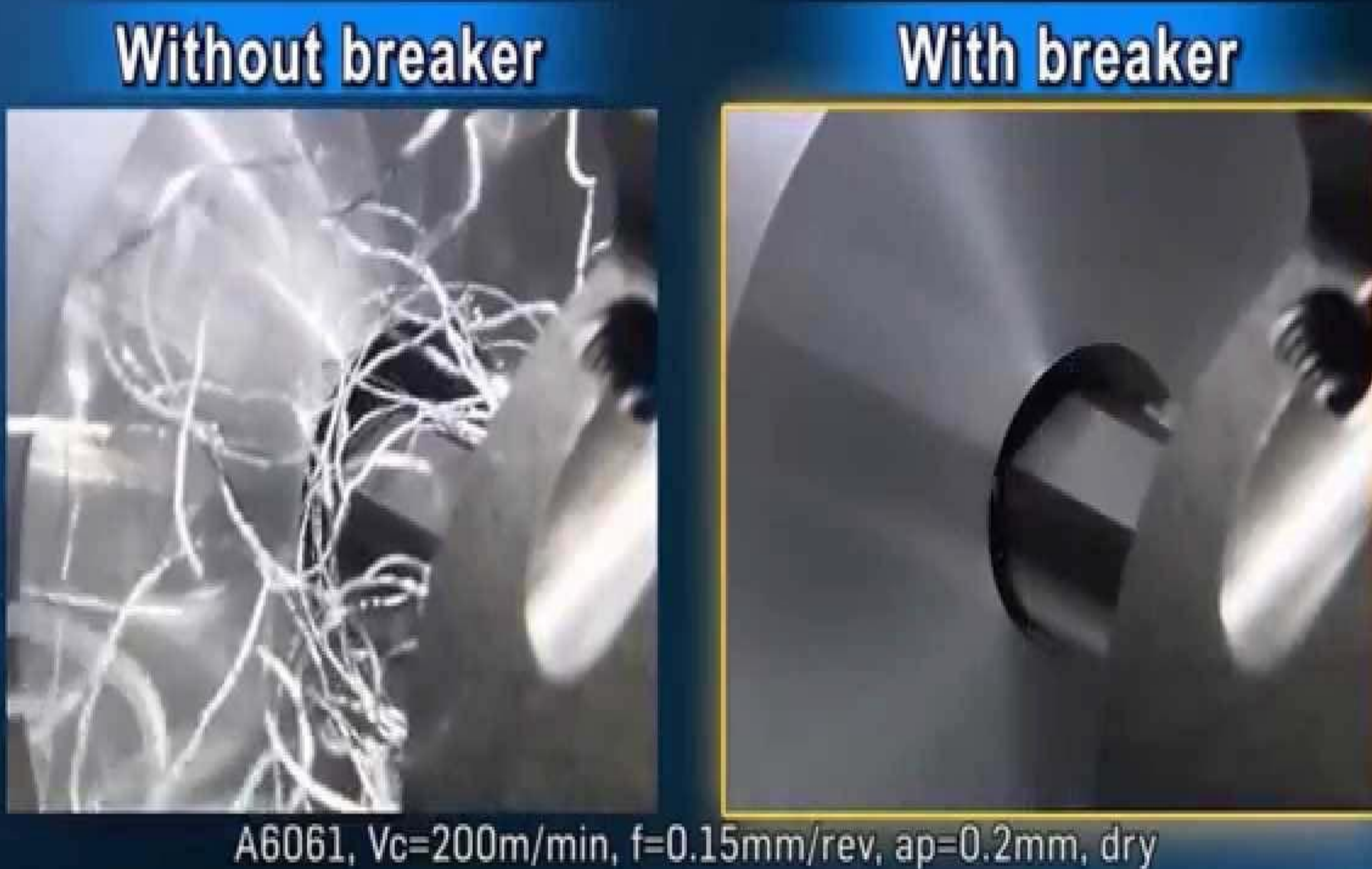
- A good surface finish.
- Low power consumption.
- Low tool-chip friction.
- High tool life

Disadvantages.

- Long chips tend to entangled with cutting tool.
- Chip disposal problem

Solution: Use of chip breakers. Chip breakers allow the chips to be broken into small pieces so that they can be disposed off easily.




Without breaker
With breaker
A6061, Vc=200m/min, f=0.15mm/rev, ap=0.2mm, dry

•These chips break into **segments** during the cutting process, resulting in a fragmented chip formation instead of a continuous ribbon.

•Formed with

•brittle materials (cast iron, brass)

•lower cutting speeds

•large feed and depth of cut

•high tool-chip friction

•negative rake angle

Advantages:

•When machining brittle materials, discontinuous chips tend to result in a **smoother surface finish** on the work piece compared to continuous chips.

•The formation of discontinuous chips can reduce wear on the cutting tool, leading to a longer **tool life.**

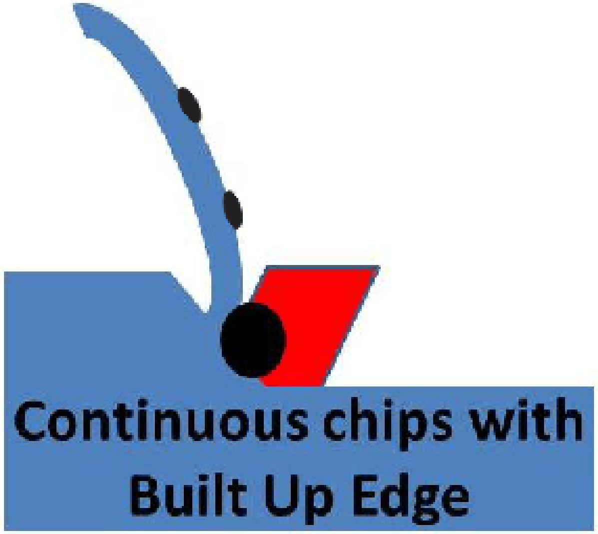
•Discontinuous chips are often **easier to handle** and remove from the machining area compared to long, continuous chips.

•Discontinuous chips can be formed with less force, leading to **lower power consumption** during the machining process.

Disadvantages.

•Increased friction and potential for chip hammering can negatively impact tool life.

•While discontinuous chips are beneficial for brittle materials, they can indicate excessive tool wear and poor surface finish when machining ductile materials.



Disadvantages:
After BUE breaks, the broken fragments adhere to the finished surface and the chip surface results in a **rough finish.**

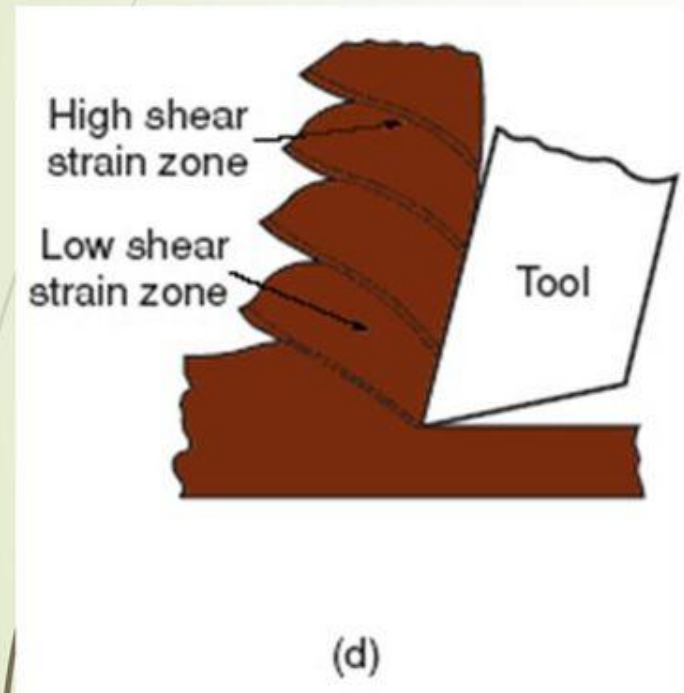
Much of the detached BUE is carried away by the chip, sometime taking portion of the tool rake face with it, which reduces the life of the cutting tool.

Continuous chips with built up edge is formed by machining:

- **ductile material**
- **high friction at the chip-tool interface**
- **excessive feed**
- **small rake angle**
- **large DOC**
- **low cutting speeds**

Friction between the tool and chip tends to cause portion of the work material to adhere to the rake face of the tool near the cutting edge leading to the formation of BUE.

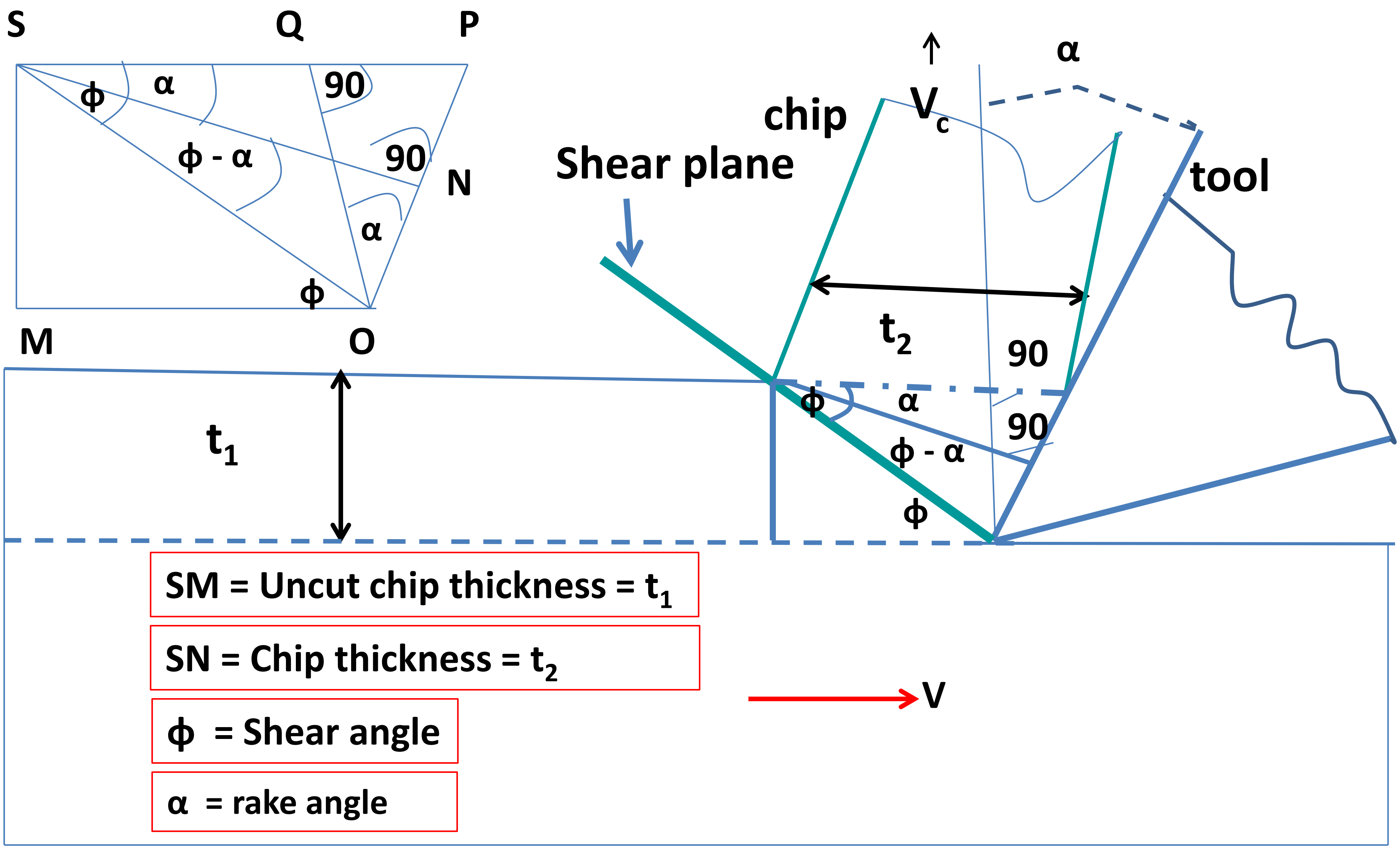
BUE can be prevented by:
•Reducing friction by increasing rake angle of the cutting tool.
•Reducing metal to metal to metal contact by use of high pressure coolant.



Serrated chips

- these chips are semicontinuous in the sense that they possess a sawtooth appearance that is produced by a cyclical chip formation of alternating high shear strain and followed by low shear strain.
- this chip is most closely associated with certain difficult-to-machine metals such as titanium alloys, nickel-base superalloys, and austenitic stainless steels when they are machined at higher cutting speeds.

Chip Thickness Ratio

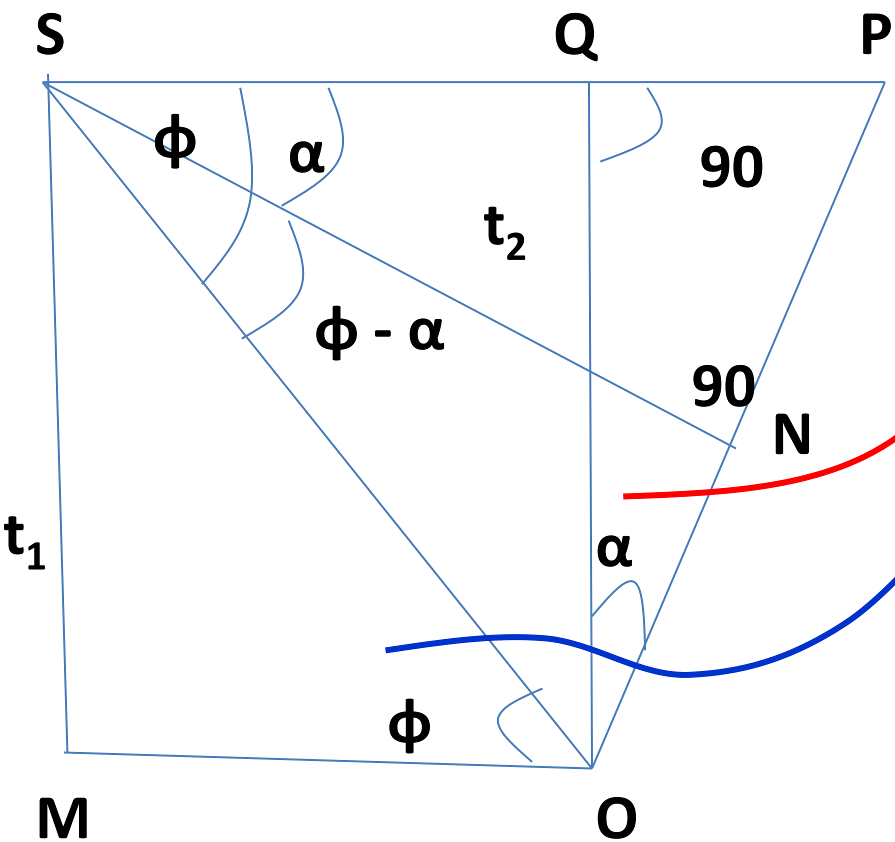


SM = Uncut chip thickness = t_1

SN = Chip thickness = t_2

ϕ = Shear angle

α = rake angle



In △ NSO

$\cos(\phi - \alpha) = SN/OS$

$OS = SN/\cos(\phi - \alpha)$

In △ SOM

$\sin\phi = SM/OS$

$OS = SM/\sin\phi$

$SN/\cos(\phi - \alpha) = SM/\sin\phi$

$$SN/SM = \frac{\sin\phi}{\cos(\phi - \alpha)}$$

$$t_1/t_2 = \frac{\sin\phi}{\cos(\phi - \alpha)}$$

$$r = \frac{\sin\phi}{\cos\phi\cos\alpha + \sin\phi\sin\alpha}$$

$r[\cos\phi\cos\alpha + \sin\phi\sin\alpha] = \sin\phi$

Divide by $\sin\phi$

$r[\cos\alpha / \tan\phi + \sin\alpha] = 1$

$r\cos\alpha / \tan\phi = 1 - r\sin\alpha$

$\tan\phi = (r\cos\alpha) / (1 - r\sin\alpha)$

$t_1 / t_2 = r$ Chip thickness ratio

- It is assumed that chip thickness $t_{2} > t_{1}$.
- It is because the chips flow upward at a slower rate than the velocity of the cut.
- The velocity of the chip flow is directly effected by the shear plane angle.
- The smaller this angle the slower will be the chip flow velocity and therefore larger will be the thickness of the chip.

$$t_2 > t_1 , \quad r = t_1 / t_2$$

$$r < 1$$

The higher value of r --- better is the cutting action.

K = 1/r Chip reduction coefficient

This is the measure of how thick he chip has become compared to the depth of cut.

$$K > 1$$

In **plastic deformation** there is negligible change in the **volume** of the work material.

Let :

t_1 = depth of cut
b_1 = width of cut
V = cutting velocity

t_2 = chip thickness
b_2 = width of chip
V_c = chip velocity

$b_1 = b_2$

$t_1 V = t_2 V_c$

$$t_1 / t_2 = V_c / V$$

Also if L_1 and L_2 are the length of the metal cut and the length of the chip produced then: $t_1 L_1 = t_2 L_2$

$$t_1 / t_2 = L_2 / L_1$$

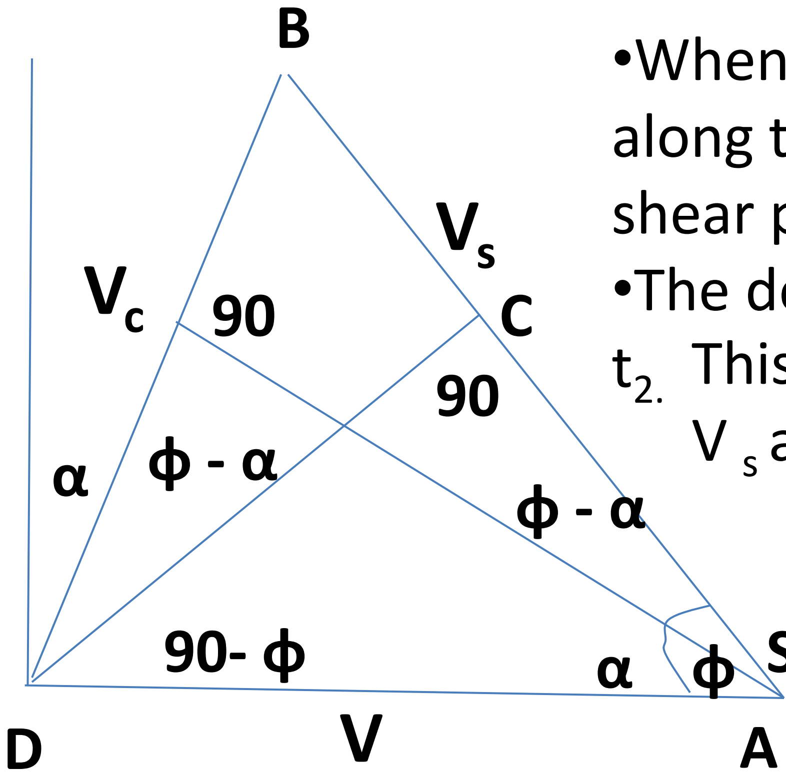
Hence

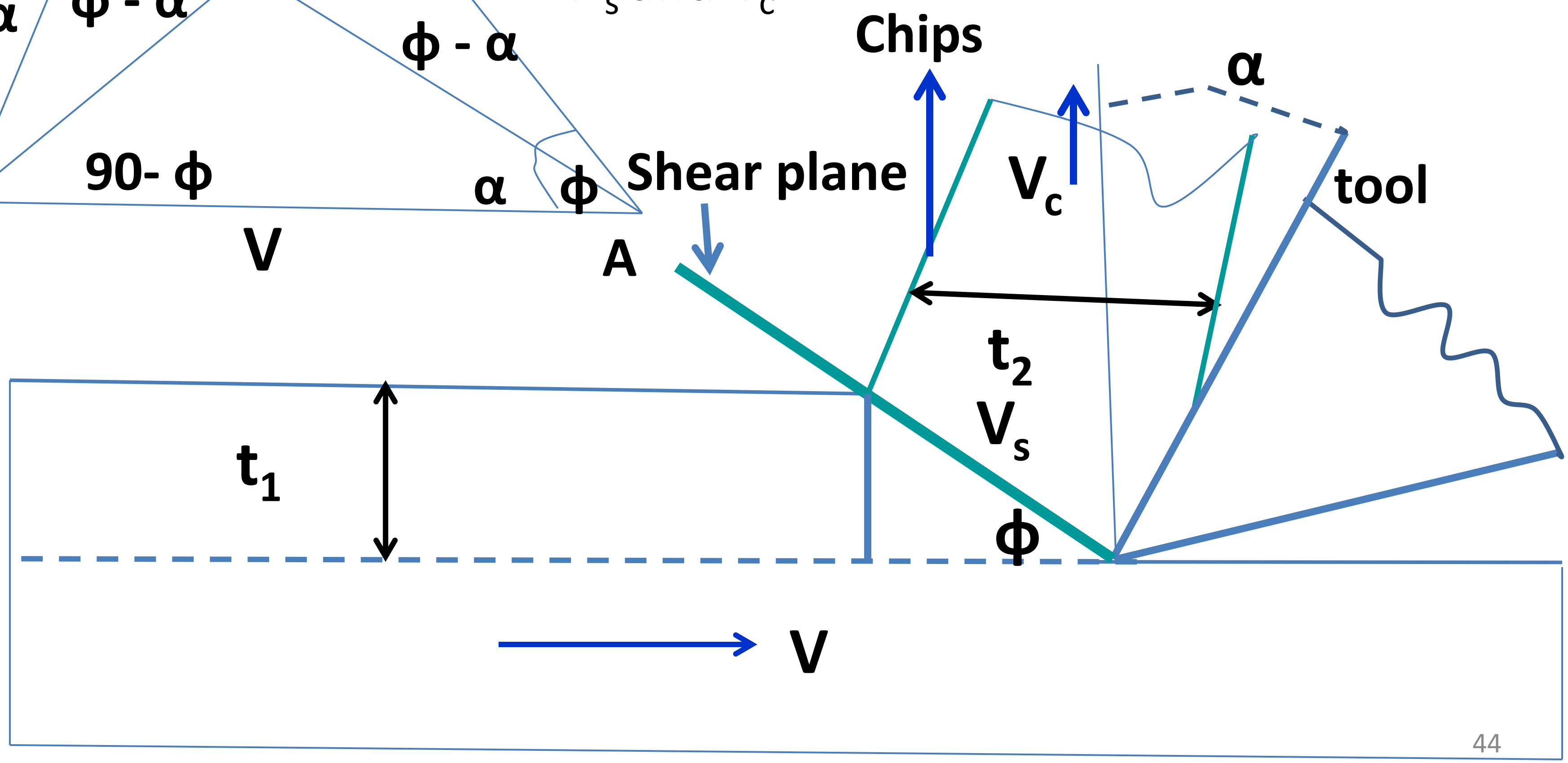
$$t_1 / t_2 = V_c / V = L_2 / L_1$$

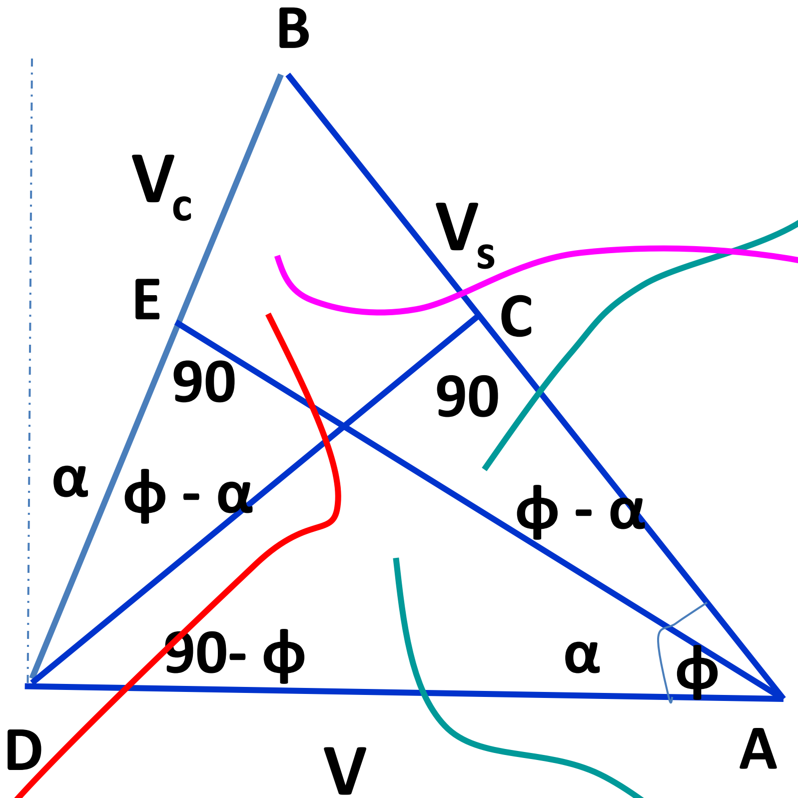
Velocity Relationship

Velocity Relationship

- When the tool moves with the velocity V along the work , it shears the metal along the shear plane AB.
- The depth of cut changes into chip thickness $t_{2.}$ This experiences two velocity components V_s and V_c







In $\triangle$ ACD

$\sin\phi = DC/AD$

$DC = AD \sin\phi$

$DC = V \sin\phi$ (i)

In $\triangle$ BDC

$\cos(\phi - \alpha) = DC/DB$

$DC = DB \cos(\phi - \alpha)$

$DC = V_c \cos(\phi - \alpha)$ (ii)

From (i) and (ii) we get

$V \sin\phi = V_c \cos(\phi - \alpha)$

$V_c = V \sin\phi \,/\, \cos(\phi - \alpha)$

Similarly in $\triangle$ AED

$\cos\alpha = AE/AD$

$AE = AD \cos\alpha$

$AE = V \cos\alpha$ (iii)

Similarly in $\triangle$ AEB

$\cos(\phi - \alpha) = AE/AB$

$AE = AB \cos(\phi - \alpha)$

$AE = V_s \cos(\phi - \alpha)$ (iv)

From (iii) and (iv) we get

$V \cos\alpha = V_s \cos(\phi - \alpha)$

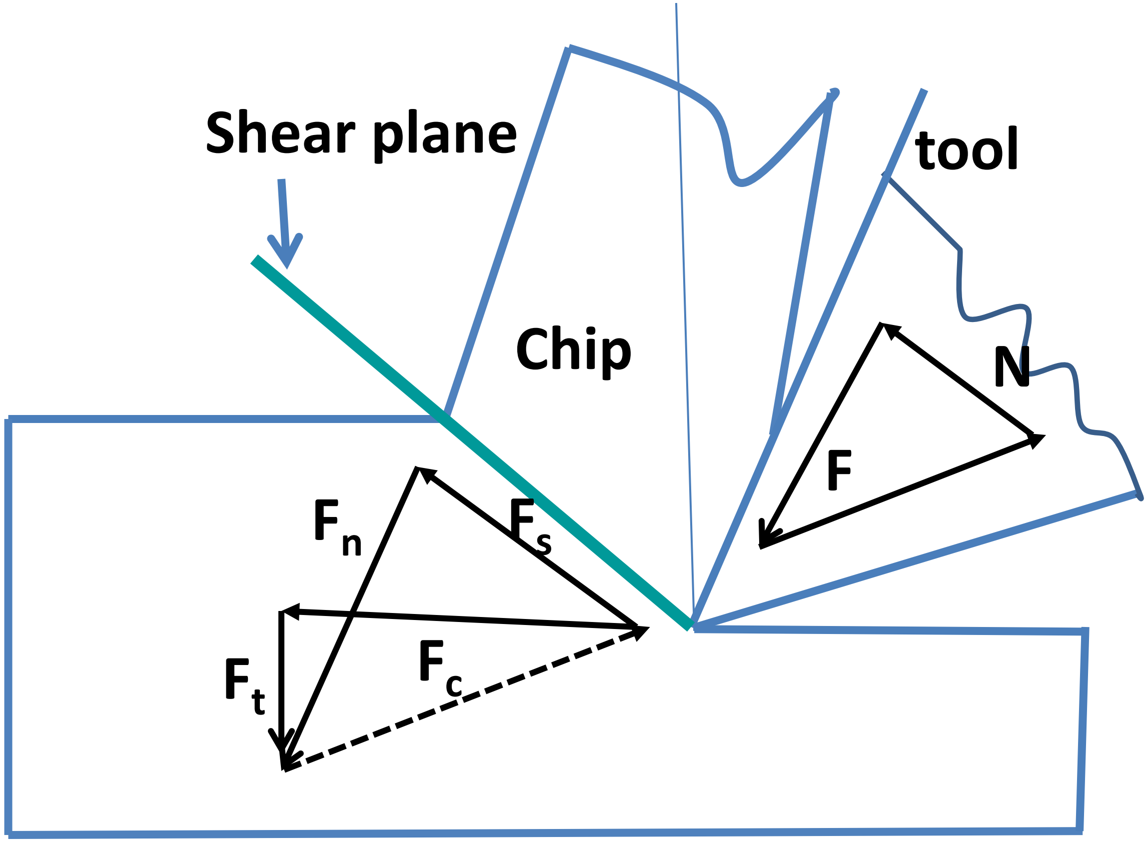
$V_s = V \cos\alpha \,/\, \cos(\phi - \alpha)$

Also $t_1 / t_2 = L_2 / L_1 = V_c / V = \sin\phi \,/\, \cos(\phi - \alpha)$

Force Relationship in Orthogonal Cutting
Merchant Theory

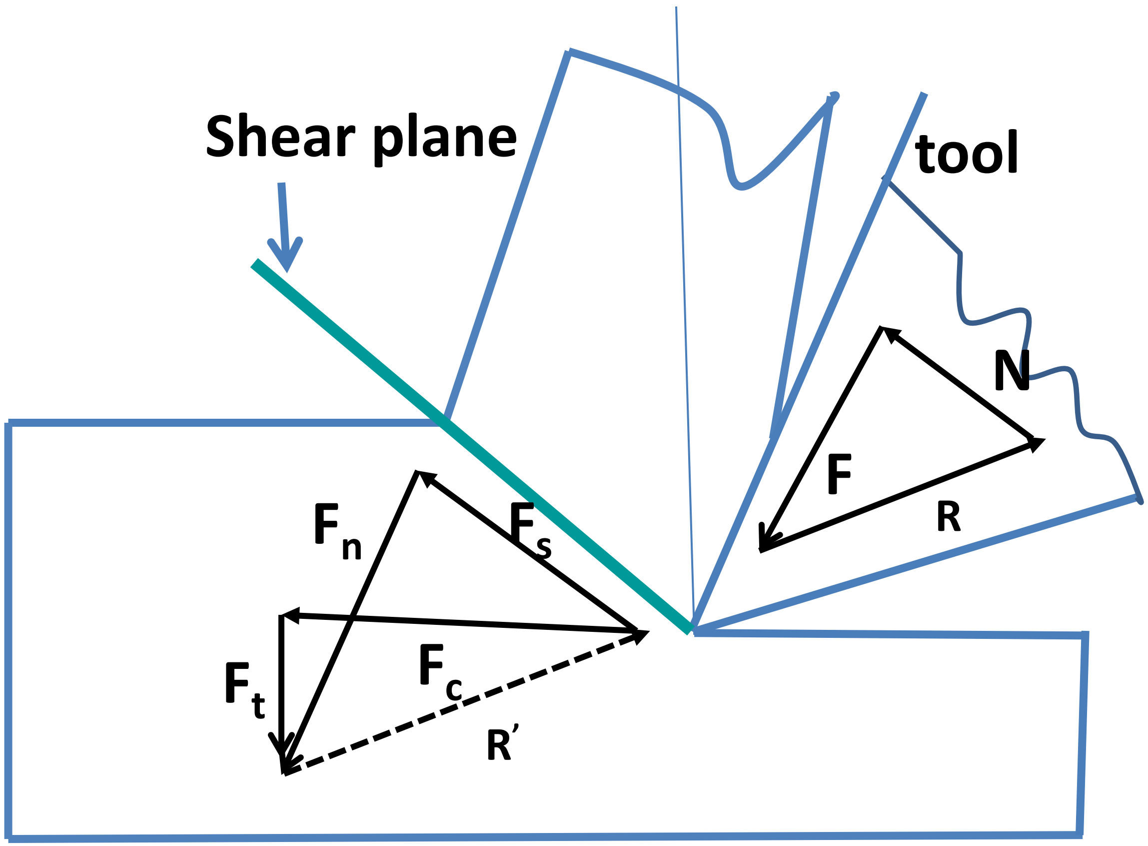
- One of the earliest analysis of orthogonal cutting is due to **Ernst** and **Merchant** (1941).
- The analysis is based on Merchant's thin shear model considering minimum energy possible.
- Number of forces act on the chip during metal cutting.
- Merchant establishes the relationship between forces under some assumption.

1. Cutting velocity always remains constant.
2. Only continuous chips are produced without built up edge.
3. Cutting edge of the cutting tool remains sharp throughout cutting.
4. The depth of cut or uncut chip thickness is constant.
5. Width of the tool is greater than the width of the work piece.



F_c	**Cutting Force: main force or power component acting in the direction of the cutting velocity.**
F_t	Thrust Force: acting perpendicular to the cutting direction pushing the tool in the work piece.

F_s	**Shear Force: force essentially required to separate a chip from the parent body by shear developed on the shaer plane.**
F_n	Normal Shear Force: inherently exists along with shear force acting normal to shear plane.
F	Friction Force: friction force at the chip tool interface acting downward.
N	Normal Force: The tool will exert another on the chip acting normal to the rake face.



Hence R = R′ Then net force on the chips will be zero. The chips will move at a constant velocity.

- The friction force (F) and Normal force (N) will have resultant (R).
- Similarly shear force (F_s) and normal to shear force (F_n) will also have resultant (R′)

- Chips are moving at a constant velocity, that is net acceleration is zero.
- On the chips there are four forces acting i.e., F_s , F_n , F and N.
- When the net acceleration is zero then no forces are acting on the chips. Hence the sum of all the forces are zero. Therefore net acceleration is zero. This will result in chips moving at a constant velocity.

Merchant Circle Diagram

It’s a Graphical method to calculate the forces in orthogonal machining

These forces are calculated from measured forces.

F_s	Shear Force
F_n	Normal Shear Force
F	Friction Force
N	Normal Force

F_c	Cutting Force
F_t	Thrust Force

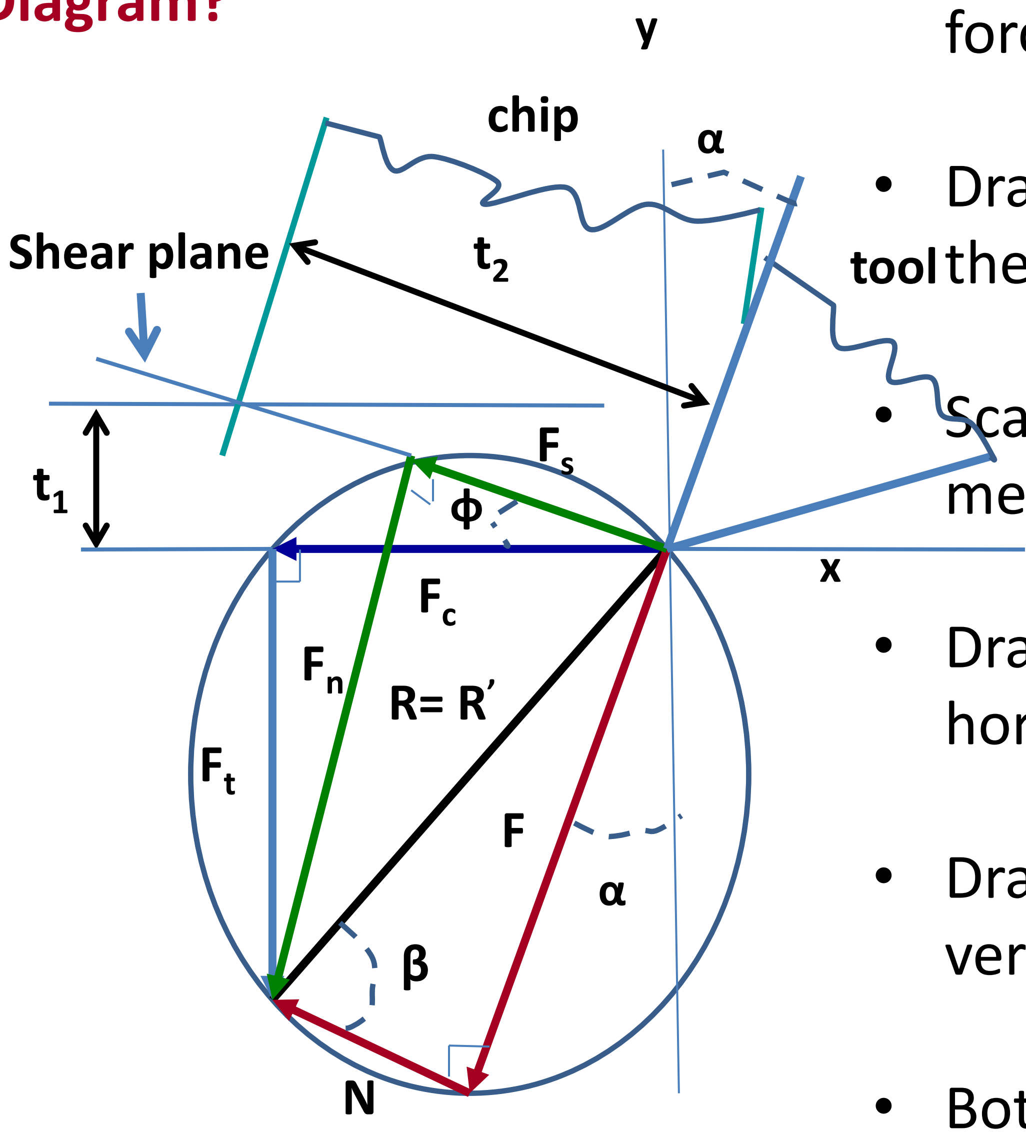
Limitations:

- Merchant’s Circle Diagram (MCD) is valid only for orthogonal cutting.
- By the ratio, F/N, the MCD gives apparent (not actual) coefficient of friction.
- It is based on single shear plane theory.

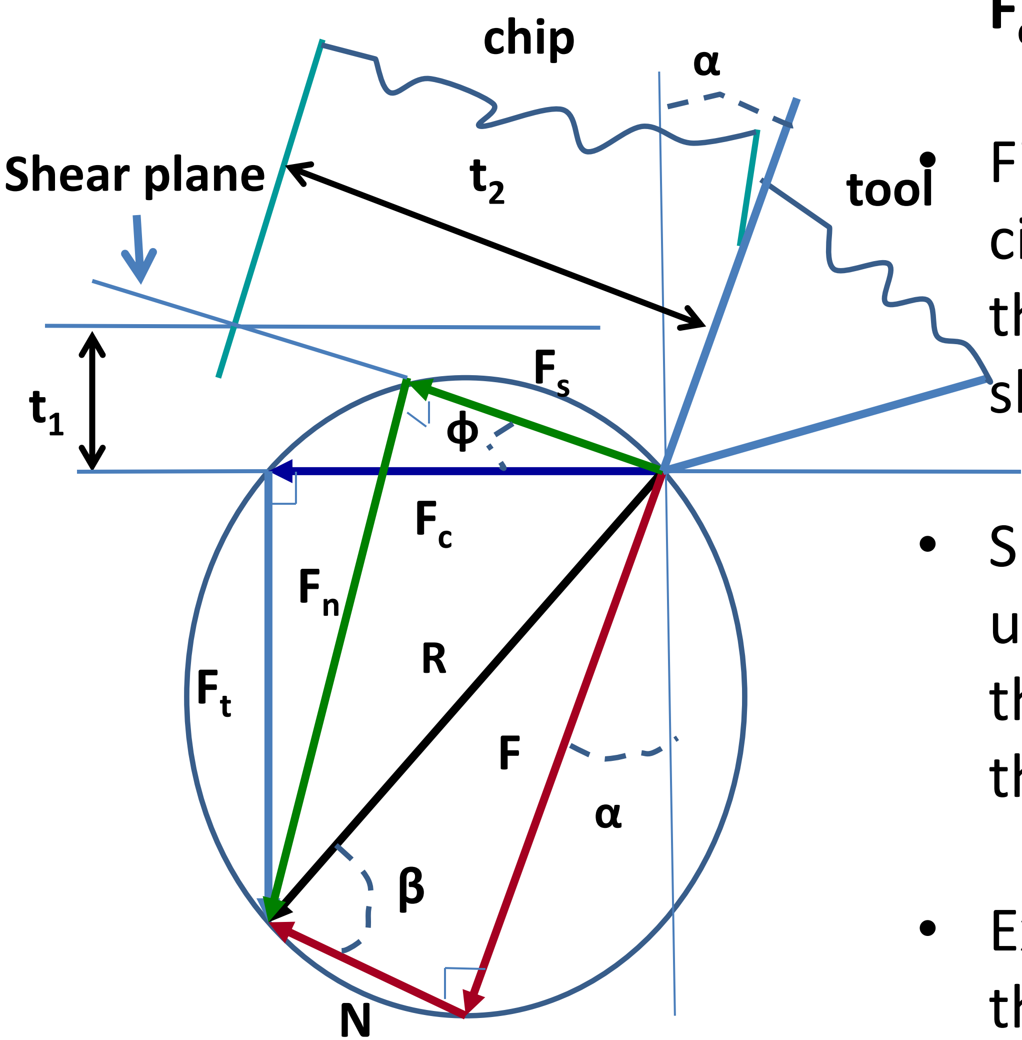
Advantages:

- Easy, quick and reasonably accurate determination several other forces from a few known forces involved in machining.
- Friction at chip-tool interface and dynamic yield shear strength can be easily determined.
- Equation relating to different forces can be easily developed.

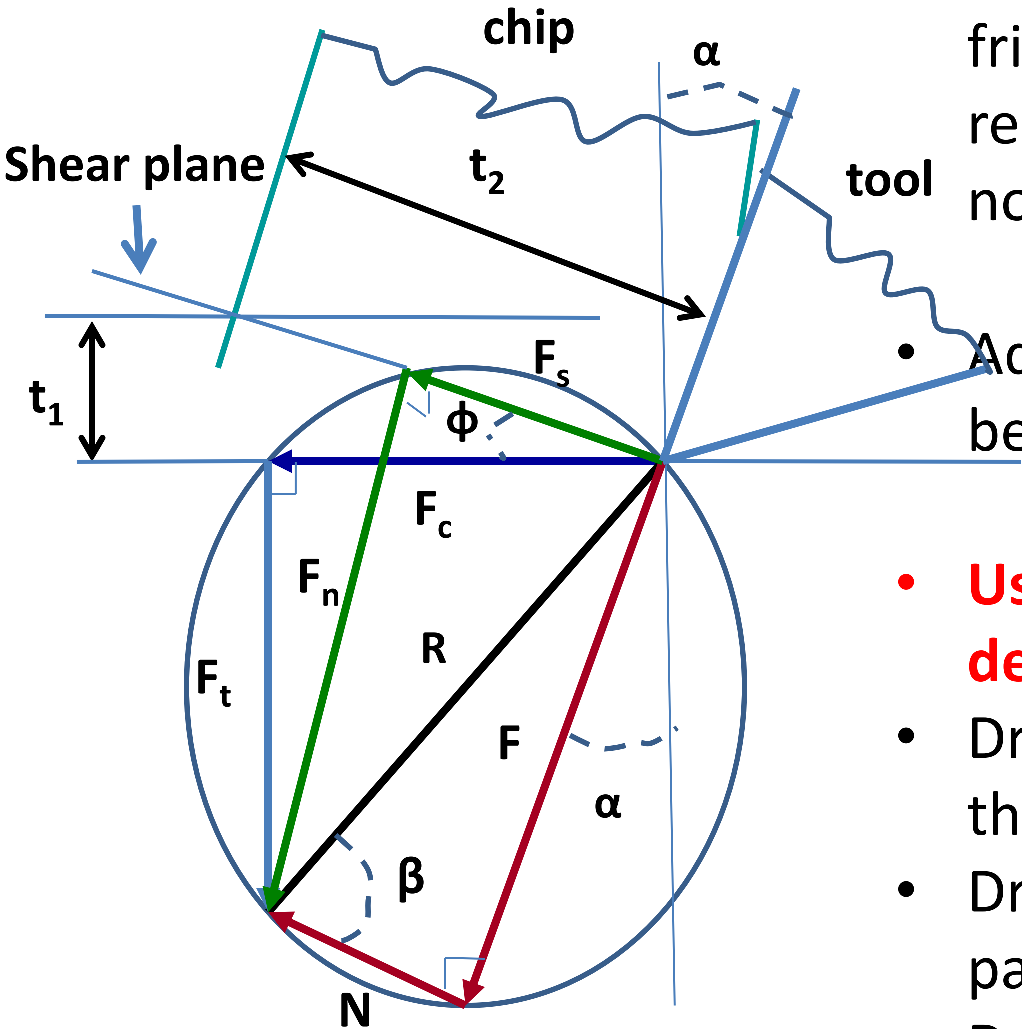
How to draw Merchant Circle Diagram?



- Merchant's Force Circle calculates forces in the cutting process.
- Draw x-y axes with the origin at the center of the page.
- Scale axes to include both measured forces.
- Draw cutting force (**F_c**) horizontally.
- Draw tangential force (**F_t**) vertically.
- Both forces appear in the lower left quadrant.



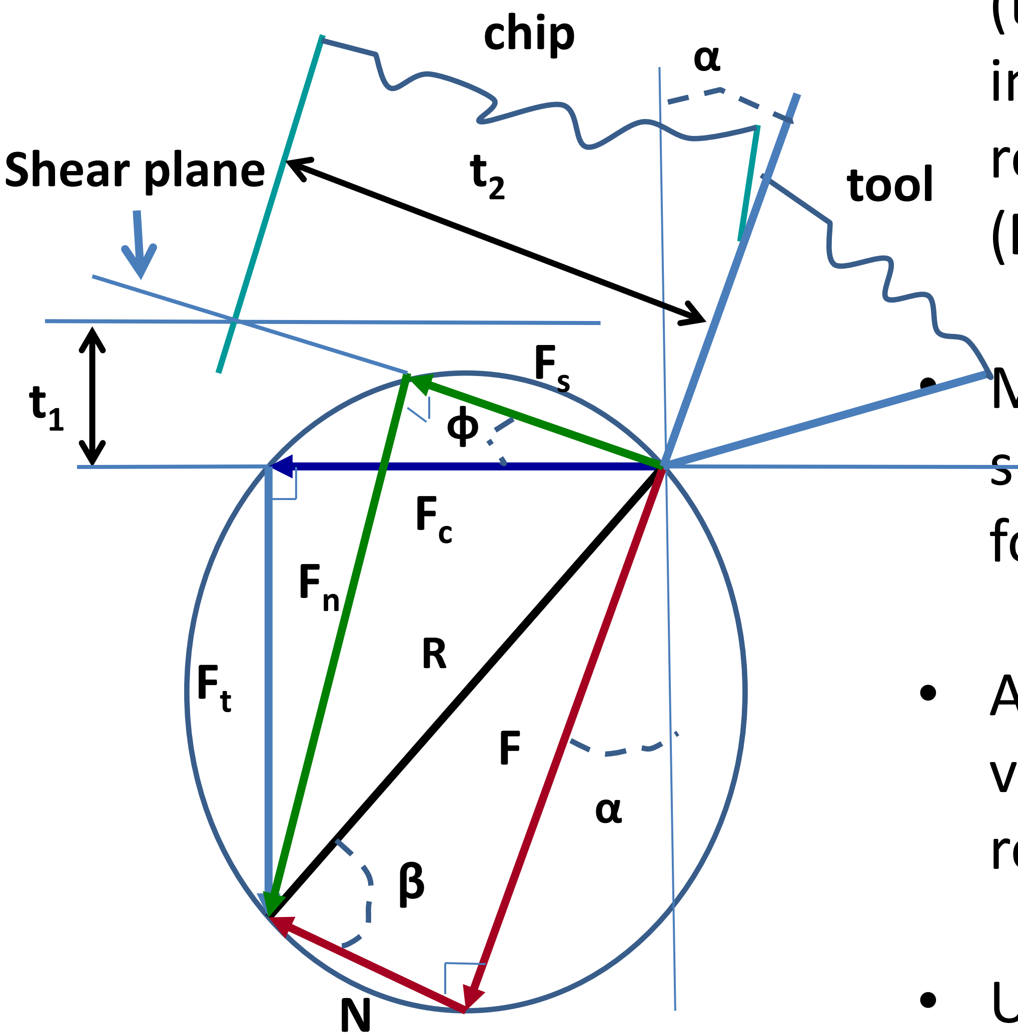
- Draw the resultant vector (R) of $\mathbf{F_c}$ and $\mathbf{F_t}$
- Find the center of R and draw a circle enclosing vector R; all three vectors' heads and tails should lie on this circle.
- Sketch the cutting tool in the upper right quadrant, ensuring the correct rake angle (**α**) from the vertical axis.
- Extend the cutting face line of the tool at the same rake angle through the circle to represent the friction vector (**F**).



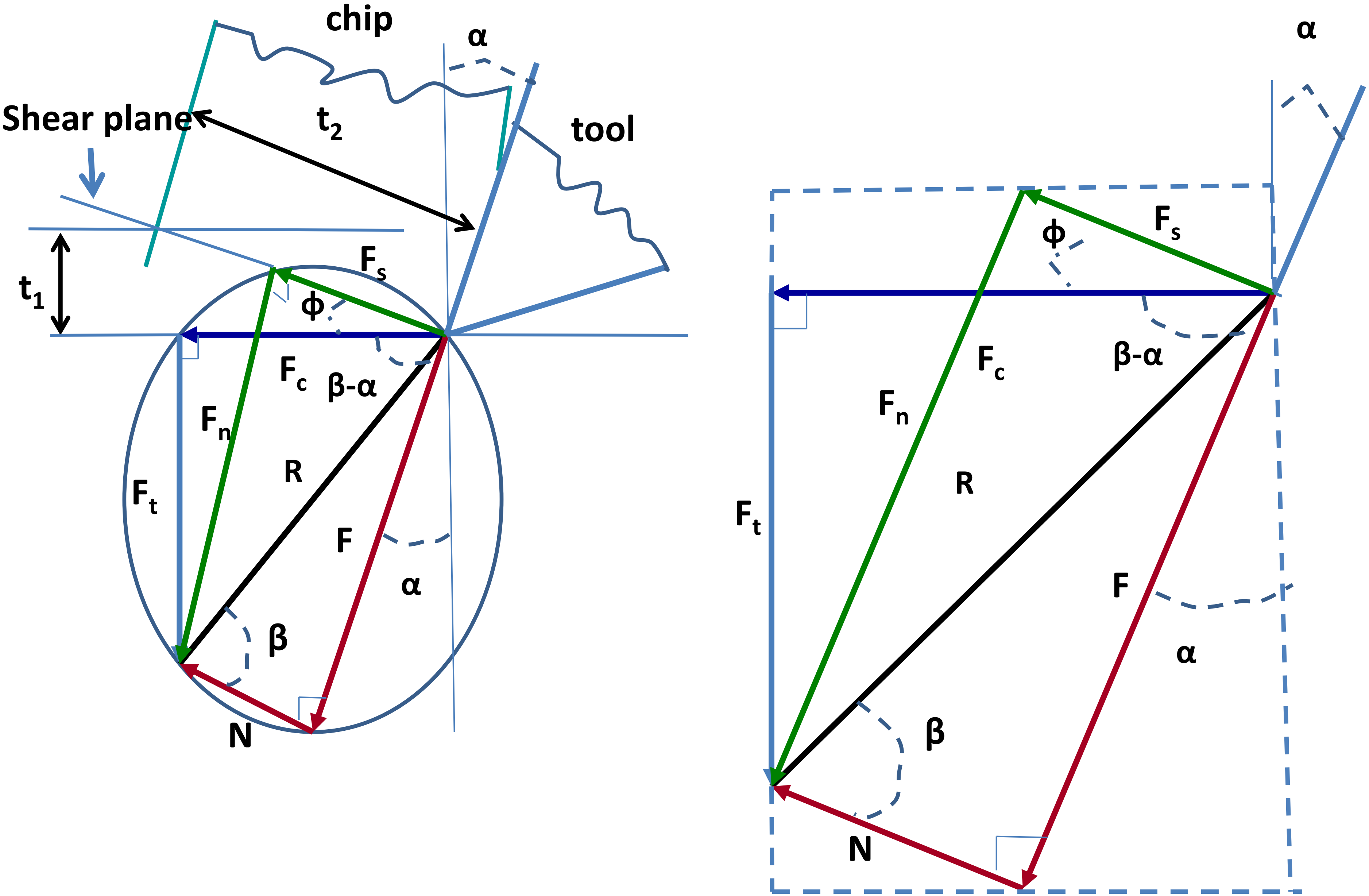
- Draw a line from the head of the friction vector to the head of the resultant vector (**R**) to get the normal vector (**N**).

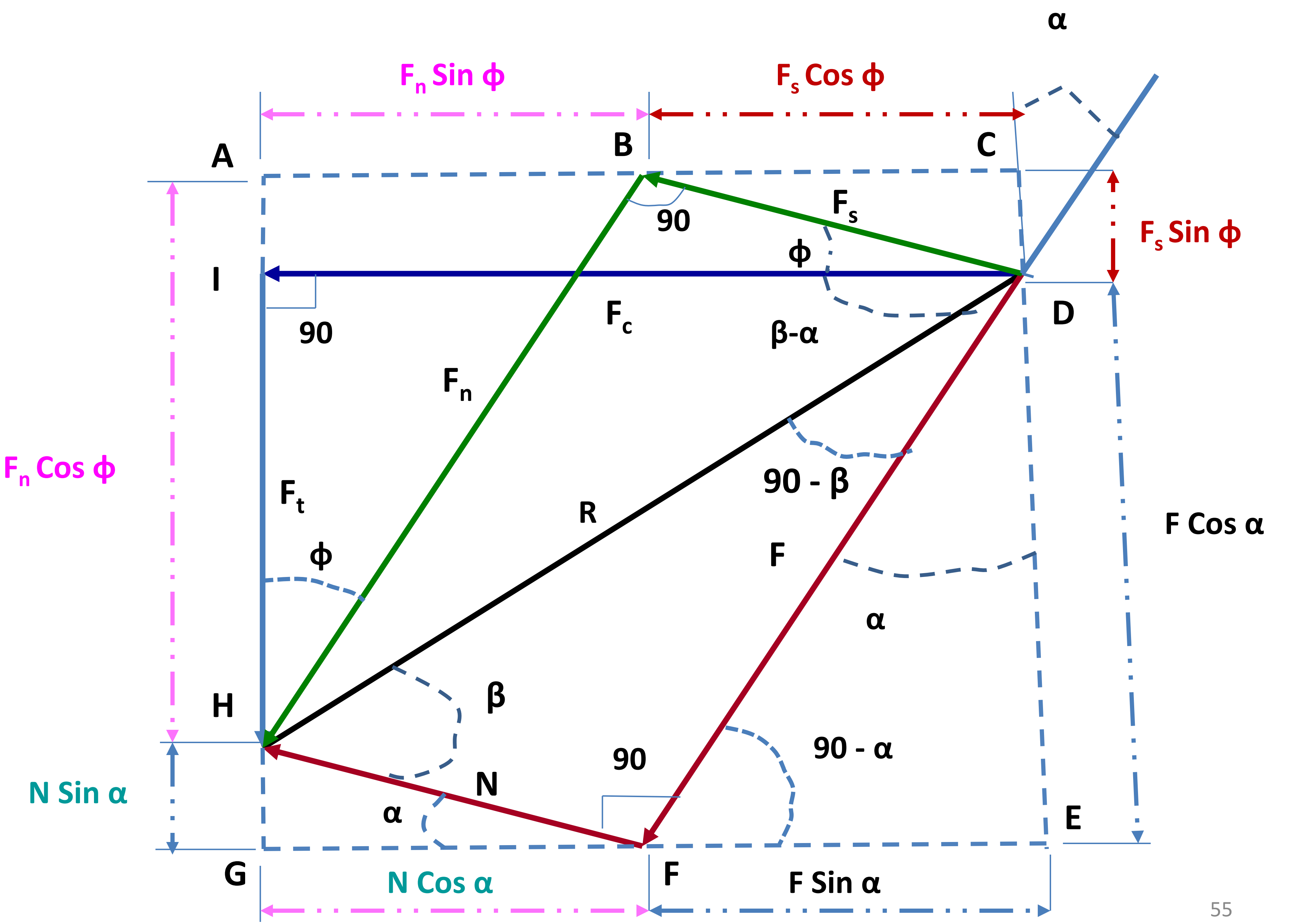
- Add the friction angle (**β**) between vectors R and N.

- **Use chip thickness and cut depth to find the shear force.**
- Draw the chip before and after the cut.
- Draw a feed thickness line (**t_1**) parallel to the horizontal axis.
- Draw a chip thickness line parallel to the tool cutting face.



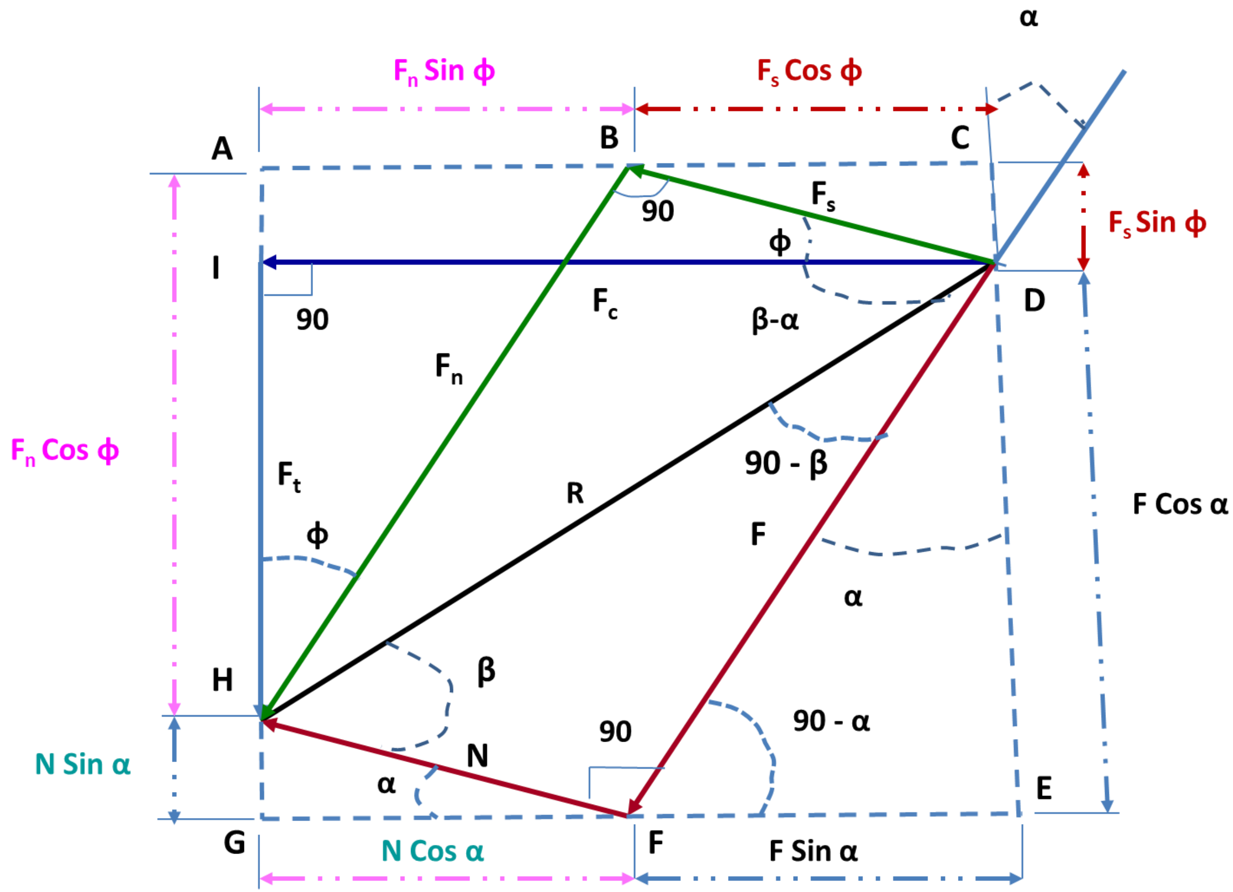
- Draw a vector from the origin (tool point) to the chip lines' intersection at the circle, representing the shear force (**F_s**).
- Measure the angle between the shear force (**F_s**) and cutting force (**F_c**).
- Add the shear force normal (**F_n**) vector from **F_s** 's head to the resultant force (**R**) head.
- Use a scale and protractor to measure all forces and angles precisely.


chip
α
Shear plane
t_2
tool
t_1
F_s
ϕ
F_c
β-α
F_n
R
F_t
F
α
β
N
α
F_s
ϕ
F_c
β-α
F_n
R
F_t
F
α
β
N


α
F_n Sin ϕ
F_s Cos ϕ
A
B
C
F_s
90
ϕ
F_s Sin ϕ
I
90
F_c
β-α
D
F_n
F_n Cos ϕ
90 - β
F_t
R
F Cos α
F
ϕ
α
β
H
90 - α
90
N
N Sin α
α
E
G
N Cos α
F
F Sin α

What to find?

Find	In terms of	
F_c	F_s	F_n
F_t	F_s	F_n
F_s	F_c	F_t
F_n	F_c	F_t
F_c	F	N
F_t	F	N

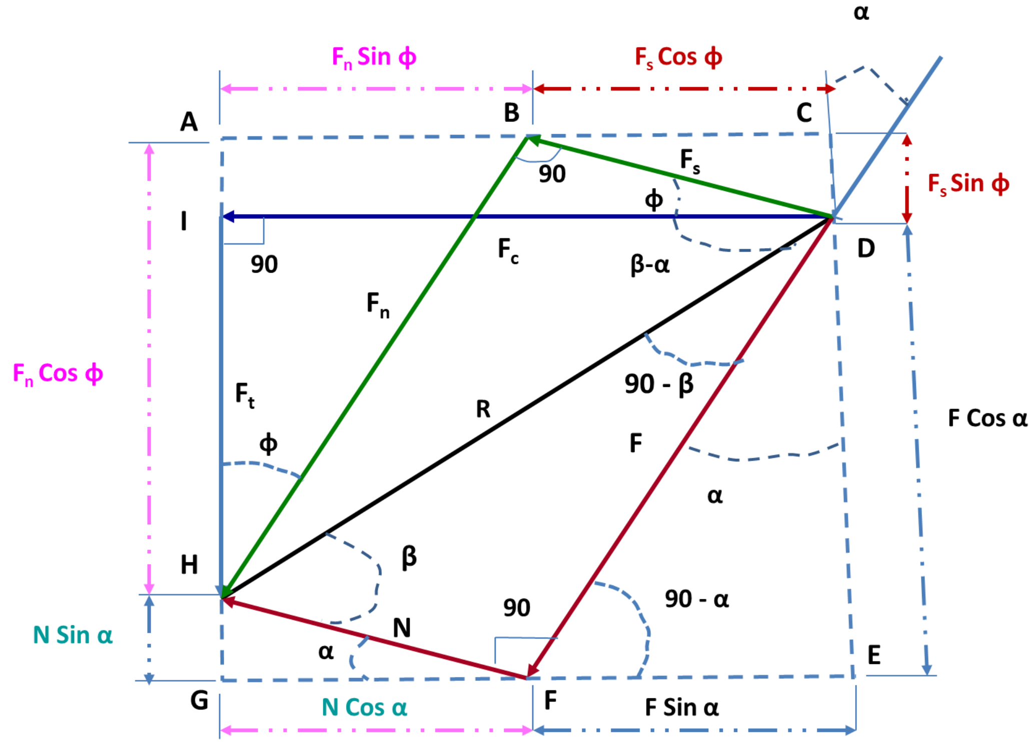


$$F_c = ID = AB + BC$$
$$AB = F_n \operatorname{Sin} \phi$$
$$BC = F_s \operatorname{Cos} \phi$$

$$F_c = F_n \operatorname{Sin} \phi + F_s \operatorname{Cos} \phi \text{ ------ (i)}$$

$$F_t = AH - AI = AH - CD$$
$$AH = F_n \operatorname{Cos} \phi$$
$$CD = F_s \operatorname{Sin} \phi$$

$$Ft = Fn \operatorname{Cos} \phi - Fs \operatorname{Sin} \phi \text{ ------ (ii)}$$



Tool material

Properties of cutting tool material

- Hardness at elevated temperatures (so-called hot hardness) so that hardness and strength of the tool edge are maintained in high cutting temperatures.

- Toughness: ability of the material to absorb energy without failing. Cutting if often accompanied by impact forces especially if cutting is interrupted, and cutting tool may fail very soon if it is not strong enough.

- Wear resistance: although there is a strong correlation between hot hardness and wear resistance, later depends on more than just hot hardness.

Other important characteristics

- Surface finish on the tool
- Chemical inertness of the tool material with respect to the work material
- Thermal conductivity of the tool material, which affects the maximum value of the cutting temperature at tool-chip interface.

Hardness ratio proposed by T.N. Loladse

$$1.35 < \left[\frac{\boldsymbol{H_{tool}}}{\boldsymbol{H_{work}}}\right]_{modified} < 1.5$$

Cutting tool materials

- Carbon Steels
  - Oldest of tool material.
  - The carbon content is 0.6~1.5%
  - with small quantities of
    - Silicon
    - Chromium
    - Manganese and
    - vanadium to refine grain size
  - Maximum hardness is about HRC 62
  - Low wear resistance and
  - low hot hardness
  - The use of these materials now is very limited.
  - Cutting speed: ~9 mpm

High-speed steel (HSS)

- First produced in 1900s.
- highly alloyed with
  - Vanadium
  - Cobalt
  - Molybdenum
  - Tungsten
    - 14% -22%
  - Chromium
  - added to increase
    - hot hardness and
    - wear resistance
- Cutting speed
  - 15 to 20 mpm
- Hardness
  - 63 to 65 Rockwell
- Used in single/ multiple point tools

Stellite

- Family of
  - Cobalt
  - Chromium
  - Tungsten
  - carbon
- Can't be
  - Rolled
  - Worked
  - Can be casted
- Good hot hardness
- Cutting speed 25 – 33 mpm

High-speed steel (HSS)

- Can be hardened to various depths
- Appropriate heat treating up to cold hardness in the range of HRC 63-65
- Cobalt component give the material a hot hardness value much greater than carbon steels.
- High toughness and
- Good wear resistance

- HSS suitable for all type of cutting tools with
  - complex shapes for
  - relatively low to medium cutting speeds.
- The most widely used tool material today for
  - Taps
  - Drills
  - Reamers
  - Gear tools
  - End cutters
  - Slitting
  - Broaches etc.

Cemented Carbides

- Introduced in the 1930s.
- High hot hardness and
- Wear resistance.
- Cutting speed ~100 mpm
- The main disadvantage
  - Low toughness.
- Produced by powder metallurgy methods
  - sintering grains of tungsten carbide (WC) in a
  - cobalt (Co) matrix (it provides toughness).
  - There may be other carbides in the mixture, such as
    - Titanium carbide (TiC) and/or
    - Tantalum carbide (TaC) in addition to
    - WC.

Cemented carbides

- Are available as inserts
  - various shapes
- Mechanically attached by means of
  - clamps to the tool holder
  - brazed to the tool holder
- The clamping is preferred because
  - after an cutting edge gets worn, the insert is indexed (rotated in the holder) for another cutting edge
- Indexable carbide inserts are never reground.
- If the carbide insert is brazed to the tool holder, indexing is not available, and after reaching the wear criterion, the carbide insert is reground on a tool grinder.

Ceramics

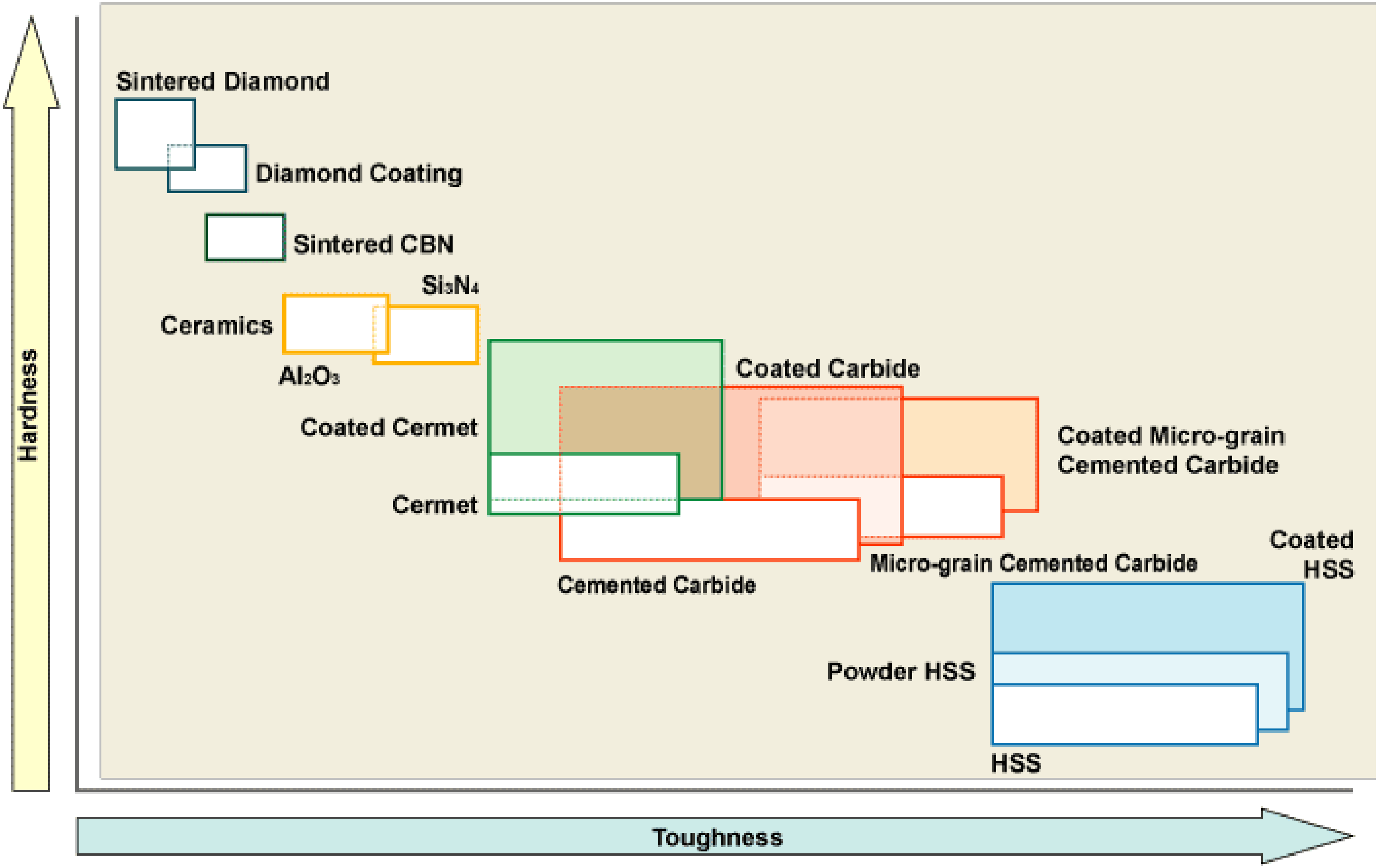
- Composed primarily of fine-grained, high-purity aluminium oxide (Al_2O_3)
- Pressed
- and sintered with no binder.
- Two types are available:
  - white, or cold-pressed ceramics
    - Consists of only Al_2O_3
    - cold pressed into inserts and
    - sintered at high temperature.
  - black, or hot-pressed ceramics, commonly known as cermet (from ceramics and metal).
  - This material consists of 70% Al_2O_3 and
  - 30% TiC.

Ceramics

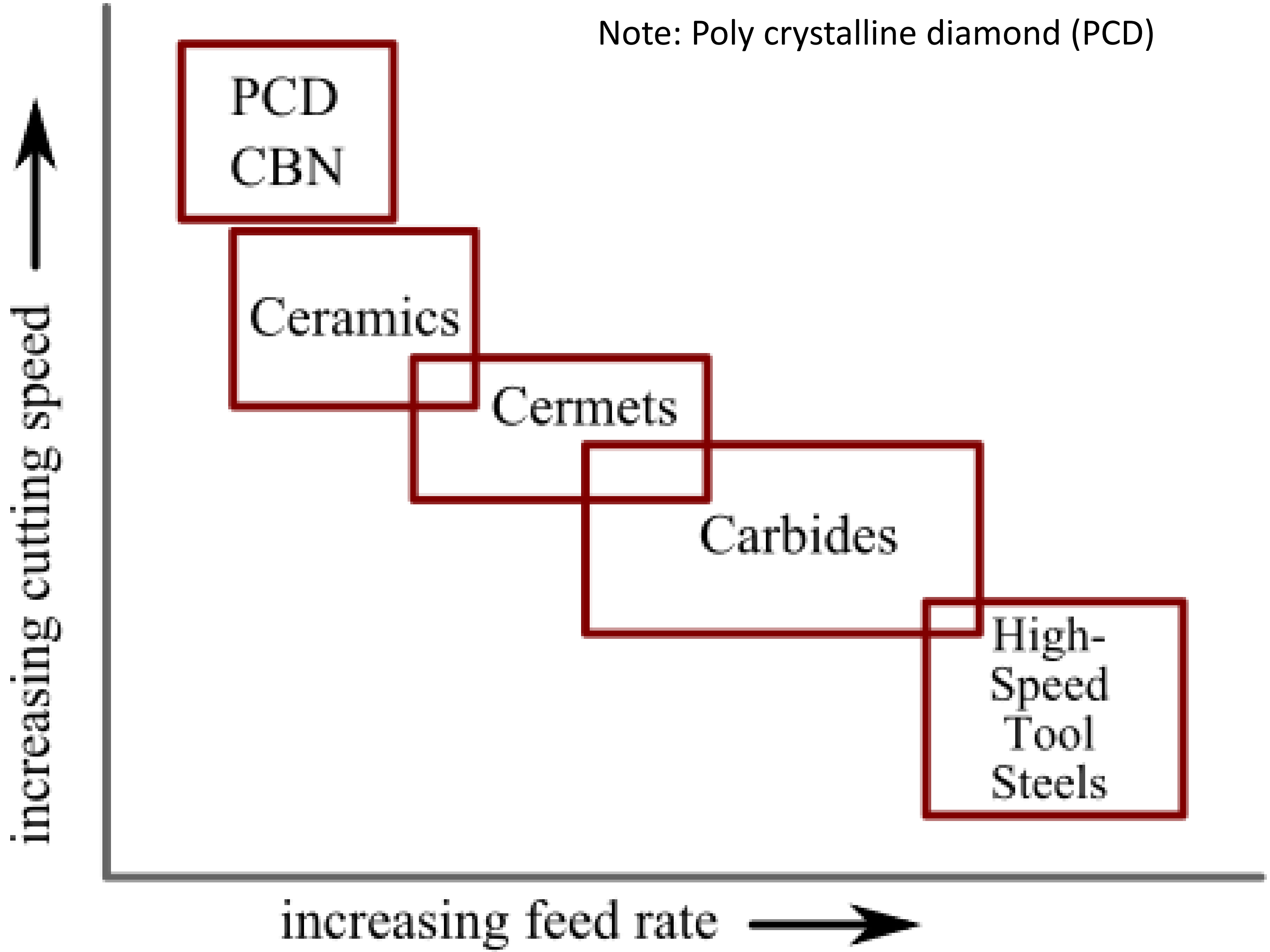
- Both materials have very high wear resistance but low toughness, therefore they are suitable only for
  - continuous operations such as finishing turning of cast iron and steel at very high speeds.
  - There is no occurrence of built-up edge, and
  - coolants are not required.
  - Cutting speed: 500 mpm

Cubic boron nitride (CBN) and synthetic diamonds

- Diamond - hardest substance ever known of all materials.
- It is used as a coating material in its
  - polycrystalline form, or
  - as a single-crystal diamond tool for special applications, such as mirror finishing of non-ferrous materials.
  - Next to diamond, CBN is the hardest tool material.
- CBN is used mainly as
  - coating material because it is very brittle. In spite of diamond, CBN is suitable for cutting ferrous materials.


Hardness
Sintered Diamond
Diamond Coating
Sintered CBN
Si3N4
Ceramics
Al2O3
Coated Carbide
Coated Cermet
Coated Micro-grain
Cemented Carbide
Cermet
Coated
HSS
Micro-grain Cemented Carbide
Cemented Carbide
Powder HSS
HSS
Toughness

Note: Poly crystalline diamond (PCD)



Cutting fluids

Desirable properties

- High thermal conductivity for cooling
- Large specific heat
- Good lubricating qualities
- High flash point, to avoid fire hazard
- Stable against oxidation
- Must not promote corrosion or discolouration of the work
- Provide corrosion protection to the machined surface
- Must not become rancid easily
- Not provide unpleasant odour
- Must not cause skin irritation or contamination
- Should permit free flow

Types of cutting fluids

- Straight or neat cutting oils
- Water miscible or water-based fluids
- Oil –based fluids
  - Containing
    - Chlorine
    - Sulphur
- Gases
- Paste or solid lubricants

- Water-based fluids acts as coolants
  - Water is the best fluid cooling
  - But poor lubricant and
  - corrosive
- Neat cutting oils act as lubricants
  - Excellent for lubrication
  - But poor for cooling
- Fatty acids are incorporated in neat oils
- Soluble oils and neat oils containing chlorine and sulphur improves lubrication at extremely difficult conditions

Emulsions

- Dispersion of oil droplets in water
- Soluble oils are mineral oils that contain emulsifiers
- Emulsifiers are
  - Soaps or soap like agents
  - Alow oil to mix with water and remain suspended
- Milky white fluids
  - Lean concentration

- Lean concentration
  - More water, less oil
  - Better cooling
  - Poor lubrication
- Rich concentration
  - Less water, more oil
  - Poor cooling
  - Better lubrication

Chemical fluids

- Emulsions with very little oil
- Mix easily with water
- Enhances
  - Lubrication
  - Bacterial control
  - Rust and corrossion characteristics

Inactive cutting fluids

- Usually neat oils with
- High corrosion inhibition
- High cooling
- Low lubrication qualities

Active cutting fluids

- Include wetting agent
- Excellent rust inhibition
- Moderate lubrication
- Moderate cooling properties
- Contain
  - Sulphur
  - Chlorine
  - Phosphorus

Straight cutting oils

- Not mixed with water
- Mixture of
  - Mineral oils
  - Animal oils
  - Vegetable oils
  - Marine oils

Types of straight cutting oils

- Inactive straight cutting oils:
- Active straight cutting oils:

Inactive straight cutting oils

- E.g. mineral oils
- Excellent lubrication
- Poor heat dissipation
- Suitable for non-ferrous materials:
  - Aluminium
  - Brass
  - Magnesium

Active straight cutting oils

  - Sulphur not firmly attached to oil
  - Sulphur is easily released
  - Reacts with work
- Good lubrication
- Good cooling properties
- Recommended for
  - low carbon steels
- Chrome-alloy steels
- Thread cutting grinding

Thanks

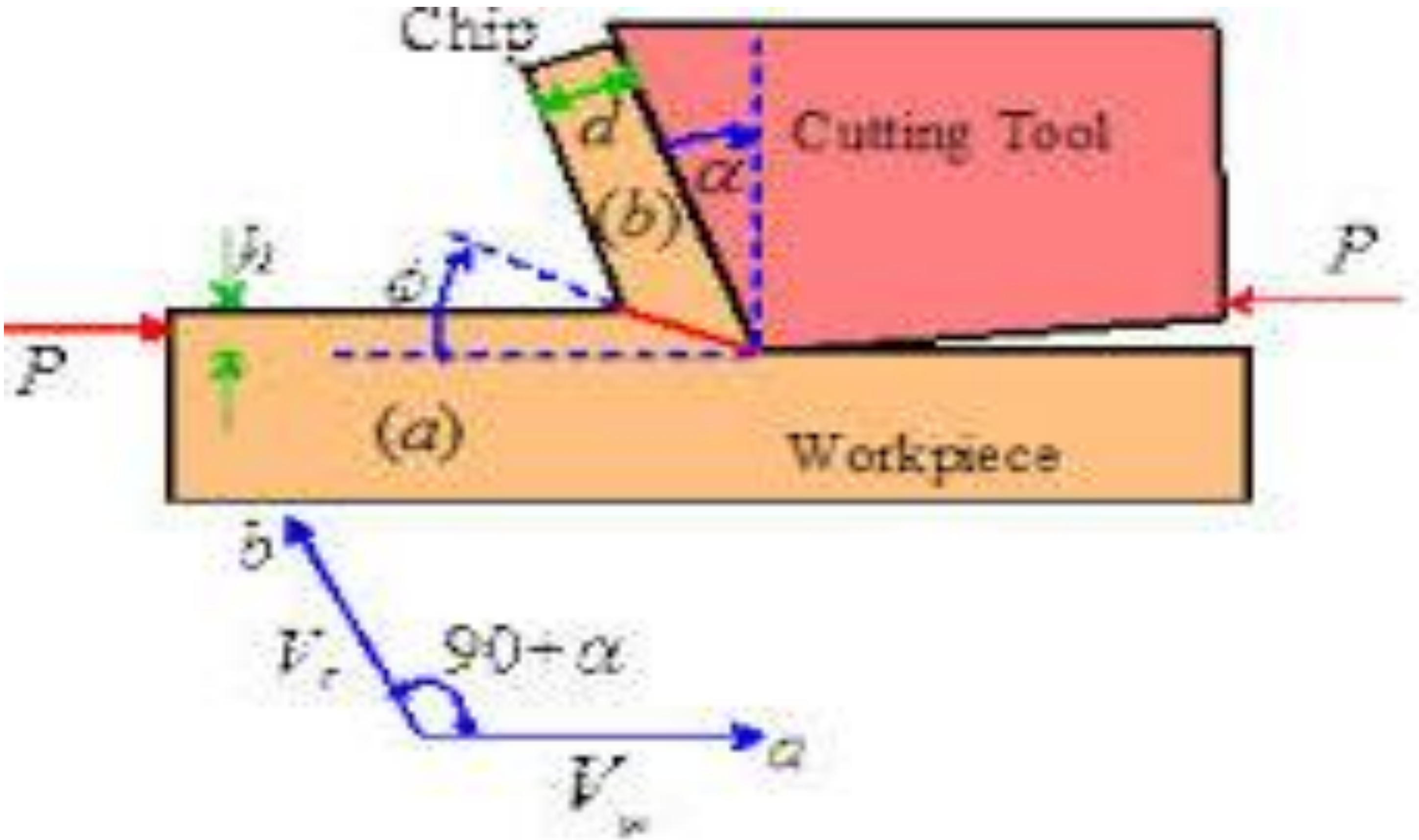
Machining processes

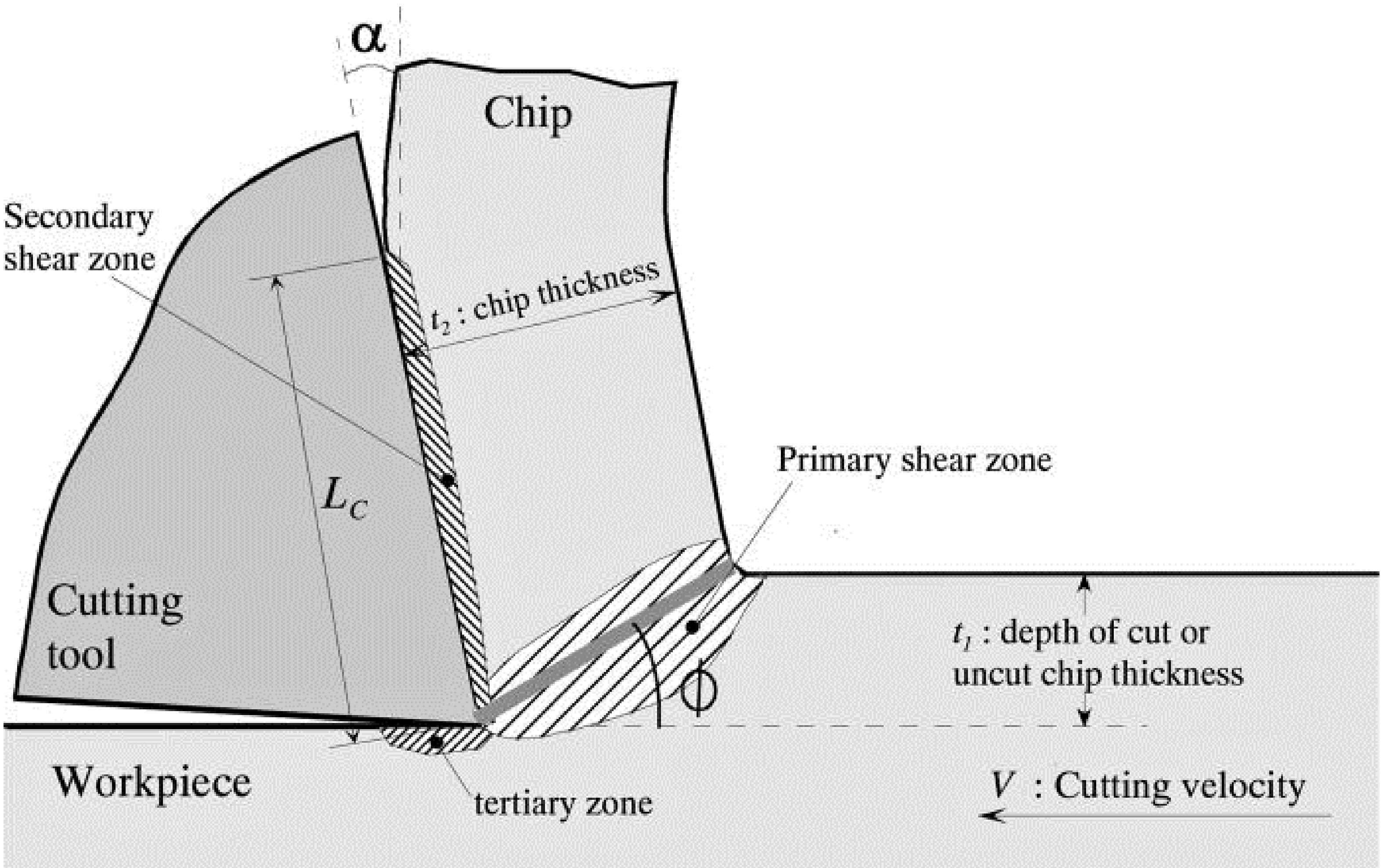
Machine Tools

A power-driven machine that performs a machining operation, including grinding

- Functions in machining:
  - Holds workpart
  - Positions tool relative to work
  - Provides power at speed, feed, and depth that have been set
- The term is also applied to machines that perform metal forming operations

Mechanics of machining




α
Chip
Secondary
shear zone
t₂ : chip thickness
Primary shear zone
L_C
Cutting
tool
ϕ
t₁ : depth of cut or
uncut chip thickness
Workpiece
tertiary zone
V : Cutting velocity

Important parameters of machining

1. Thickness of uncut layer
2. Thickness of chip
3. Inclination of the chip-tool interface with respect to the face of the tool (rake angle)
4. The relative velocity of the work piece and the cutting tool

A clearance angle between the work and the flank surface make the cutting possible.

Classification of Cutting Tool

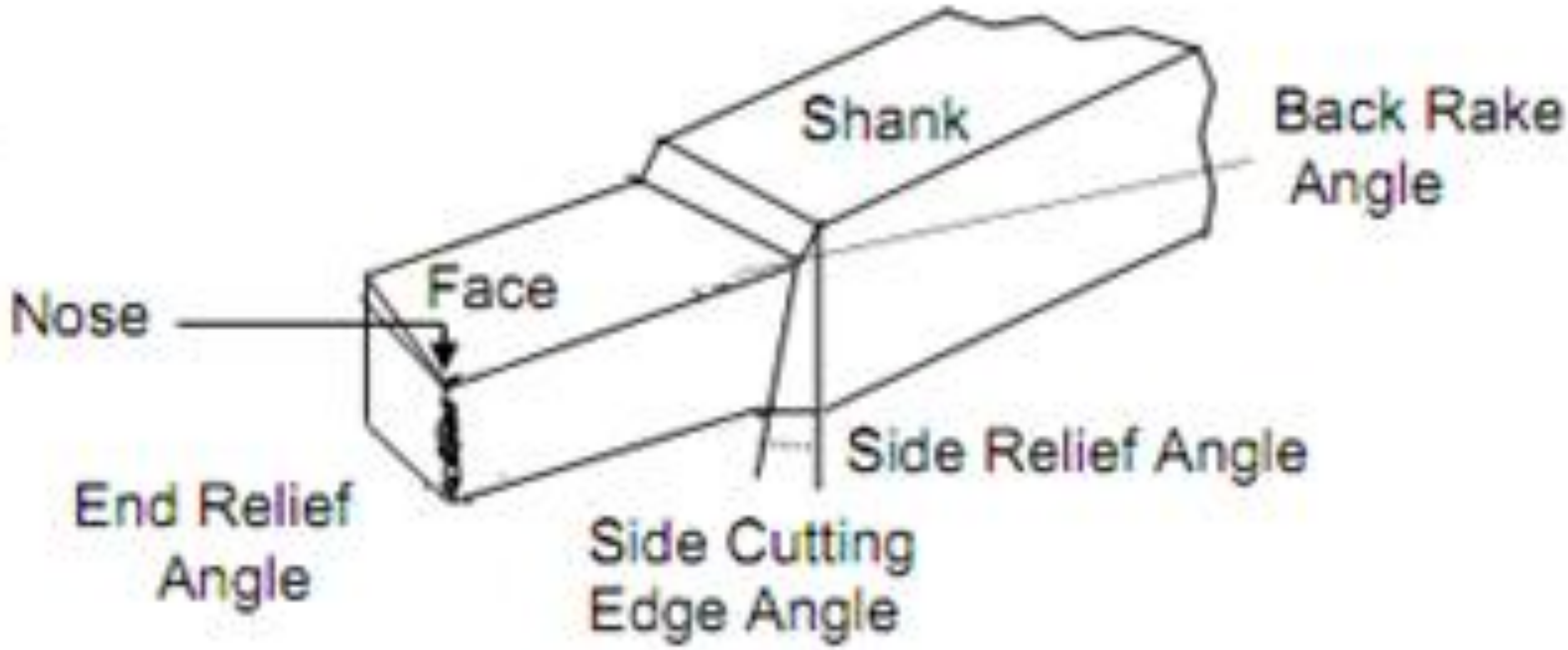
1. Single-Point Tools

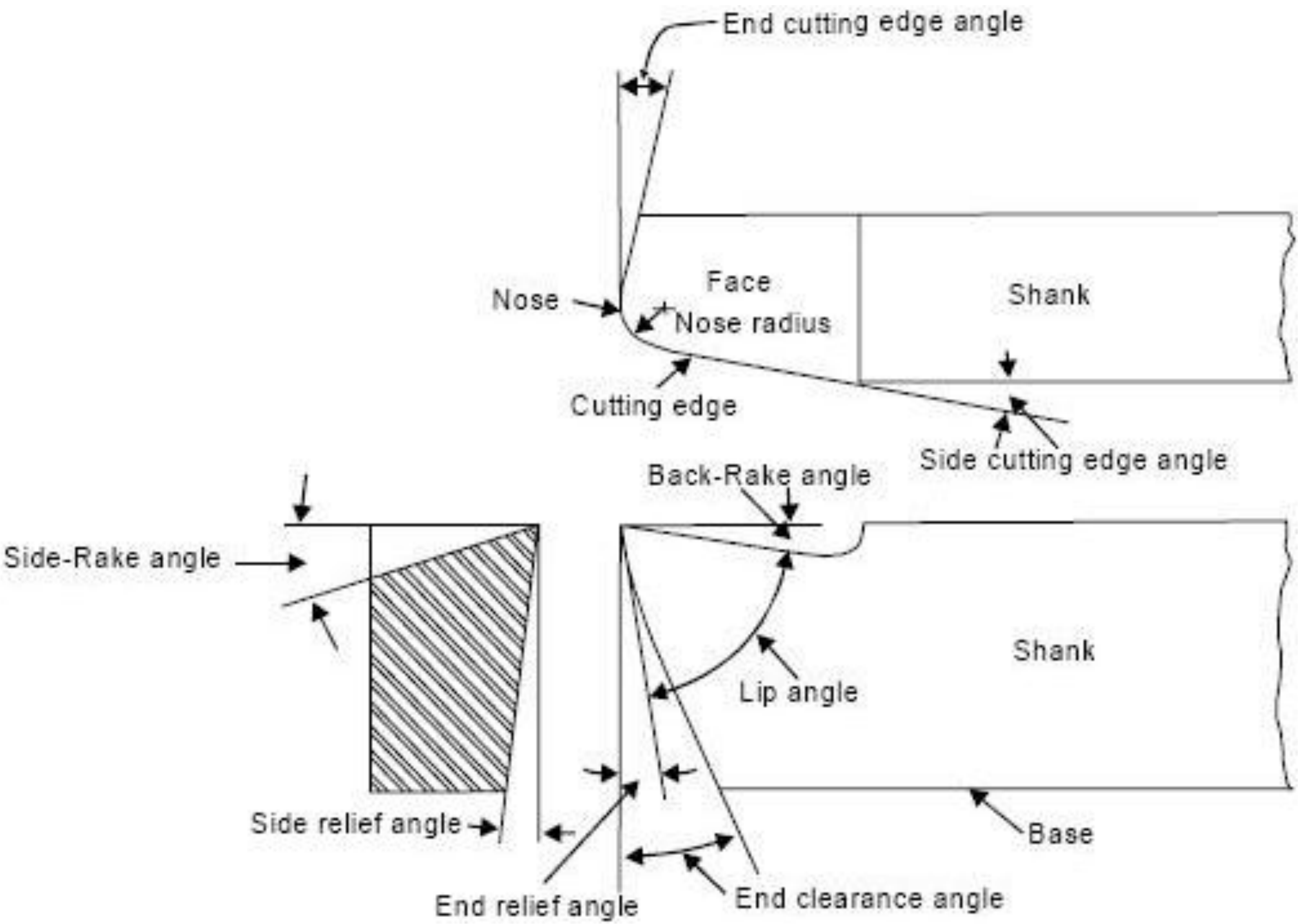
- One cutting edge
- *Turning* uses single point tools
- Point is usually rounded to form a *nose radius*

2. Multiple Cutting Edge Tools

- Also called multipoint cutting tools
- More than one cutting edge
- Motion relative to work usually achieved by rotating
- *Drilling* and *milling* use rotating multiple cutting edge tools.

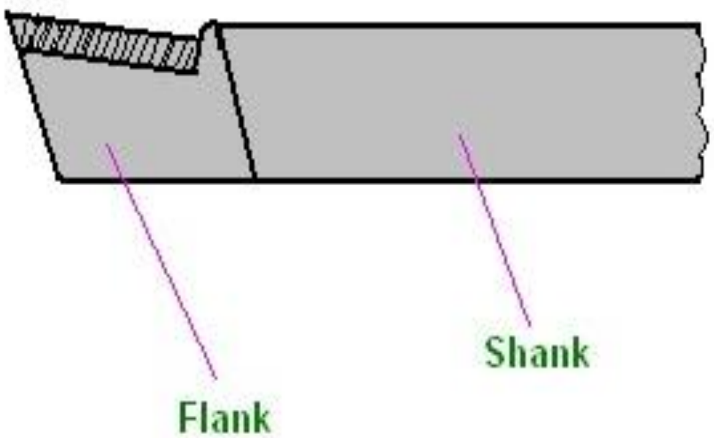
Single Point Cutting Tools

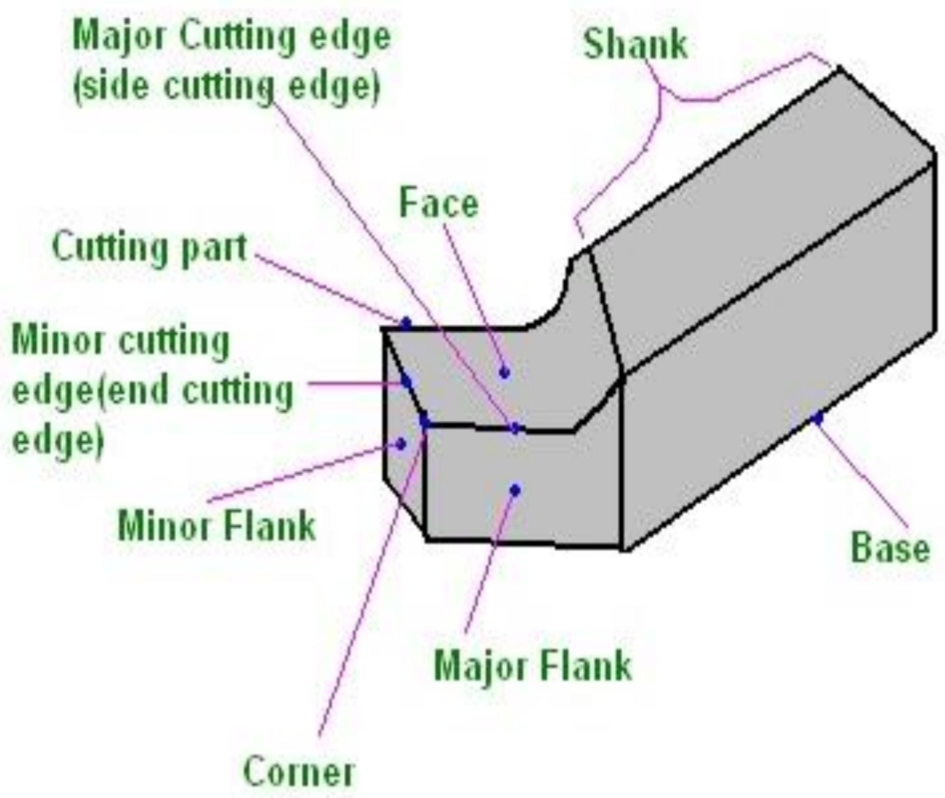

Shank
Back Rake Angle
Face
Nose
Side Relief Angle
End Relief Angle
Side Cutting Edge Angle

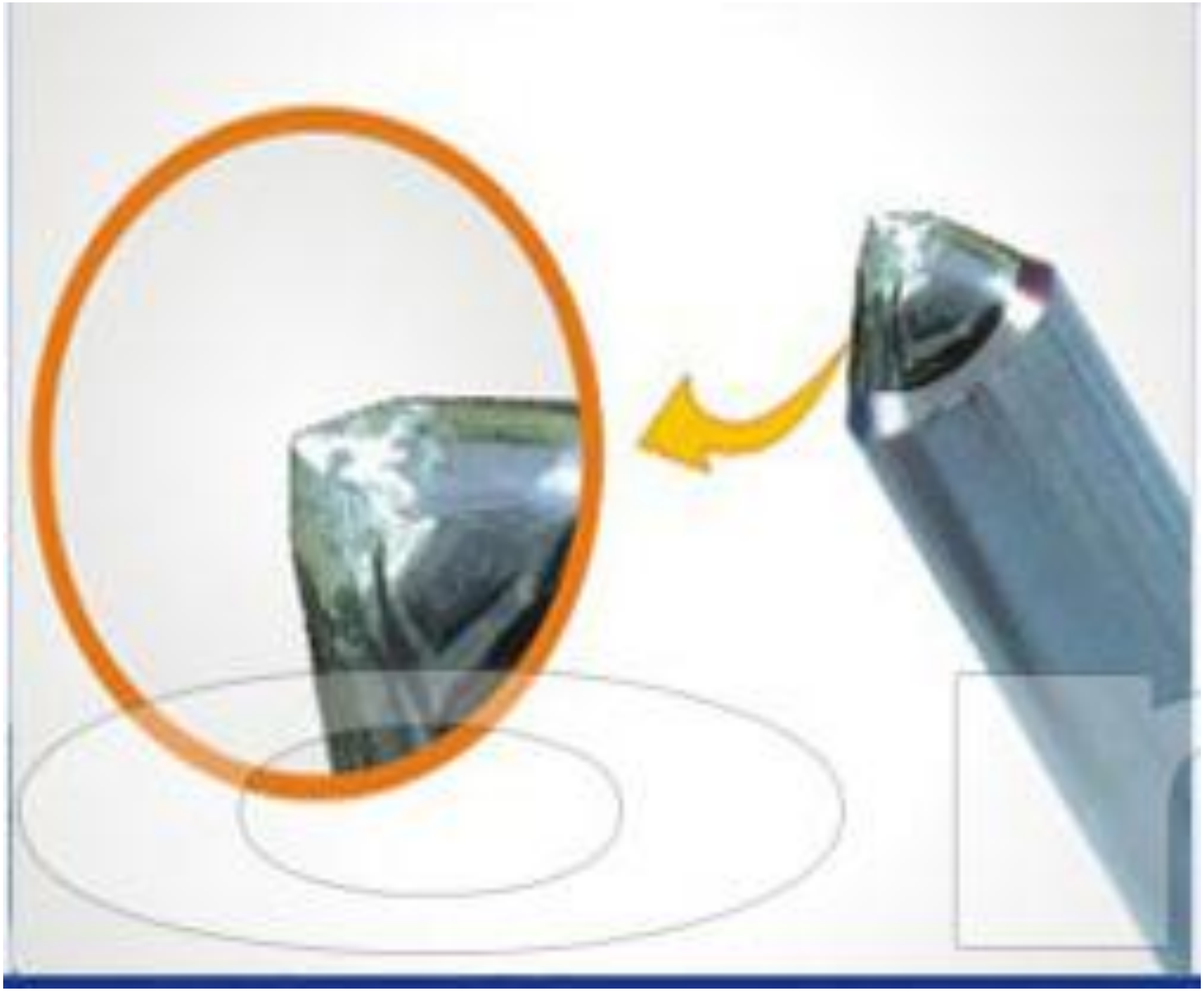


End cutting edge angle
Face
Shank
Nose
Nose radius
Cutting edge
Side cutting edge angle
Back-Rake angle
Side-Rake angle
Shank
Lip angle
Side relief angle
Base
End relief angle
End clearance angle

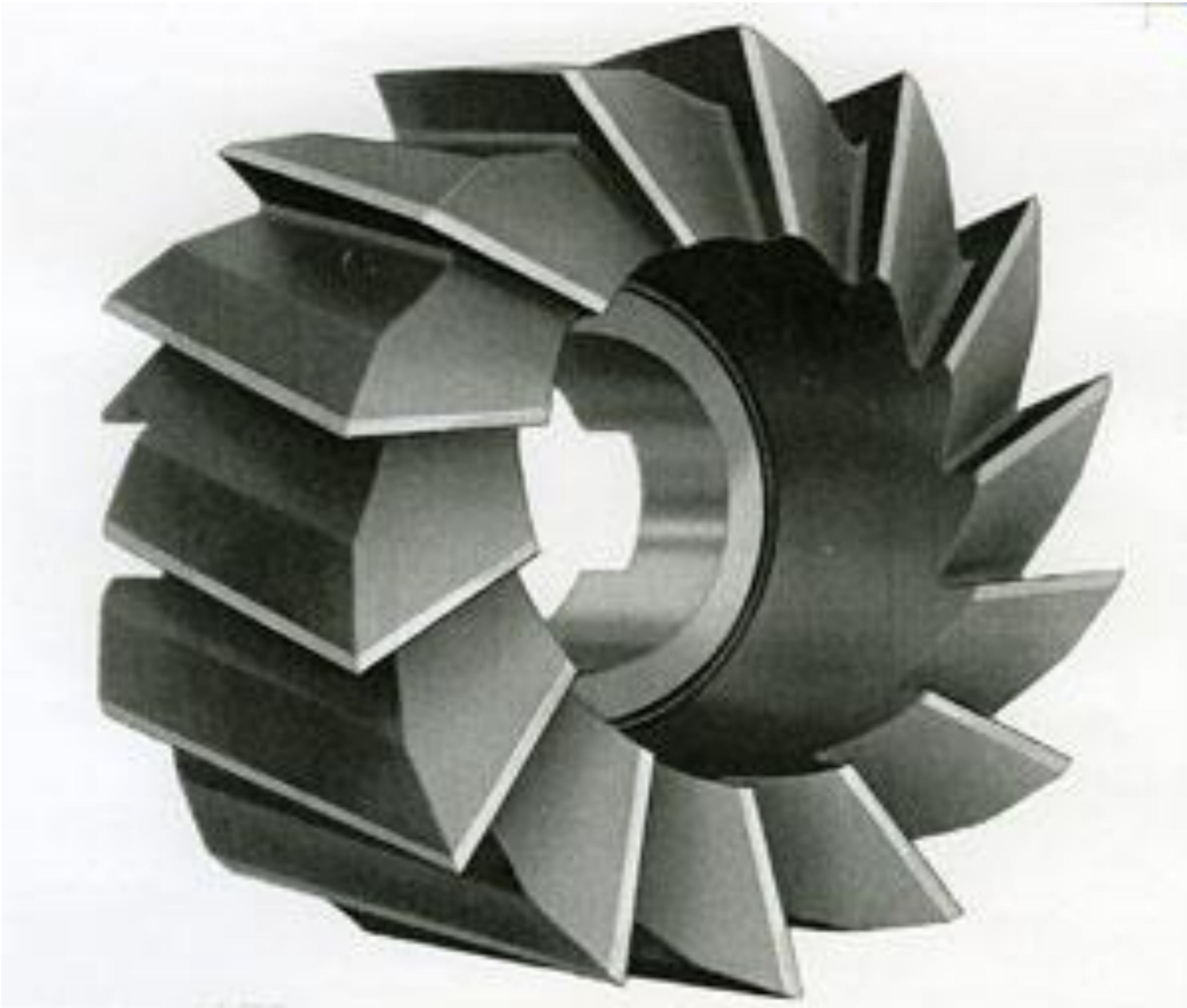
Nomenclature of single point cutting tool:

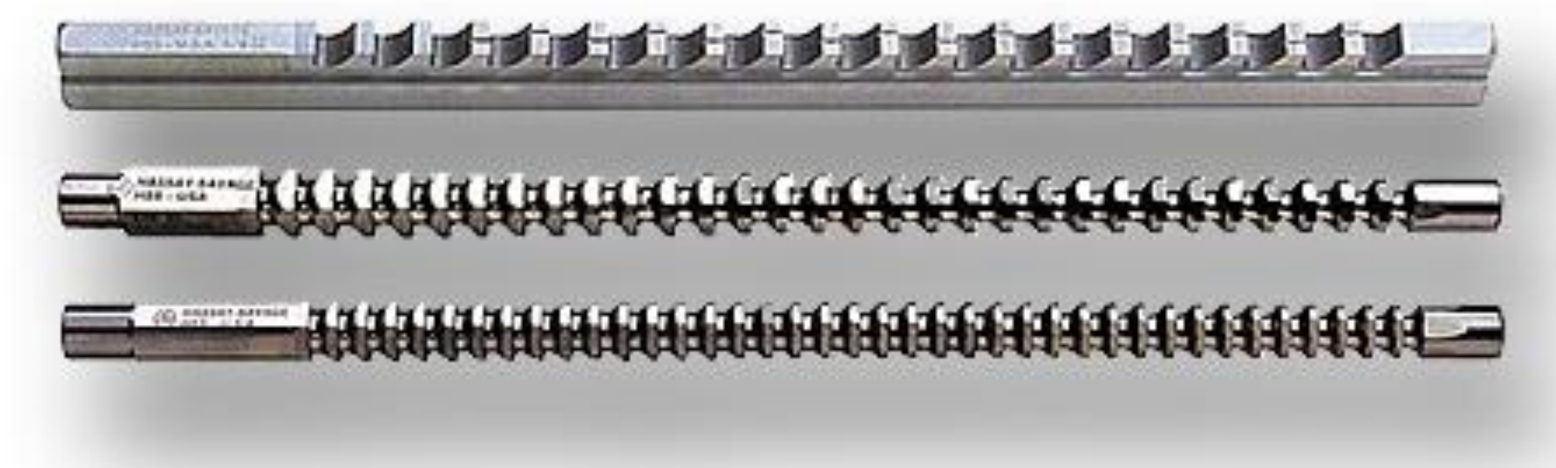






Multipoint cutting tools



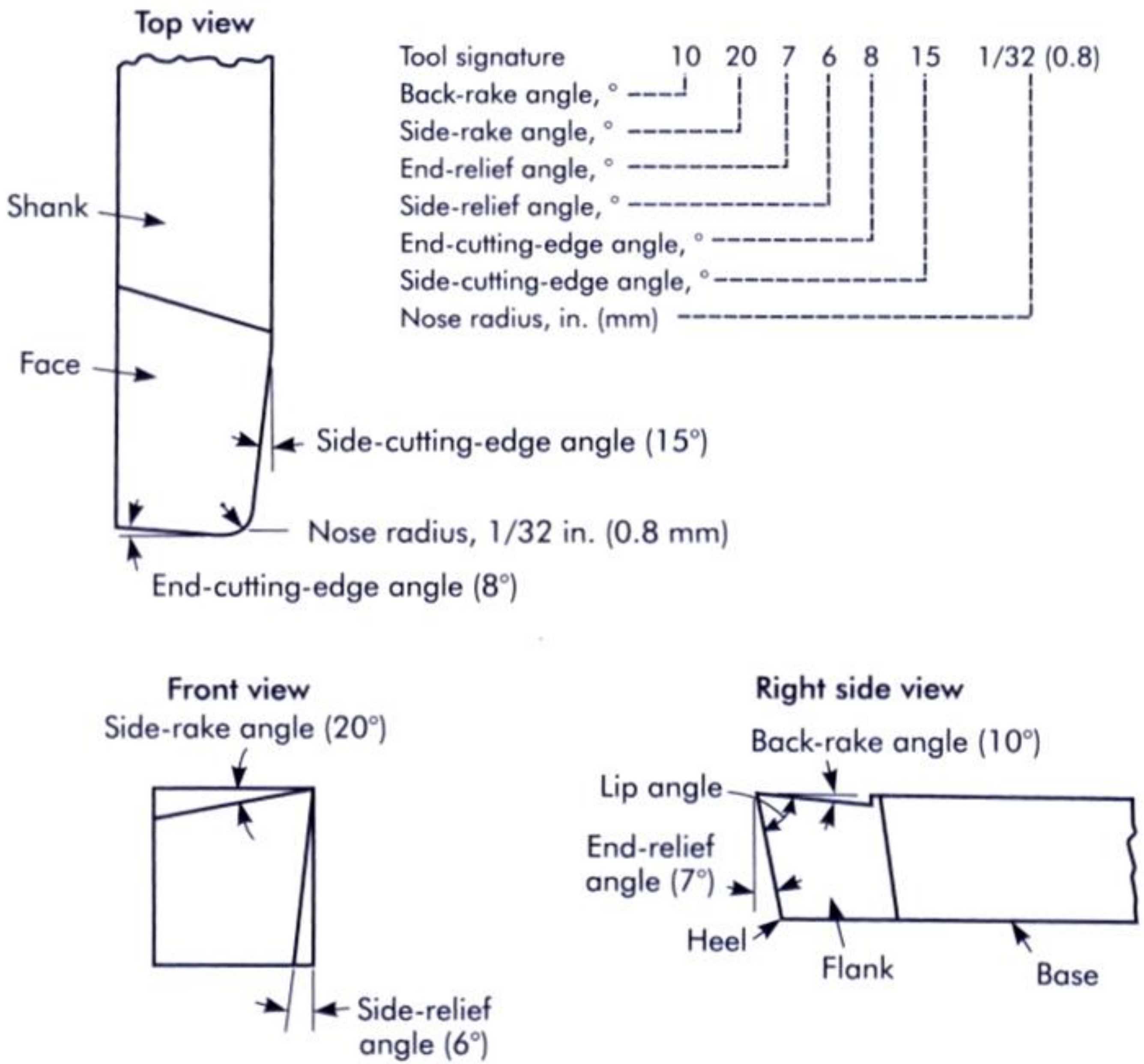


Broaching tools

Broaching tools

Signature of right hand single point cutting tool

10-20-7-6-8-5-0.8


Top view
Tool signature 10 20 7 6 8 15 1/32 (0.8)
Back-rake angle, °
Side-rake angle, °
End-relief angle, °
Side-relief angle, °
End-cutting-edge angle, °
Side-cutting-edge angle, °
Nose radius, in. (mm)
Shank
Face
Side-cutting-edge angle (15°)
Nose radius, 1/32 in. (0.8 mm)
End-cutting-edge angle (8°)
Front view
Side-rake angle (20°)
Side-relief angle (6°)
Right side view
Back-rake angle (10°)
Lip angle
End-relief angle (7°)
Heel
Flank
Base

Orthogonal cutting

- Can be represented by a 2-dimensional figure
- The work move in the plane parallel to the plane of the paper
- The chip material particles also move in the plane parallel to the plane of the paper
- No component of velocity in the direction perpendicular to the plane of the paper

Orthogonal Cutting Model

A simplified 2-D model of machining that describes the mechanics of machining fairly accurately

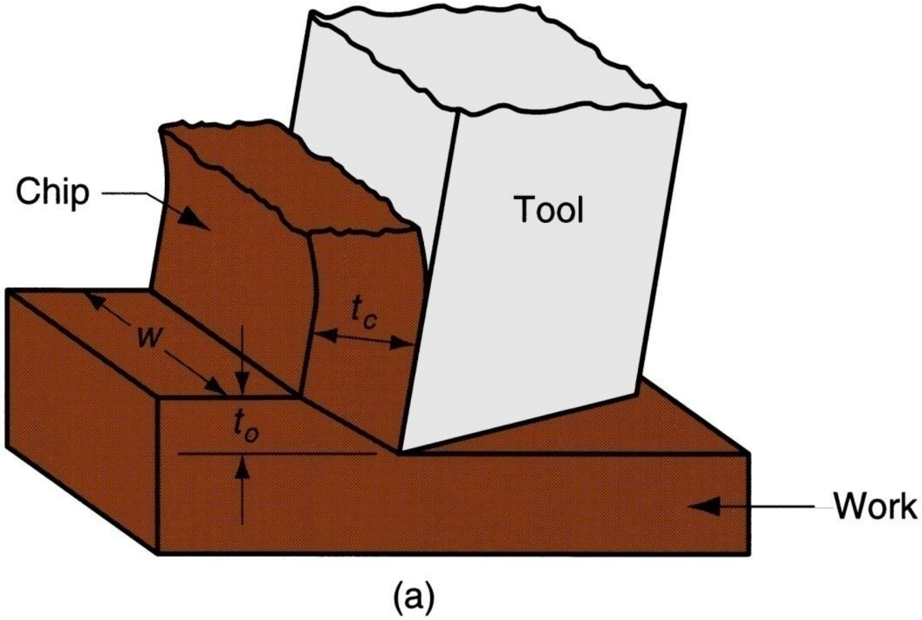
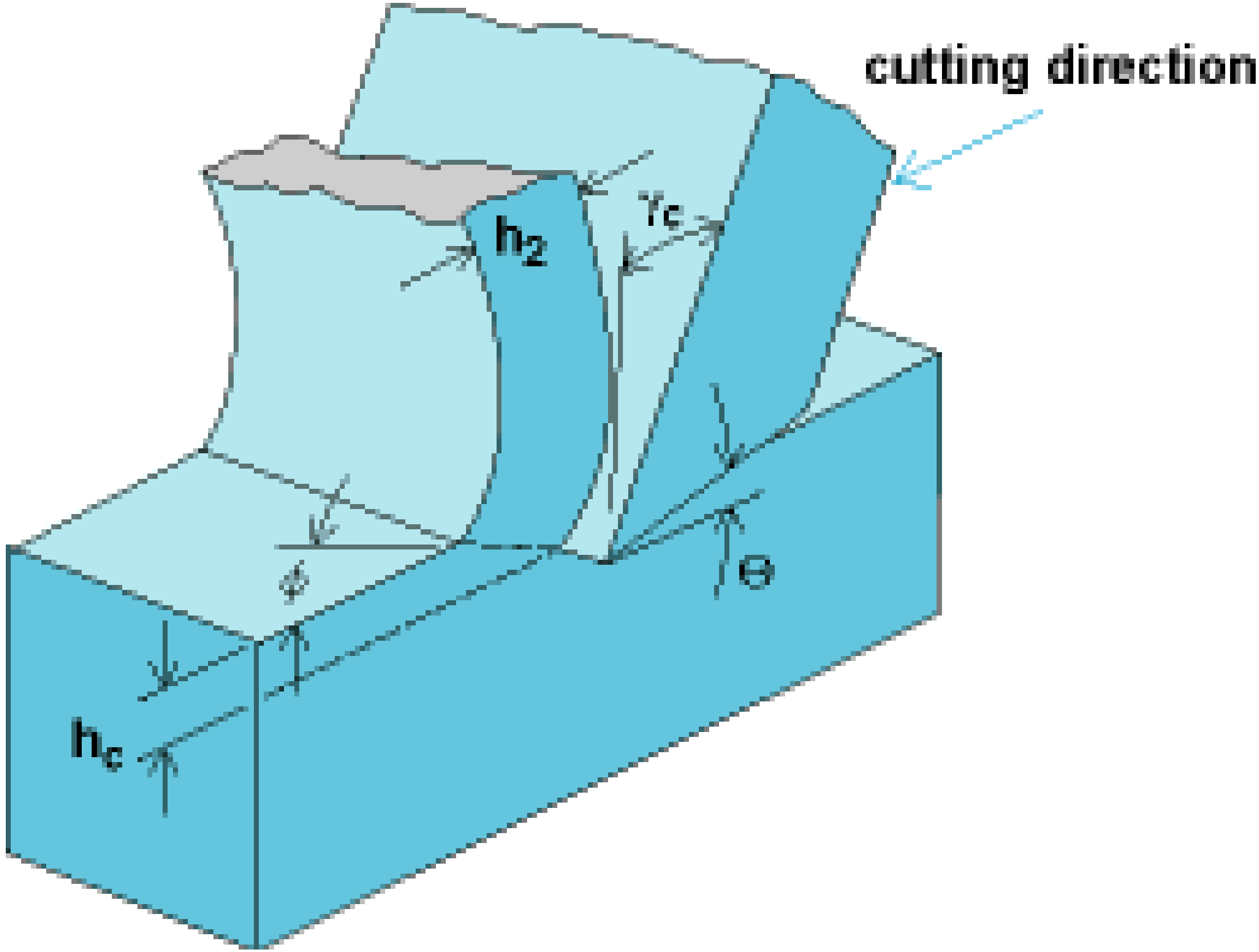
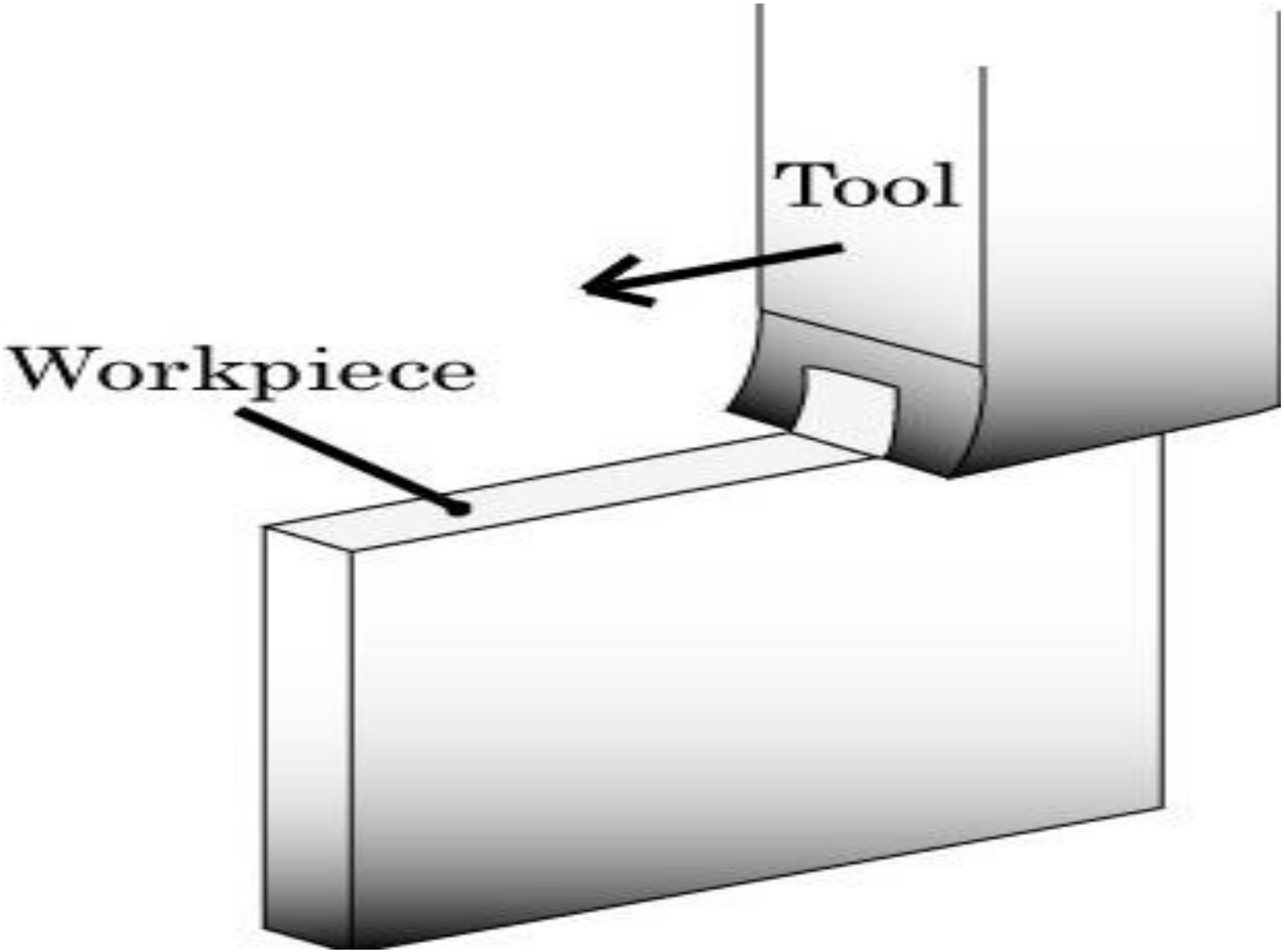
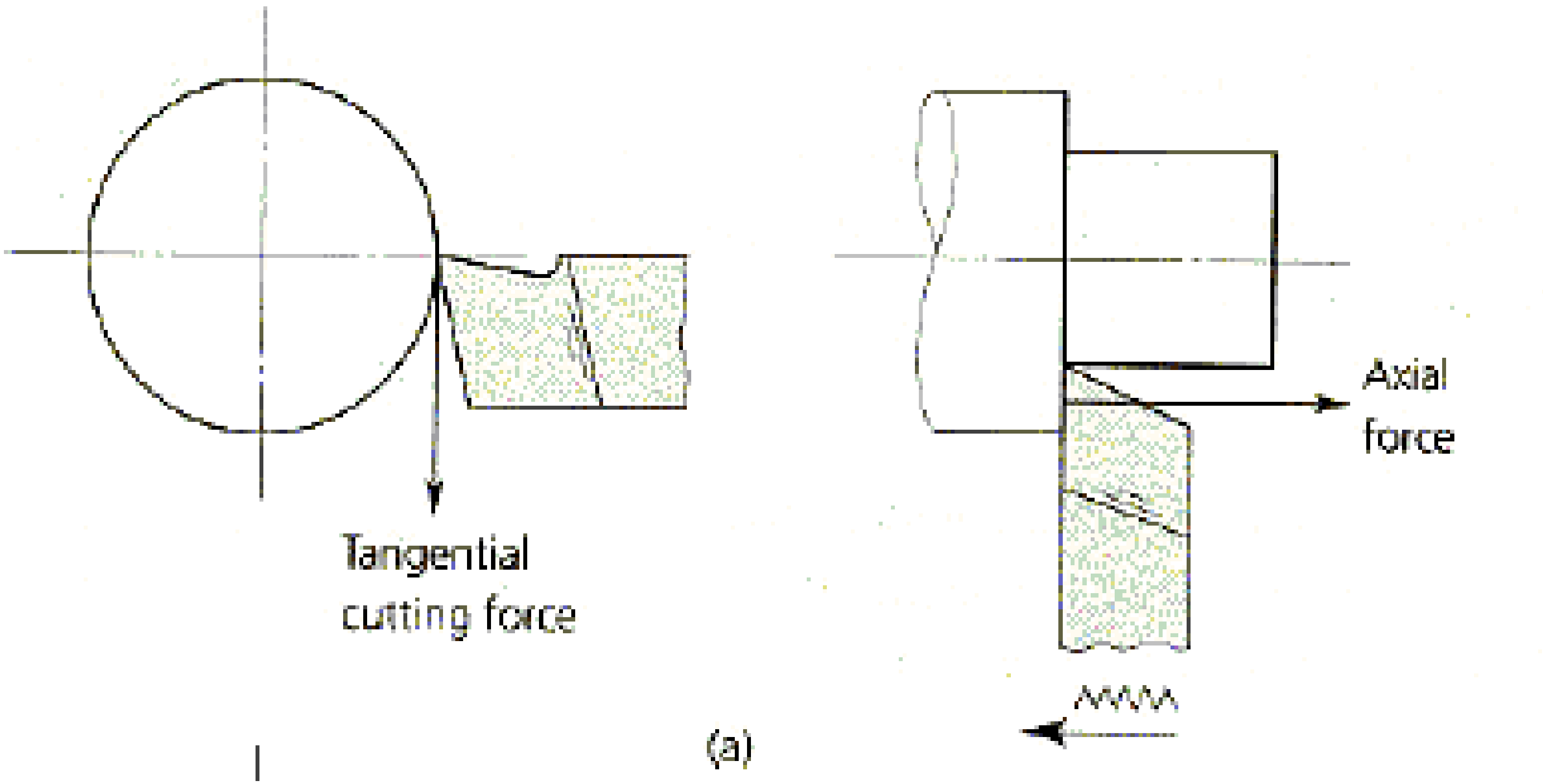


Figure - Orthogonal cutting: (a) as a three-dimensional process


cutting direction
h_2
γ_c
ϕ
Θ
h_c


Tool
Workpiece

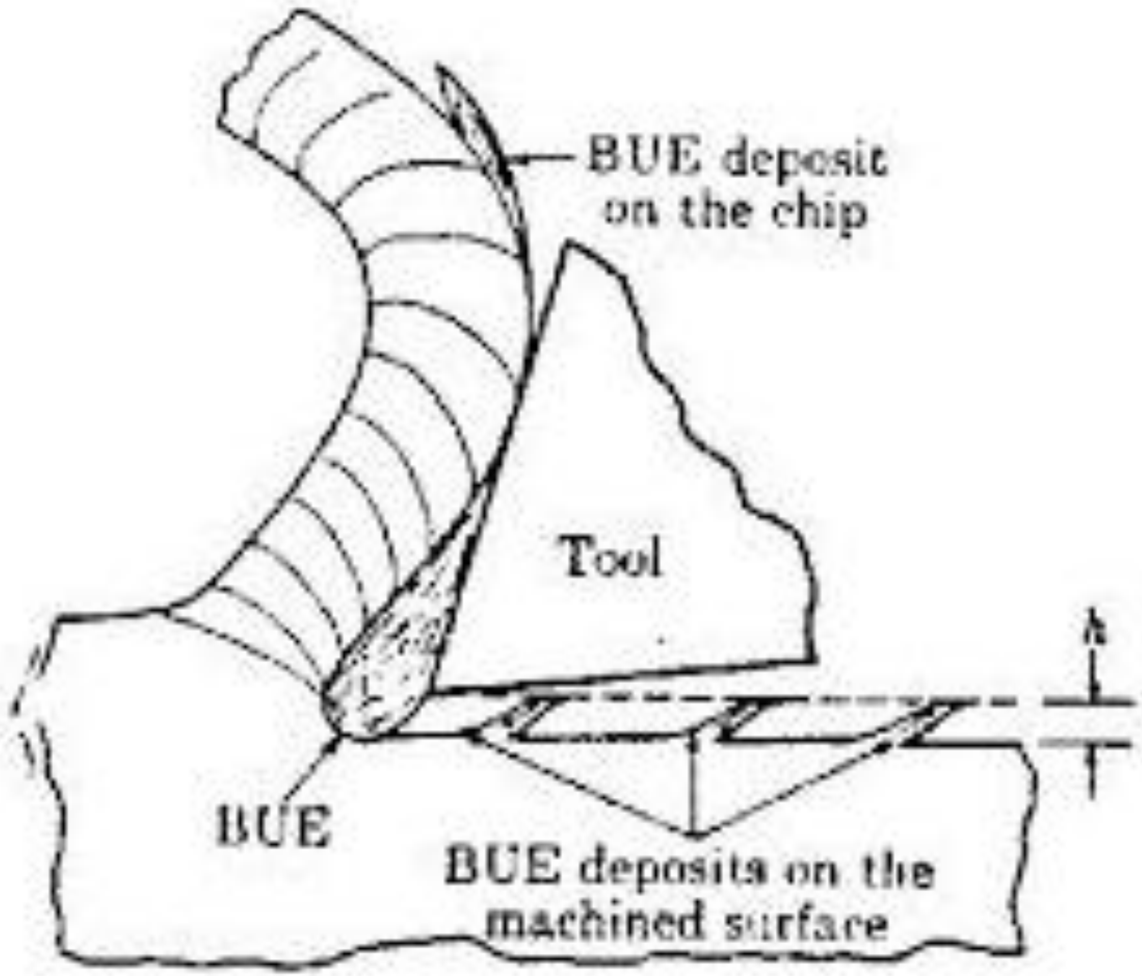


Orthogonal cutting

Types of chips

- Continuous chip without built-up edge (BUE)
  - Ductile material
  - Small uncut thickness
  - High cutting speed
  - Large rake angle
  - Suitable cutting fluid
- Continuous chip with built-up edge (BUE)
  - Stronger adhesion between chips and tool face
  - Large uncut thickness
  - Low rake angle
- Discontinuous chip
  - Brittle material
  - Large uncut thickness
  - Low cutting speed
  - Small rake angle

Continuous chip withBUE



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

where,

μ = the coefficient of friction

$$\boxed{r_c = \frac{t_1}{t_2}}$$

where,

r_c = the cutting ratio

Cutting ratio

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

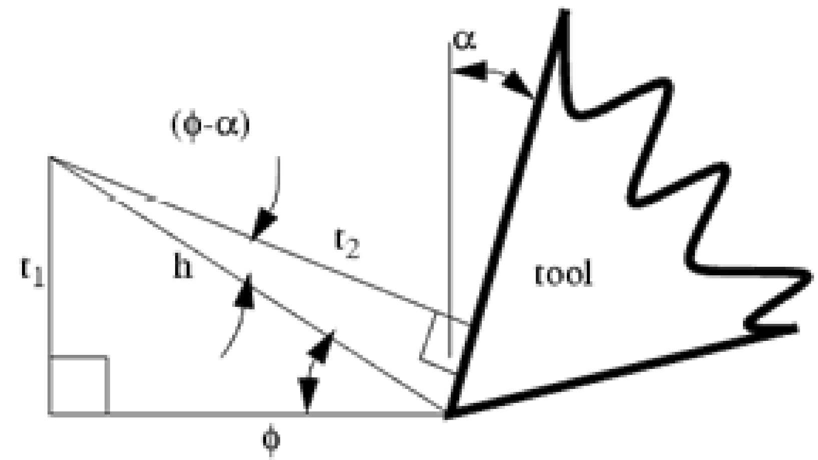
where,

μ = the coefficient of friction

$$r_c = \frac{t_1}{t_2}$$

where,

r_c = the cutting ratio



Shear angle

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

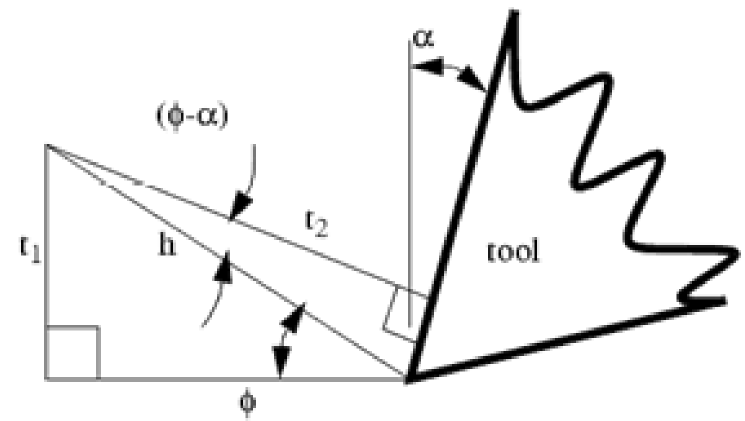
$$r_c = \frac{t_1}{t_2} = \frac{h\sin\phi}{h\cos(\phi-\alpha)} = \frac{\sin\phi}{\cos\phi\cos\alpha + \sin\phi\sin\alpha}$$

$$\therefore r_c\cos\phi\cos\alpha + r_c\sin\phi\sin\alpha = \sin\phi$$

$$\therefore \frac{r_c\cos\phi\cos\alpha}{\sin\phi} + \frac{r_c\sin\phi\sin\alpha}{\sin\phi} = 1$$

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

$$\boxed{\therefore \tan\phi = \frac{r_c\cos\alpha}{1 - r_c\sin\alpha}}$$



Shear angle

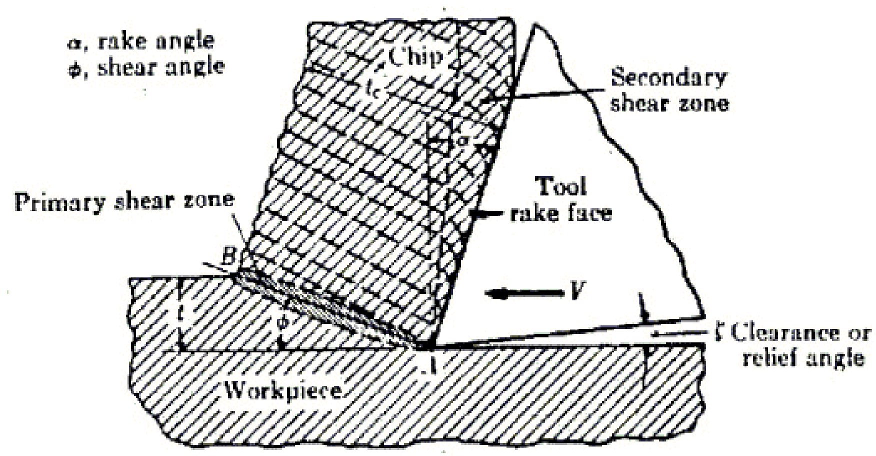
Cutting ratio, $r = t/t_c$

$= r = \sin\varnothing/\cos(90^o - \varnothing + \alpha)$

$= \sin\varnothing/\cos(\varnothing - \alpha)$

$= \sin\varnothing/(\cos\varnothing\cos\alpha + \sin\varnothing\sin\alpha)$

$= \tan\varnothing/\{\cos\alpha + \tan\varnothing\sin\alpha\}$

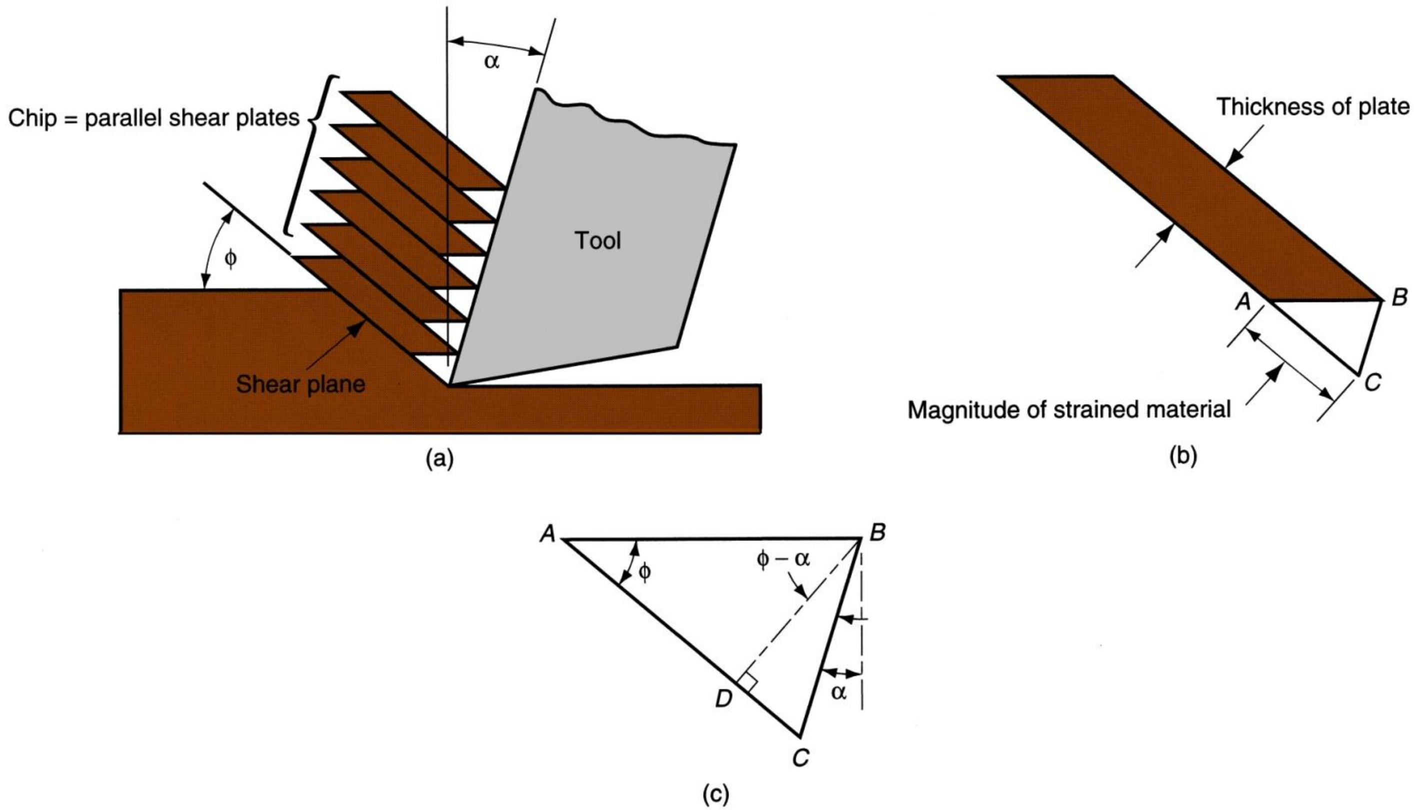


$r(\cos\alpha + \tan\varnothing\sin\alpha) = \tan\varnothing$

Hence,

$\tan\varnothing = r\cos\alpha/(1 - r\sin\alpha)$

Shear strain



∴ Shear Strain $=AC/BD$

Shear Strain

Shear strain in machining can be computed from the following equation, based on the preceding parallel plate model:

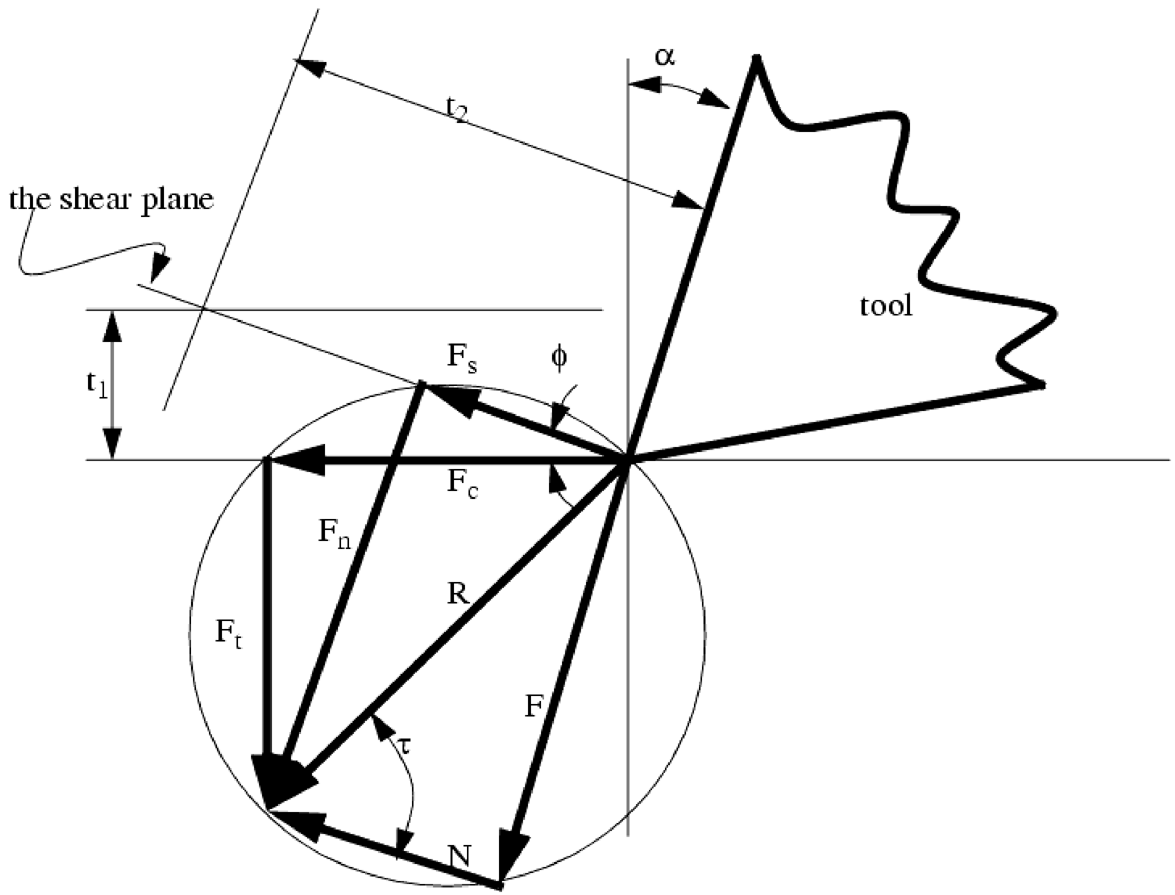
$$\gamma = \tan(\phi - \alpha) + \cot \phi$$

where γ = shear strain, ϕ = shear plane angle, and α = rake angle of cutting tool

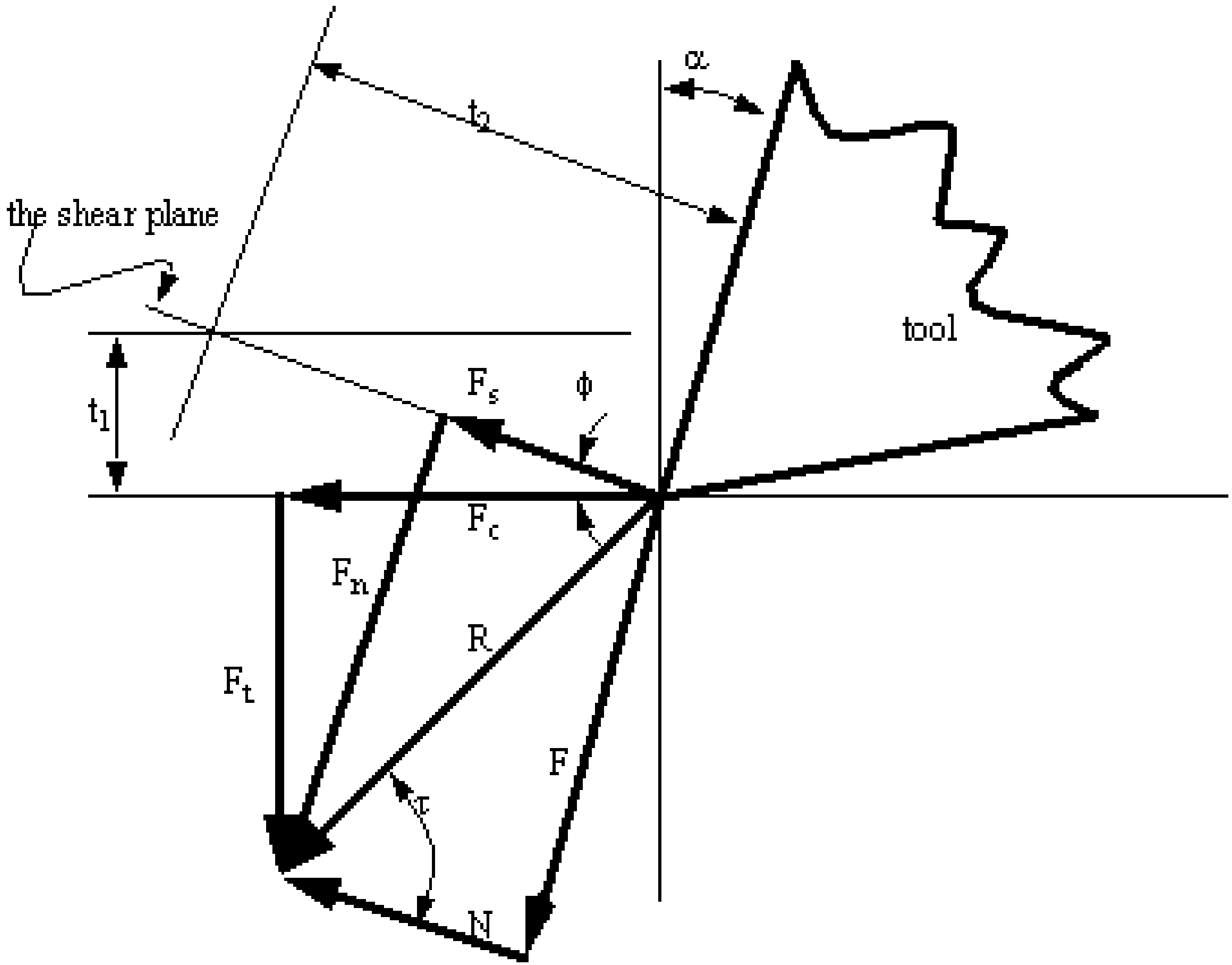
Mechanics of chip formation

- First proposed by Ernst and Merchant
  - Trans. ASME, 29, 299,1941.
  - Considered idealized case of a single plane
  - An approximate is predicted
  - Forces on chip from rake face = Forces on work surface along shear plane
- Forces on tool
  - F_C -along the direction of cutting velocity v
  - F_T-normal to the direction of cutting velocity v

Merchant’s circle diagram



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



F_s = shear force
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α = tool rake angle (positive as shown)
ϕ = shear angle
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Forces in Metal Cutting

- Equations can be derived to relate the forces that cannot be measured to the forces that can be measured:

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

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

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

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

- Based on these calculated force, shear stress and coefficient of friction can be determined

Shear Stress

Shear stress acting along the shear plane:

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

where A_s = area of the shear plane

$$A_s = \frac{t_o w}{\sin \phi}$$

Shear stress = shear strength of work material during cutting

The Merchant Equation

$$W(\phi) = F_C v = \frac{t_1 w \tau_s \cos(\lambda - \alpha)}{\sin\phi \cos(\phi + \lambda - \alpha)}$$

Whereas, t_1, w, and τ_s are constants.

For minimum power, differentiating *W* w.r.t Ø, we get:

$$\cos\phi \cos(\phi + \lambda - \alpha) - \sin\phi \sin(\phi + \lambda - \alpha) = 0$$

$$\cos(2\phi + \lambda - \alpha) = 0 = \cos(\pi / 2)$$

Hence,

$$2\phi + \lambda - \alpha = \pi / 2$$

Shear angle relations

Source	Results
Ernst and Merchant	$2\emptyset + \lambda - \alpha = \pi / 2$
Merchant's second solution	$2\emptyset + \lambda - \alpha = C_m$
Lee and Shaffer	$\emptyset + \lambda - \alpha = \pi / 4$
Stabler	$\emptyset + \lambda - \alpha / 2 = \pi / 4$

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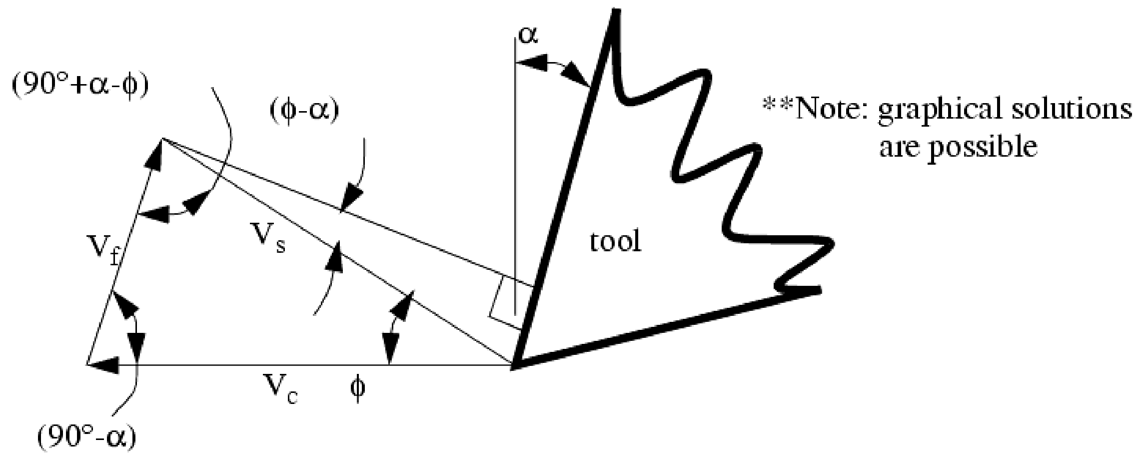


where,

V_c = cutting velocity (ft./min.) - as set or measured on the machine
V_s = shearing velocity
V_f = frictional velocity

Using the sine rule,

$$\frac{V_s}{\sin(90^\circ - \alpha)} = \frac{V_c}{\sin(90^\circ + \alpha - \phi)}$$

$$\therefore V_s = \frac{V_c \sin(90^\circ - \alpha)}{\sin(90^\circ + \alpha - \phi)} = \frac{V_c \cos\alpha}{\cos(\phi - \alpha)}$$

Also,

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

Heat generation and temperature profile

- During cutting
  - Plastic deformation
    - Primary shear zone
    - Secondary shear zone
  - 99% of energy converted into heat
    - Heat taken away
      - Chip
        - Major portion
      - Work
      - Tool
  - Faster wear
  - Failure of tool

Heat calculation

- W = total power consumed

  $= F_C v$ "v = cutting velocity
- W_p & W_s are heat generated in primary and secondary deformation zones
- $W = W_p + W_s$
- $W_s = F v_c = Fr\ v$ "v_c = chip velocity
- Wp = W – Fr v

- Temperature at primary shear zone T_p is

$$T_p = \frac{(1-x)W_p}{\rho s v w t_1}$$

Where

- X = fraction of primary heat goes to work
- ρ = density of the work material
- s = specific heat of the work material
- t_1, = uncut chip thickness
- w = width of cut

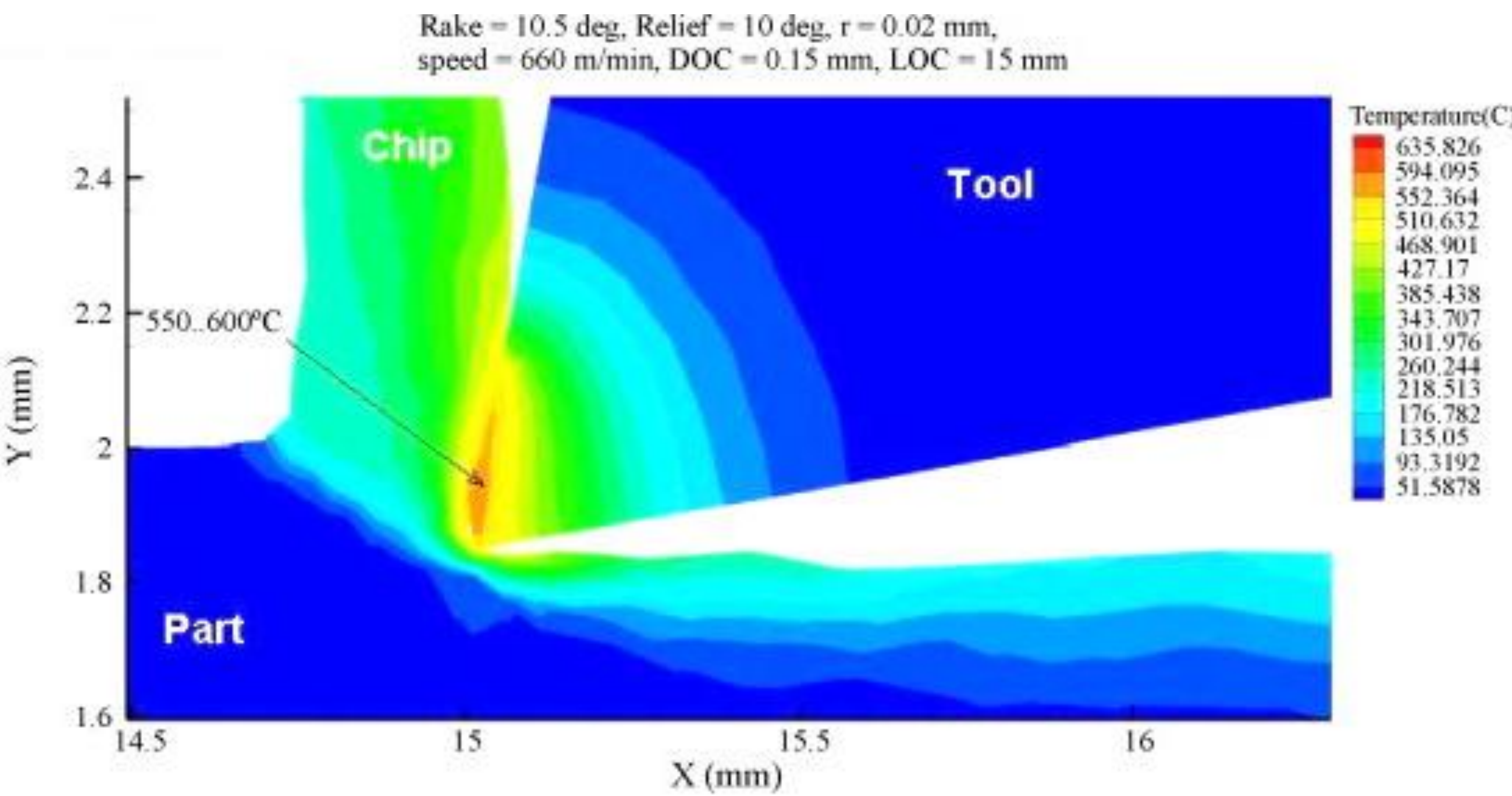
- T_s = temperature rise at secondary shear zone
- T_o = initial temperature of the work piece

- Total temperature, T is given by

$$T = T_o + T_s + T_p$$

The maximum temperature is along the rake face of the tool.

Temperature profile when cutting with a single cutting tool



Thanks