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MACHINING SCIENCE & METROLOGY [BME402]

Module-1
Introduction to Metal Cutting & Machine Tools

Prof. Devaraj M R
Associate Professor,
Dept. of Mechanical Engineering,
ATMECE, Mysuru

MODULE-1

Introduction to Metal cutting: Orthogonal and oblique cutting. Classification of cutting tools: single, and multipoint; tool signature for single point cutting tool. Mechanics of orthogonal cutting; chip formation, shear angle and its significance, Merchant circle diagram. Numerical problems. Cutting tool materials and applications.

Introduction to basic metal cutting machine tools: Lathe- Parts of lathe machine, accessories of lathe Machine and various operations carried out on lathe. Kinematics of lathe. Turret and Capstan lathe.

Metal Cutting

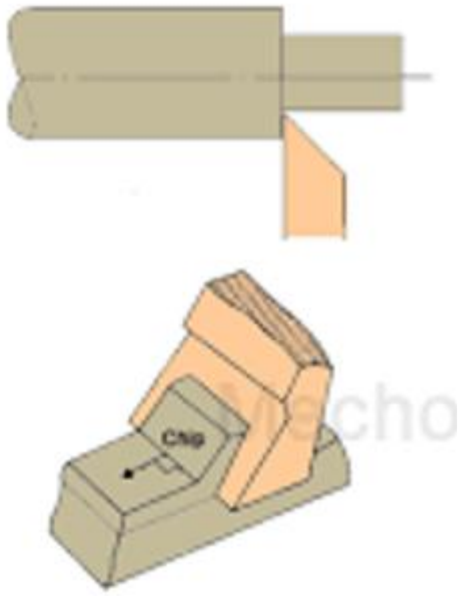
- Metal Cutting is a process of removing (cutting) a layer of material from a metal blank by means of a tool, which is harder than the metal being cut.
- *The Process of Metal Cutting is classified into two types:*

1) Orthogonal Cutting
2) Oblique Cutting

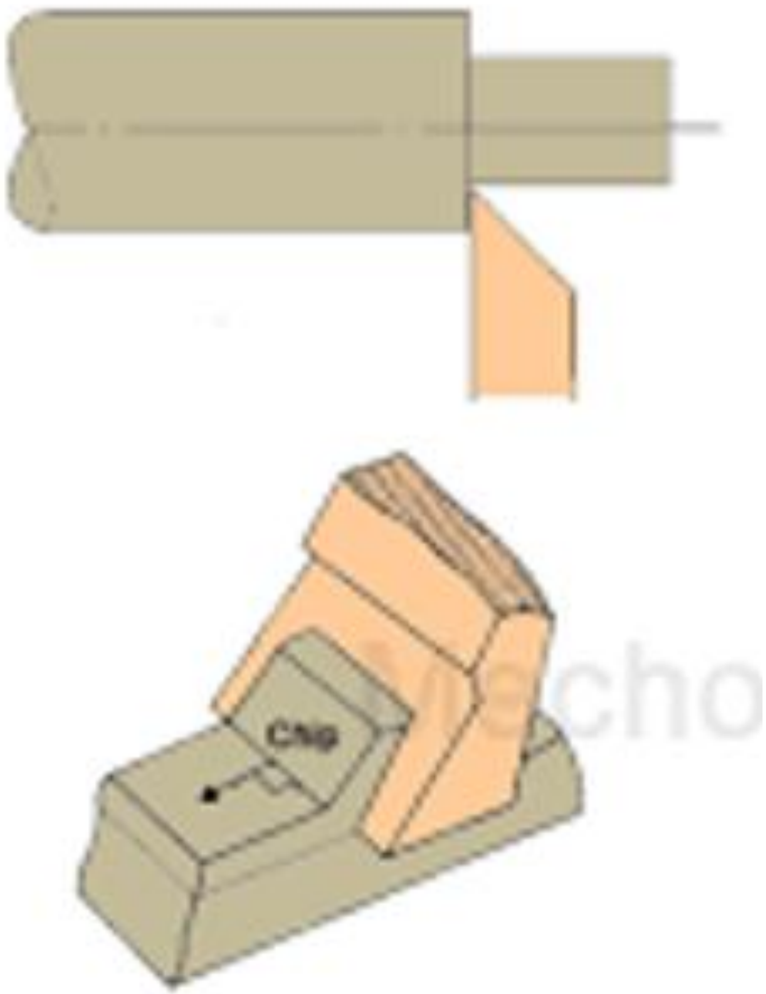
Orthogonal Cutting

- It is a type of cutting operation in which the cutting edge of the tool is straight and perpendicular to the direction of work or tool travel.
- It is also referred as 2-D cutting operation. Only two components of cutting force acts on the tool and both are perpendicular to each other.
- The chip does not flow to either side, but flows over the tool face.

Orthogonal cutting

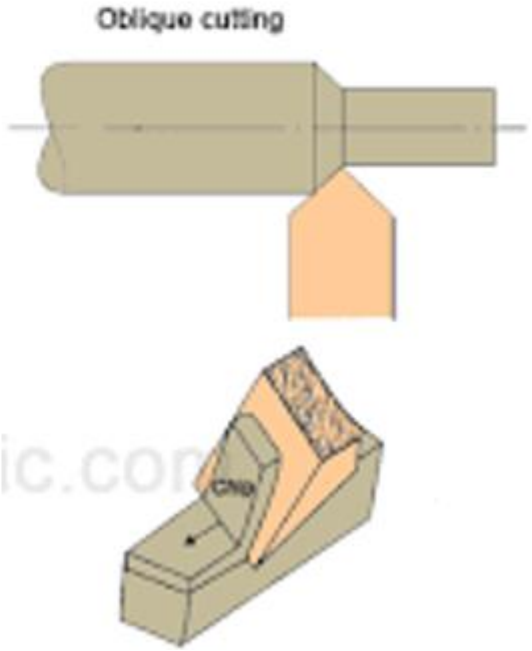


Orthogonal cutting

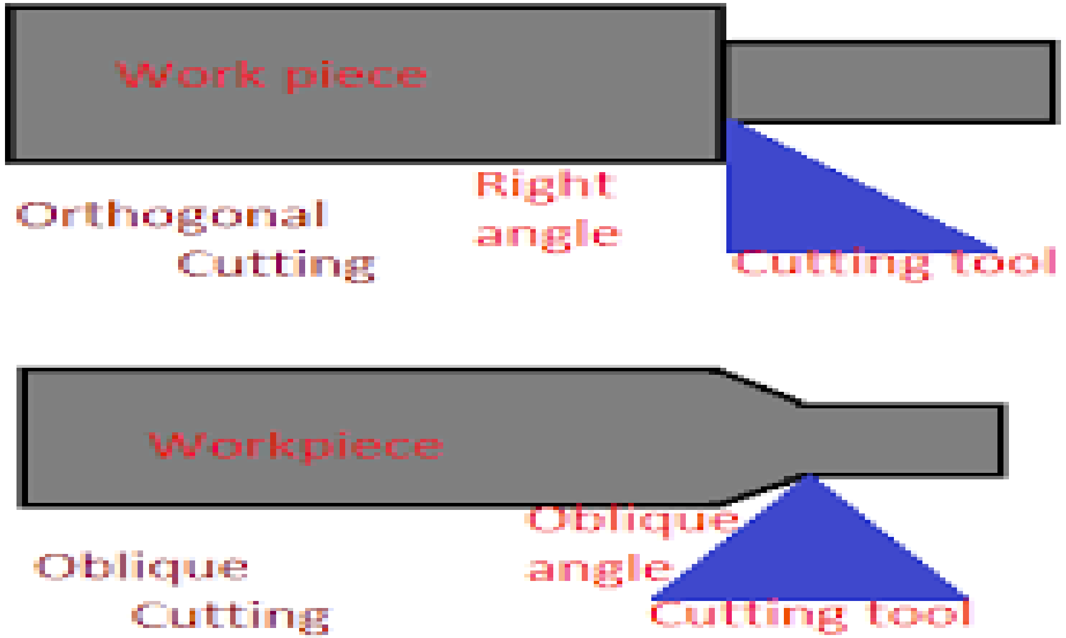


Oblique Cutting

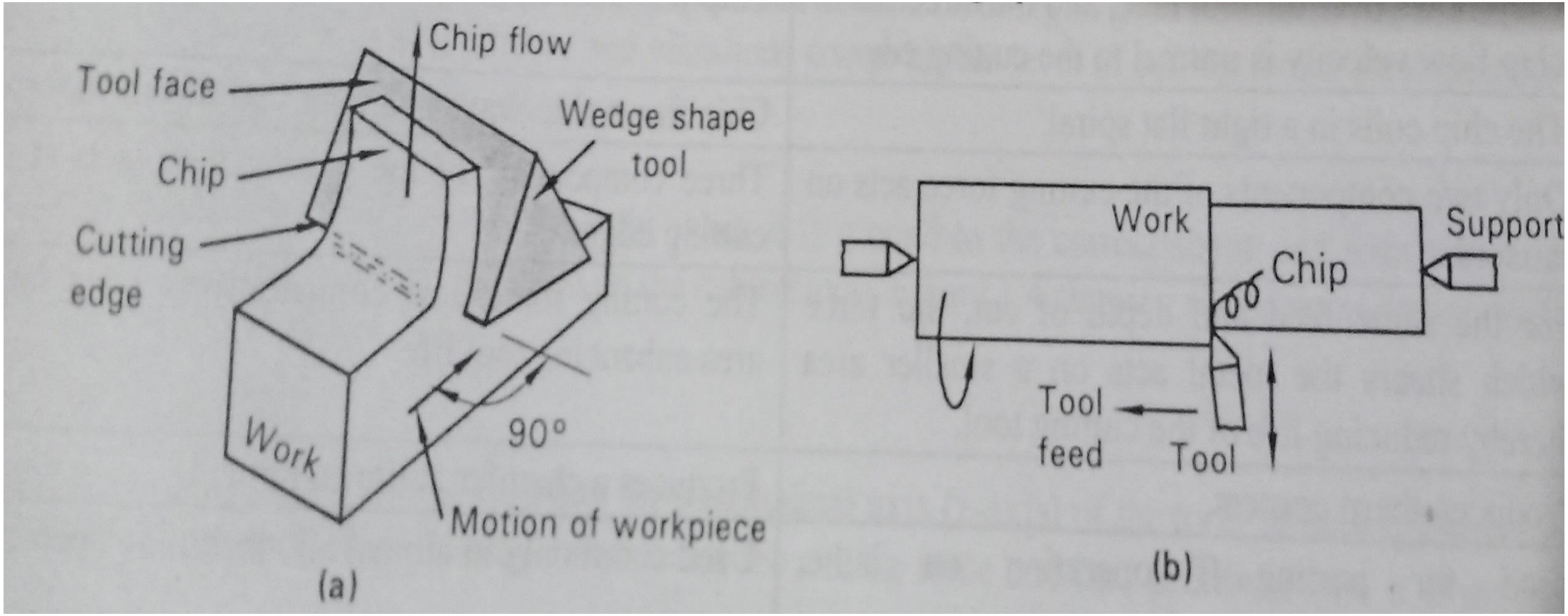
- It is a type of cutting operation in which the cutting edge of the tool is straight and inclined to the direction of work or tool travel.
- It is also referred as 3-D cutting operation. Three components of cutting force acts at the cutting edge and they are mutually perpendicular to each other.
- The chip flow across the tool face with a side-ways movement producing a helical form of chip.



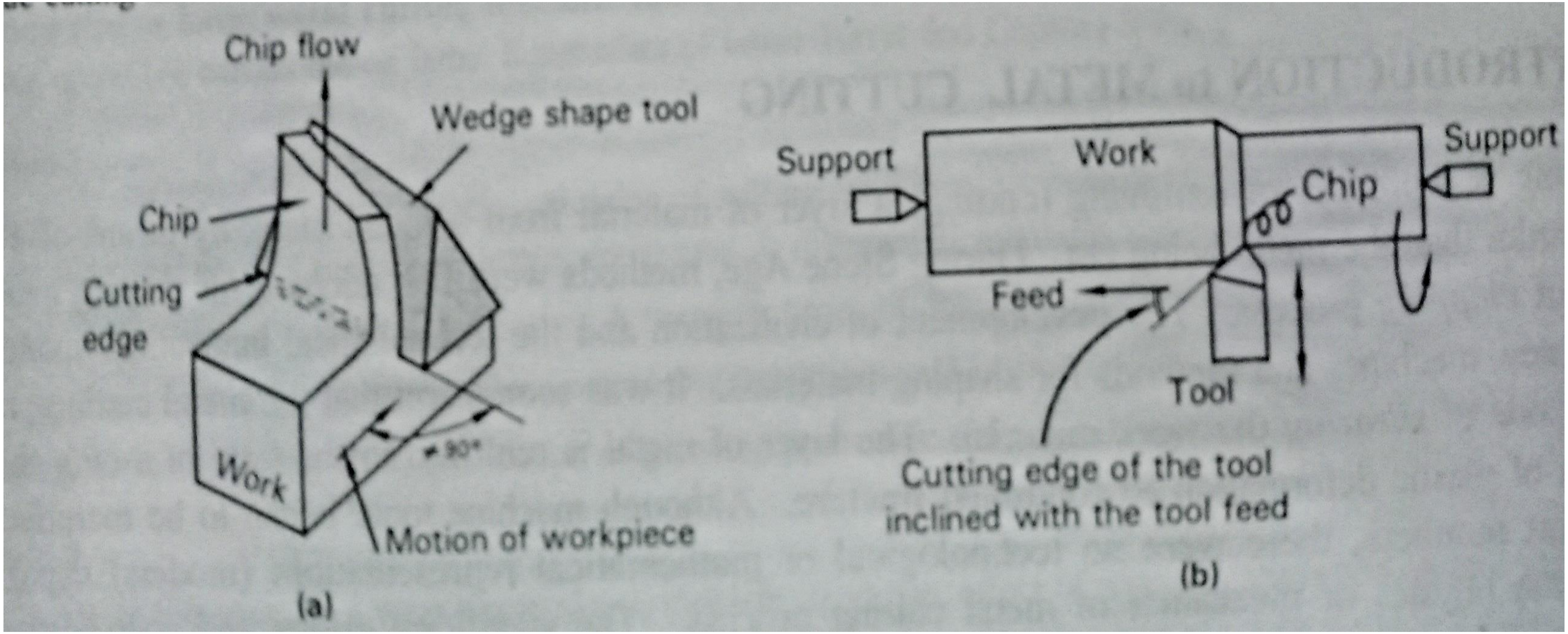
Orthogonal and oblique cutting



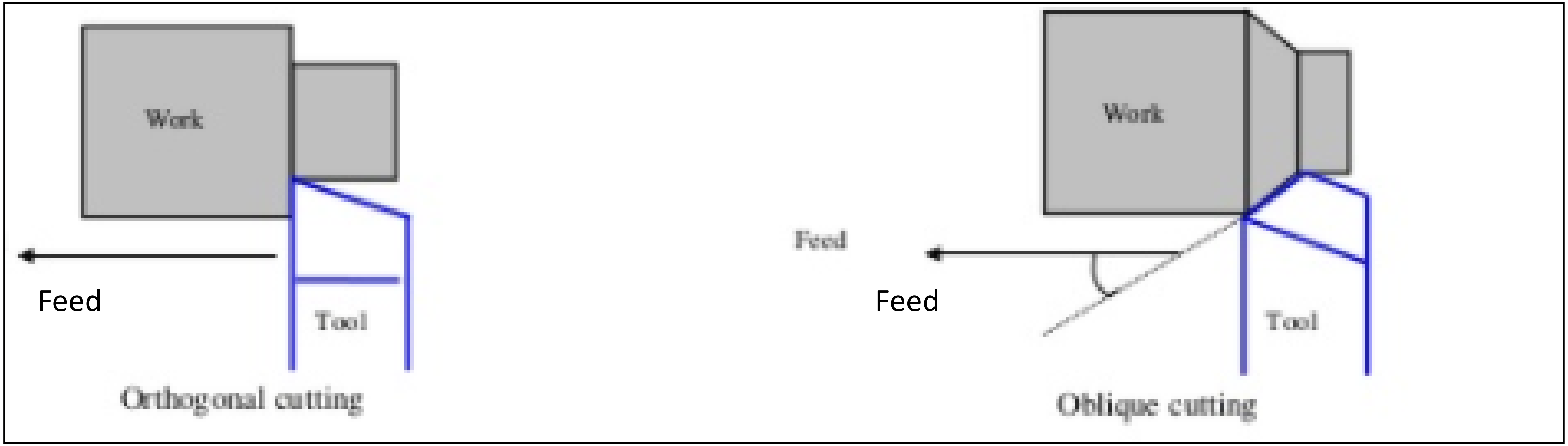
Orthogonal cutting



Oblique Cutting



Comparison Between orthogonal and Oblique cutting



Orthogonal cutting	Oblique Cutting
❖ Cutting edge of the tool is straight and perpendicular to the tool travel	❖ cutting edge of the tool is straight and incline and to the direction of work or tool travel
❖ Cheap flows over the whole face and direction of chip flow velocity is normal to the cutting edge	❖ chip flows across the tool face at an angle
❖ Chip coils in a tight flat spiral	❖ chip flows sideways in a long curl of helical form
❖ Only two components of the cutting force acts on the tool	❖ three components cutting force at the cutting edge
❖ Produces sharp corners	❖ produces a chamfer at the end of cut
❖ Used for parting-off on lathe broaching and slotting machines	❖ used commonly in almost all machining operations

In orthogonal cutting, ***only two force components*** (Tangential force and feed force) acts on the cutting tool.	Whereas in oblique cutting, ***there are three force components*** (such as Tangential force, Feed force, and Radial force) acting on the cutting tool, and they are mutually perpendicular to each other.

Classification of Cutting tool

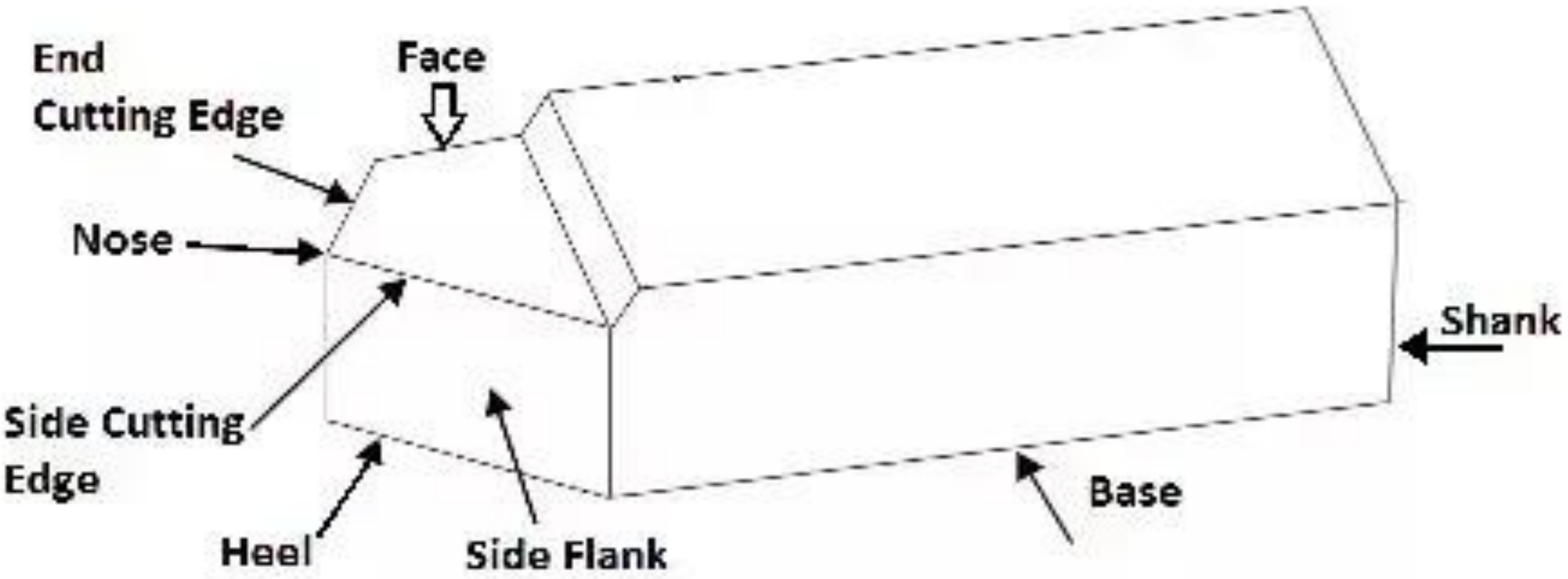
Single point cutting tool **and** **Multipoint cutting tool**

Single Point Cutting Tool

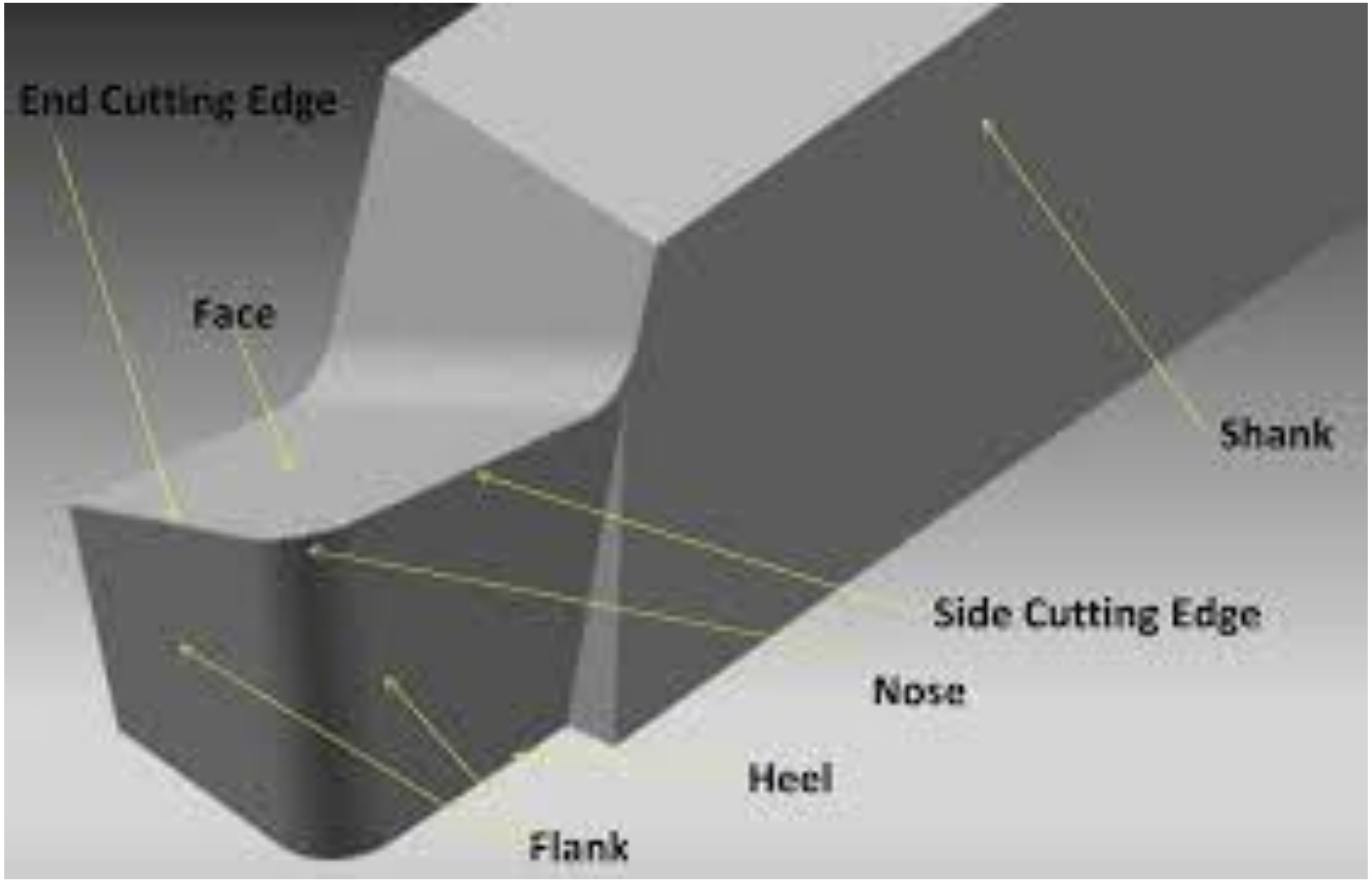
- A single point cutting tool is the simplest type consisting of a single effective cutting edge that removes excess material from the work piece.

- Lathe Tools (chamfering tool, parting tool, facing tool etc), Shaper Tools, Planar Tools, Boring Tools etc., are single point cutting tools.

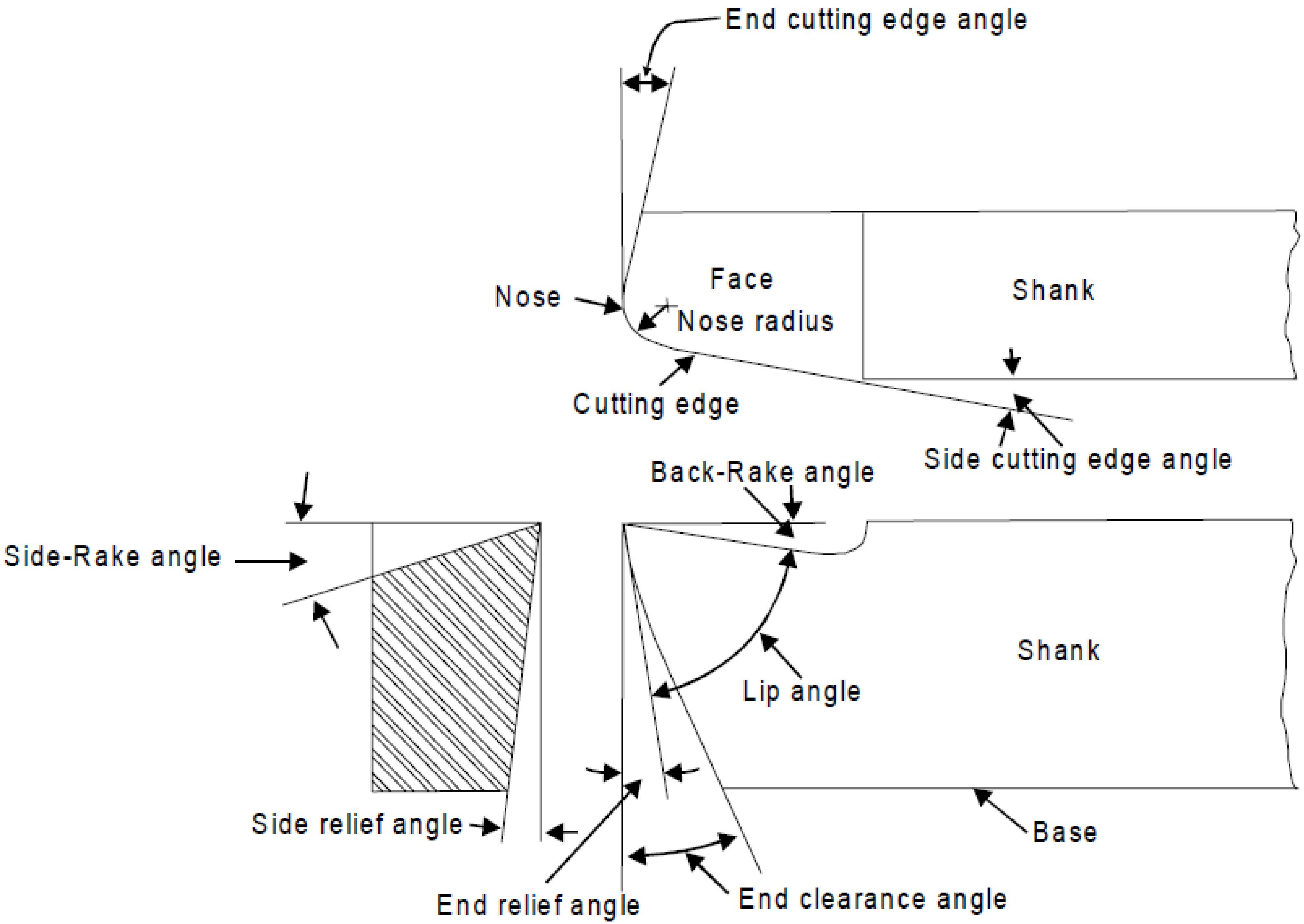
Single Point Cutting Tool Nomenclature



Single Point Cutting Tool Nomenclature



Single Point Cutting Tool Nomenclature



- **Tool Shank:** It is the main body of the cutting tool and is also the part of the tool that is gripped in the tool holder.
- **Face:** It is the top surface of the tool over which the chip flows during cutting.
- **End cutting edge:** It is the cutting edge formed at the end of the tool.
- **Side cutting edge:** It is the cutting edge on the side of the tool.
- **Flank:** It is the surface adjacent to, and below the cutting edge when the tool lies in the horizontal position.
- **Nose:** It is the tip of the cutting tool and is formed by the ***intersection of the side cutting edge and the end cutting edge.***

Tool Signature

ASA- (AMERICAN STANDARD ASSOCIATION)

ORA-(ORTHOGONAL RAKE ANGLE)

Tool Signature

ASA (AMERICAN STANDARD ASSOCIATION)

- Tool signature of a tool as 10,9,6,5,8,7,2 mm represents:

a) Back rake angle = 10°

b) Side rake angle = 9°

c) End relief angle = 6°

d) Side relief angle = 5°

e) End cutting edge angle = 8°

f) Side cutting edge angle = 7°

g) Nose radius = 2mm

Tool Signature

ORA-(ORTHOGONAL RAKE ANGLE)

- Tool signature of a tool as 5, 10,6,6,5,90,1mm represents:

a) Angle of inclination = 5^{o}

b) Normal rake angle = 10^{o}

c) Side relief angle = 6^{o}

d) End relief angle = 6^{o}

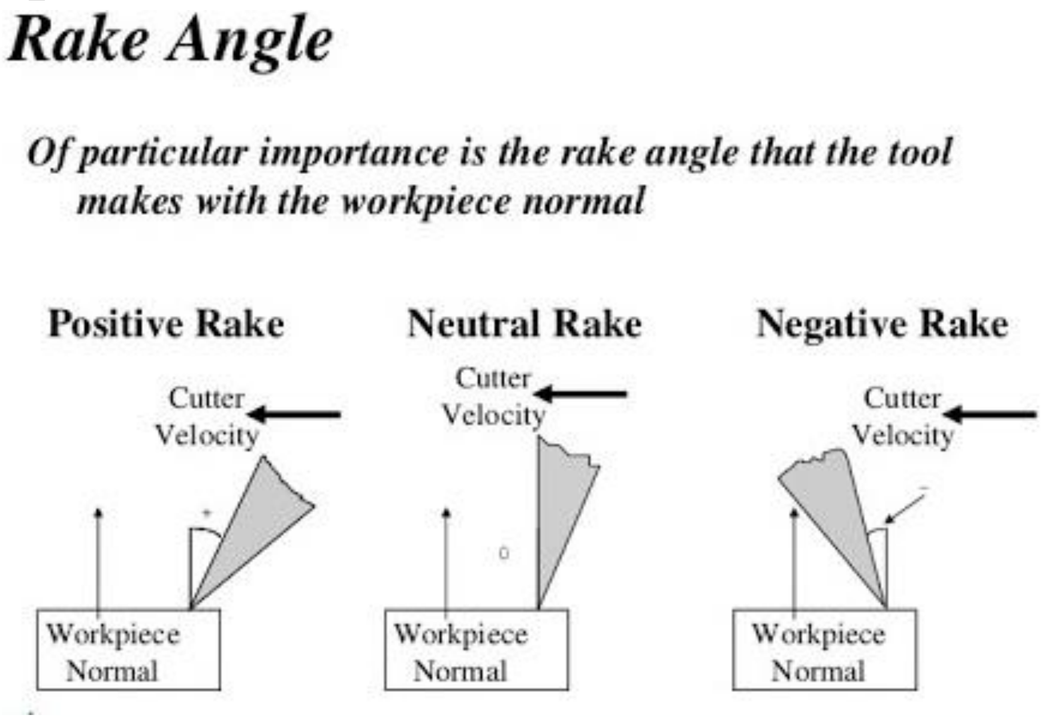
e) End cutting edge angle = 5^{o}

f) Approach angle = 90^{o}

g) Nose radius = 1mm

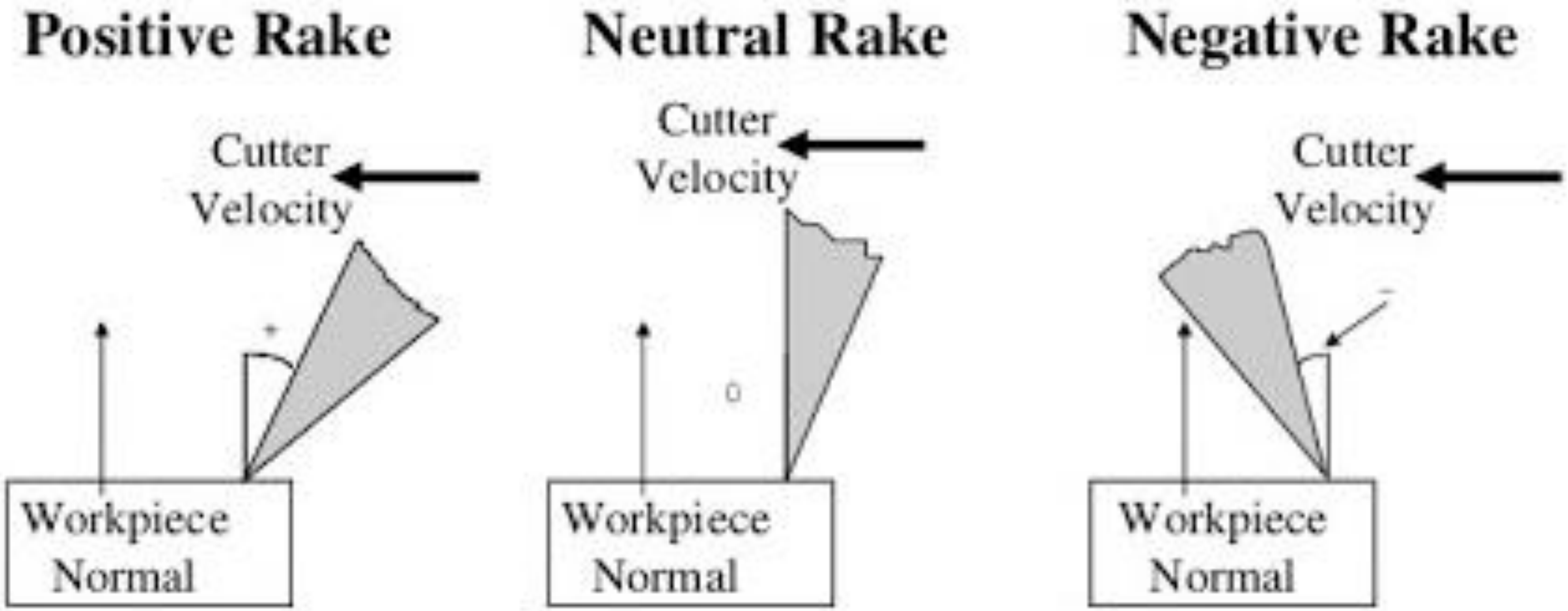
Tool Geometry

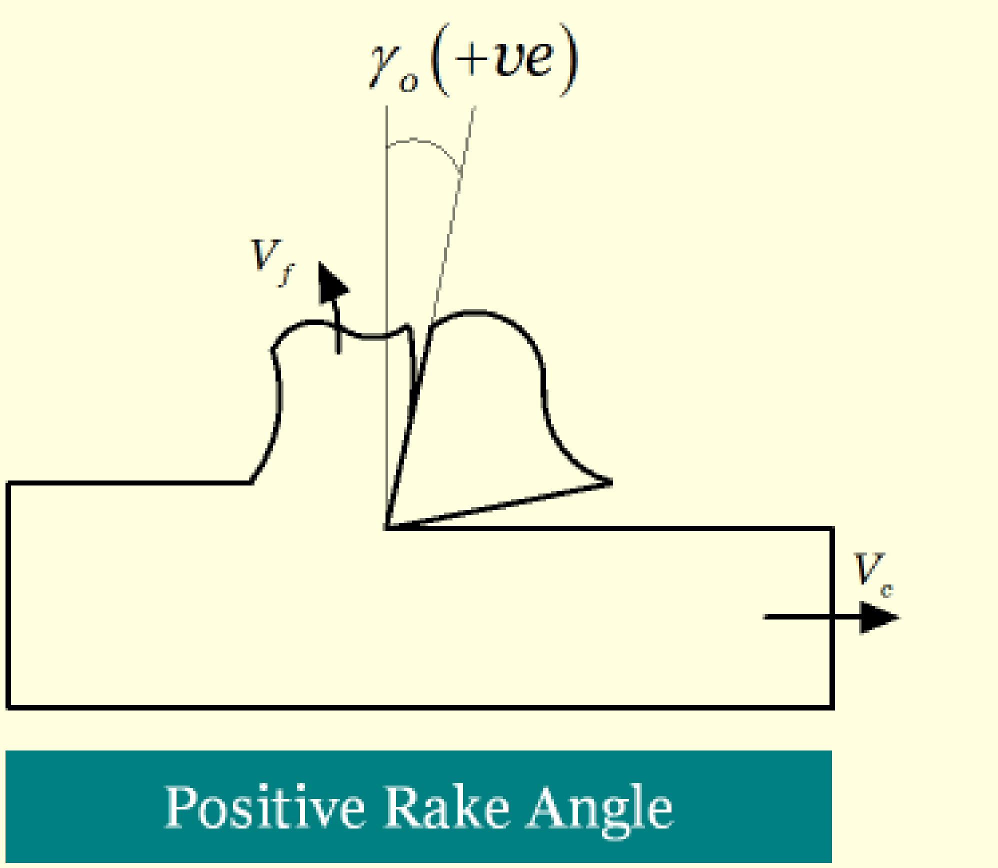
a) **Rake angle:** It is the inclination of the face (top surface) of the tool with respect to the horizontal reference surface. The rake angle helps the chips to flow away from the cutting edge thereby reducing the pressure of the chip on the tool face.

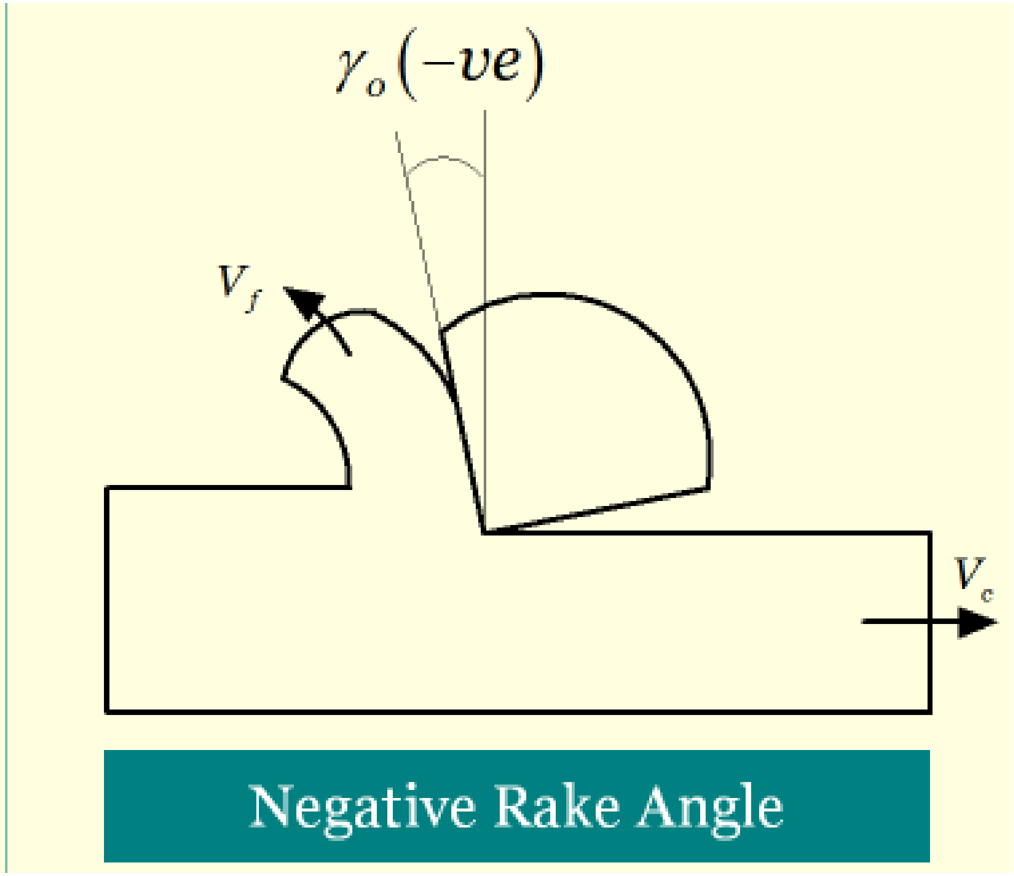


Rake Angle

Of particular importance is the rake angle that the tool makes with the workpiece normal




$\gamma_o(+ve)$
V_f
V_c
Positive Rake Angle


$\gamma_o(-ve)$
V_f
V_c
Negative Rake Angle

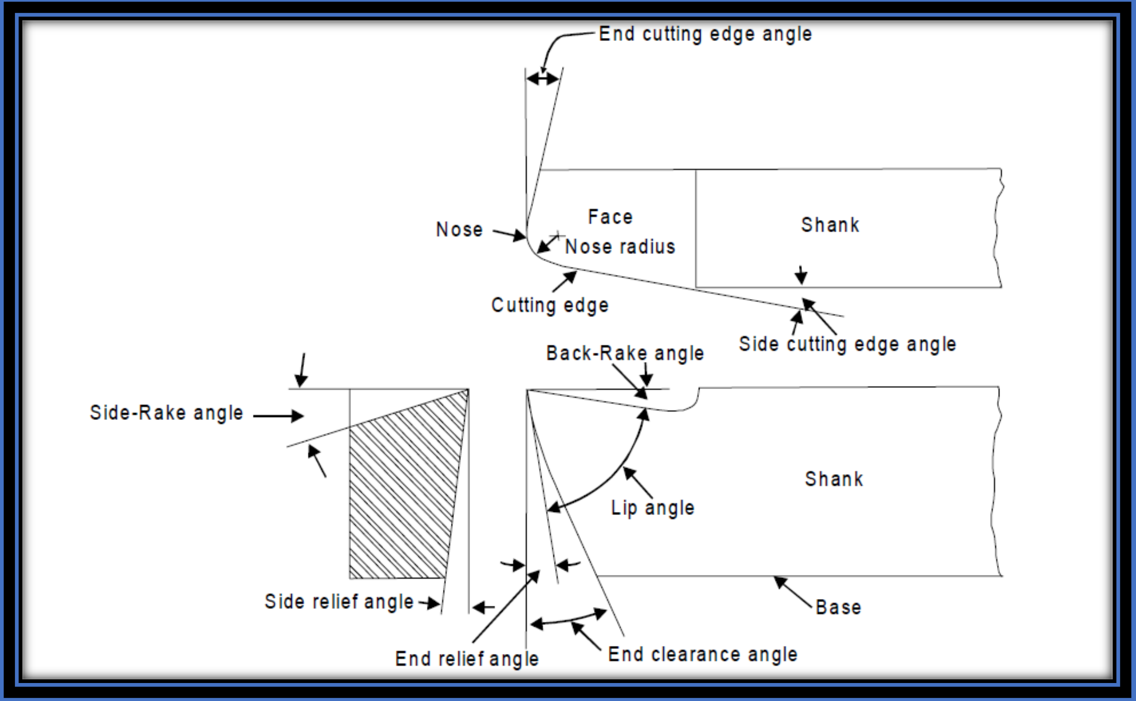
Irrespective of the plane or direction it is measured, rake angle can be either positive or negative or even zero. This concept evolved from relative orientation of rake surface with respect to fixed reference plane— in one direction it is considered as positive, in other direction it is considered as negative and when they merge together rake angle is considered as zero.

- A **positive rake** occurs when sum of wedge angle and clearance angle is below 90° on a particular plane. It offers a sharp cutting edge and thus can efficiently shear off material from workpiece requiring less force. Now if sum of wedge angle and clearance angle becomes equal to 90° on a particular plane, then **rake angle becomes zero**.
- Similarly, when sum of wedge angle and clearance angle is more than 90° on a particular plane, **rake angle becomes negative**. Negative rake offers stronger tool tip and thus enhanced tool life. Various differences between positive rake and negative rake are given below in table format.

Rake angle is a combination of *back rake angle* and *side rake angle*

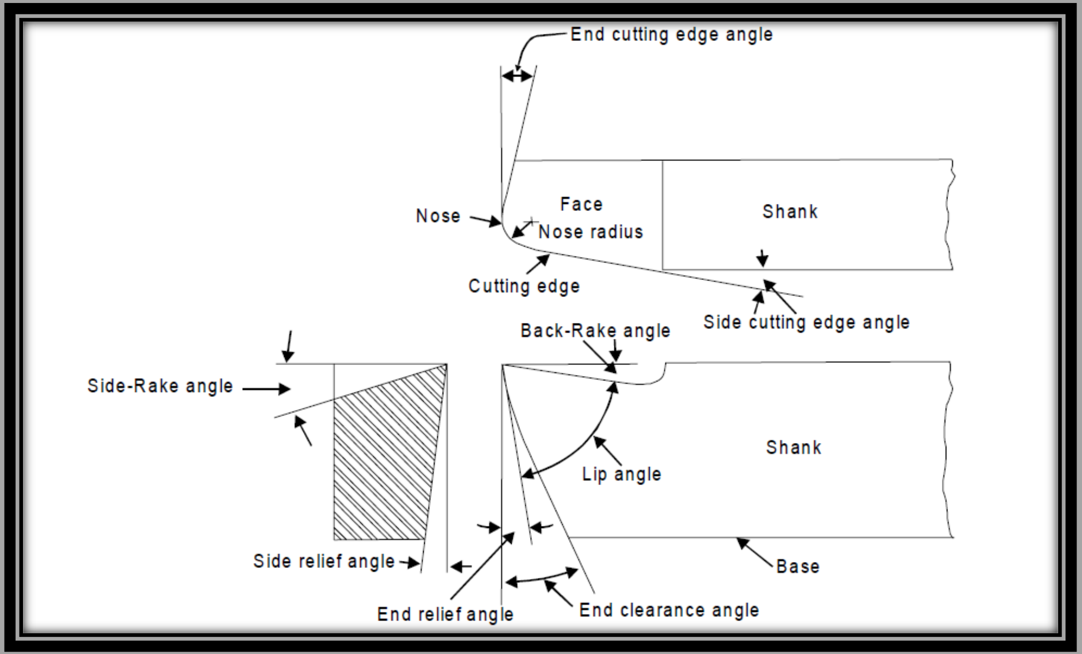
Back rake angle: measures the downward slope of the top surface of the tool from the tip of the tool (nose) to the rear along the longitudinal axis (z-axis).

Side rake angle: measures the slope of the top surface of the tool to the side in a direction perpendicular to the longitudinal axis (z-axis).



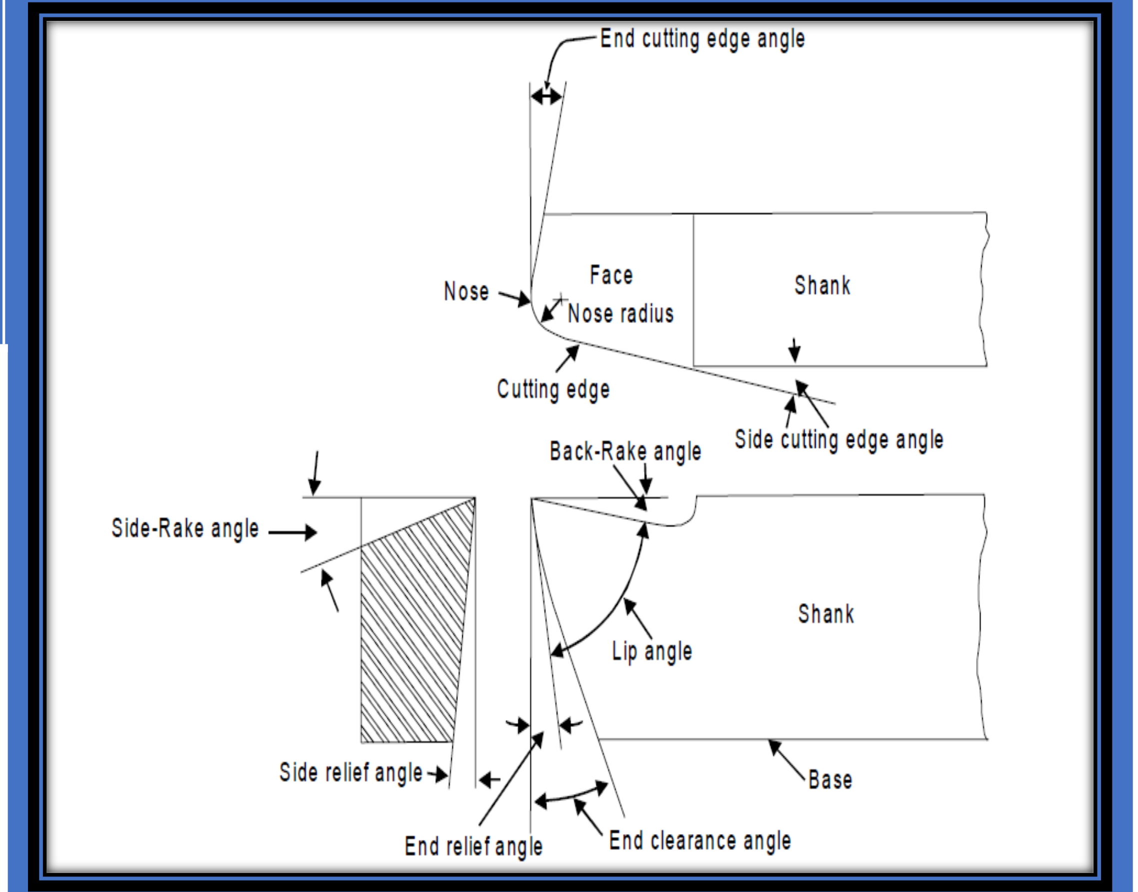
End Cutting edge angle: It is the angle between the end cutting edge and a line perpendicular to the tool shank. It acts as a relief angle by allowing only a small section of the end cutting edge to participate in the cutting action thereby preventing vibrations.

Side Cutting edge angle: It is the angle between the side cutting edge and the longitudinal axis (z-axis) of the tool. It avoids formation of built-up-edge, controls the direction of chip flow, and distributes the cutting force and heat produced over a larger cutting edge.

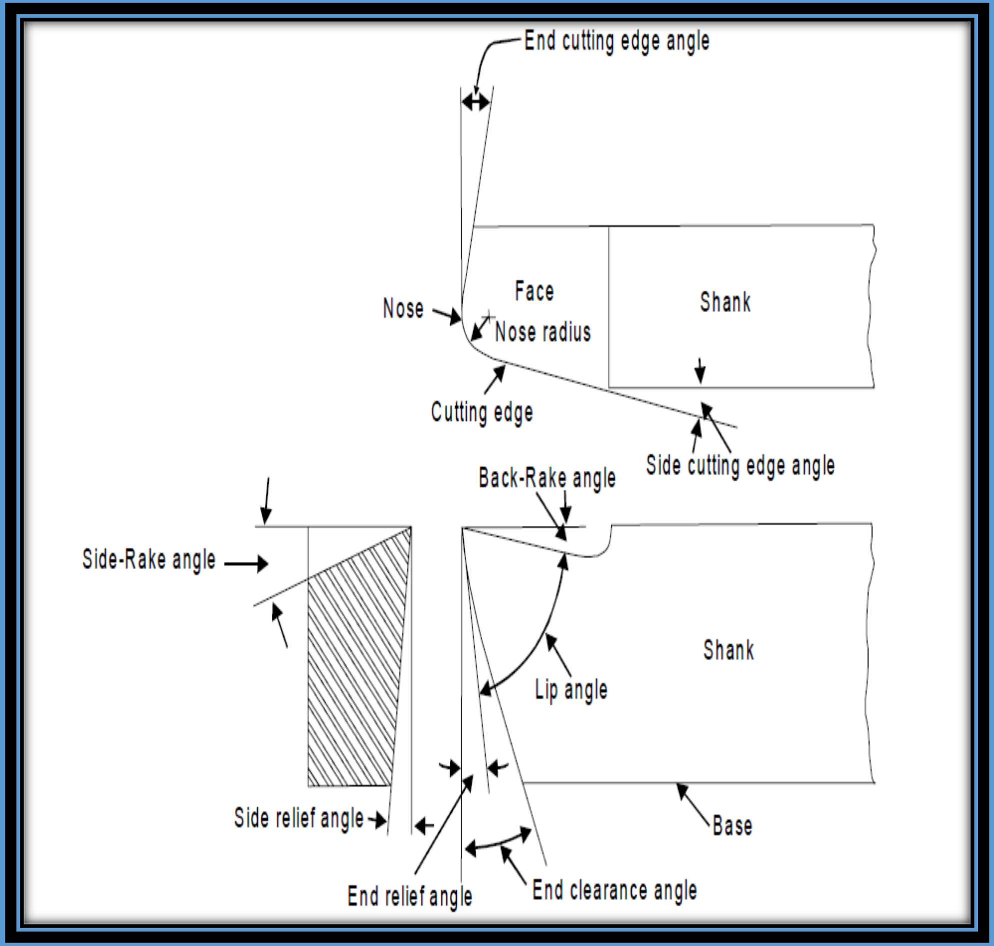


End relief angle: It is the angle between a plane perpendicular to the base and the end flank of the tool. End relief angle prevents the end of the cutting tool from rubbing against the job during machining.

Side relief angle: It is the angle made by the flank of the tool and a plane perpendicular to the base just under the side cutting edge. Side relief angle permits the tool to be fed sideways into the job, so that it can cut without rubbing.



Lip angle: It is the angle between the tool face and the ground end surface of the flank.



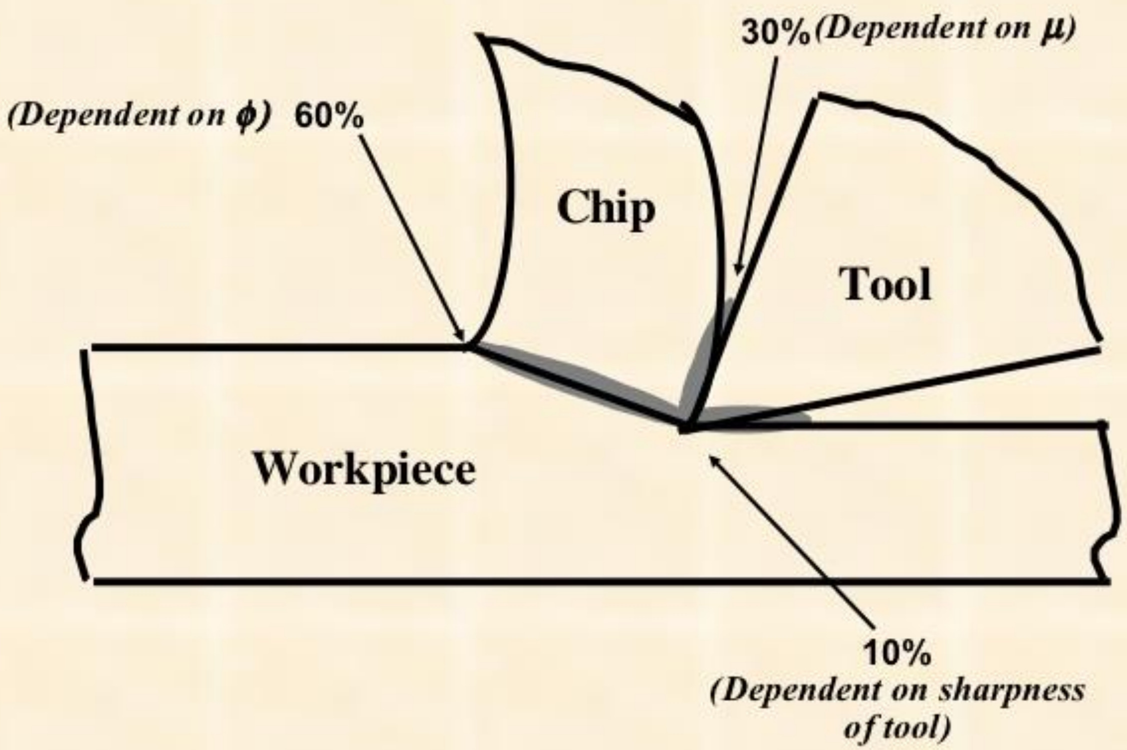
Mechanics of Orthogonal Cutting

- When the cutting tool is forced to move against the work piece, the tool exerts a compressive force on the work piece.
- The material of the work piece is stressed beyond its yield point causing it to deform plastically and shear off.
- The sheared portion of the metal begins to flow along the cutting tool face in the form of small pieces called *chips*.

Mechanics of Orthogonal Cutting

- Work is done by the tool on the work piece, and more than 90% of the energy is transformed into heat.
- The heat is concentrated near the tip of the tool, and as a result, in some cases causes the chips to weld to the cutting tool.
- Hence, the cutting force, heat and wear of the tool form the basic features of the metal cutting.

Heat Generation Zones



Mechanics of chip formation

In the process of metal cutting, as the cutting tool moves forward, the tool removes the work piece metal along the shear plane in the form of chips. Three different types of chips are formed:

- Continuous chips
- Continuous chips with built-up-edges (BUE)
- Discontinuous chips

Continuous Chips

When the work piece material is ductile fracture will not occur in the shear plane, and the chip comes off in the form of a long string or ribbon like shining surface. These are called continuous chips.

Continuous chips are desirable, as it creates smooth finish on the work piece, absorb less energy/power, create less machining noise and enhances tool life.

Continuous chip indicates:

- Work piece material is ductile.
- Large rake angle is provided on the tool.
- Fine feed and high cutting speeds are selected during cutting.
- Efficient coolants are used

Continuous Chips

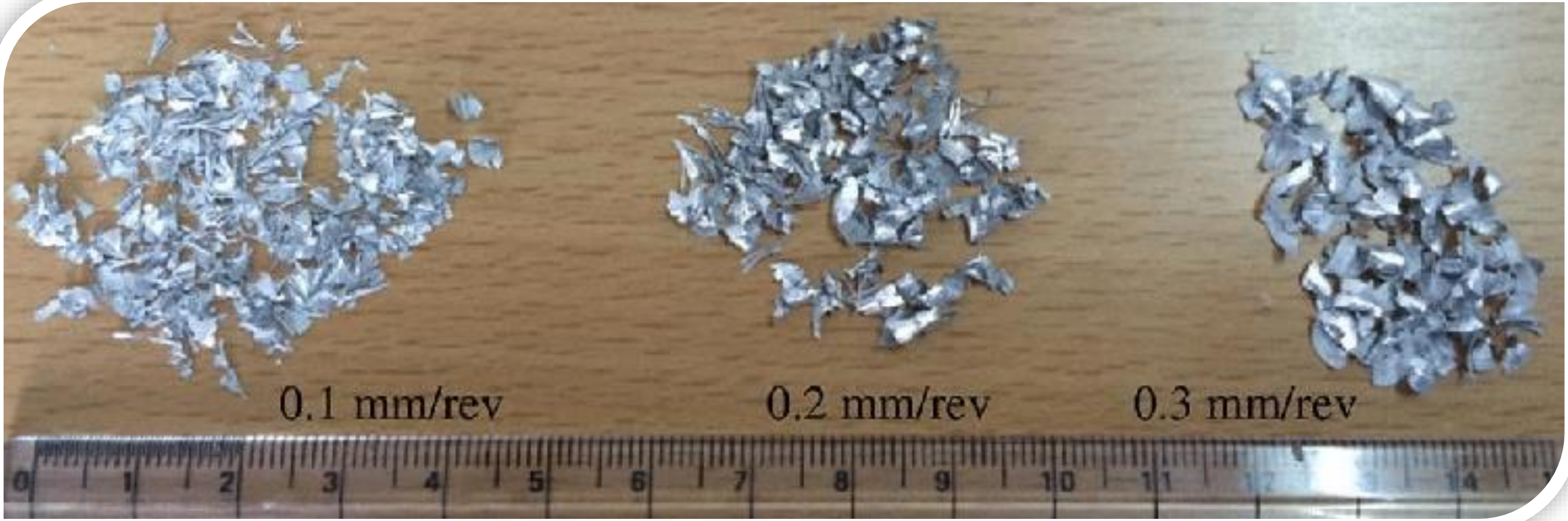
Discontinuous or segmented chips

When cutting brittle materials like Cast iron, bronze etc., the work piece material along the shear plane will periodically fracture producing a segment of the chip. This type of chip is called *Discontinuous chips.*

Discontinuous chips normally degrade tool life and enhance tool wear.

A discontinuous chip from the work piece material indicate:

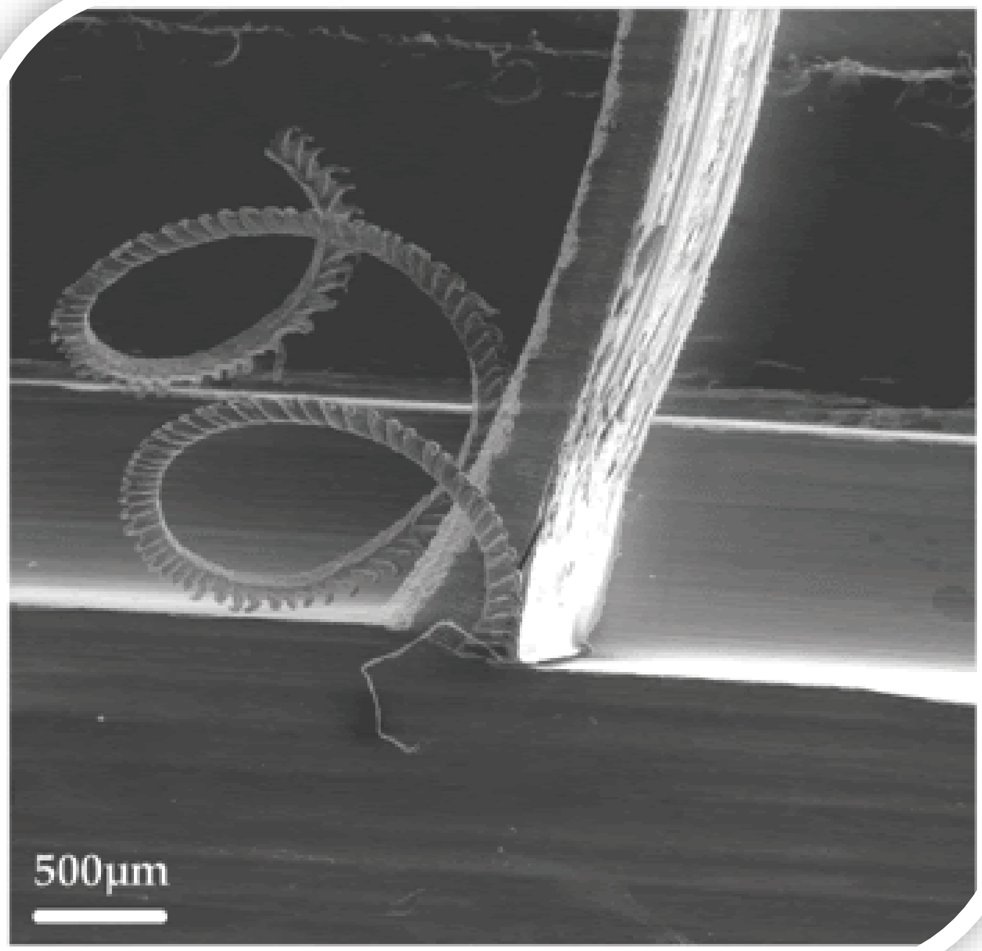
- The work piece material is brittle.
- Small rake angle is provided on the tool.
- Coarse feeds and low speeds are selected during cutting.



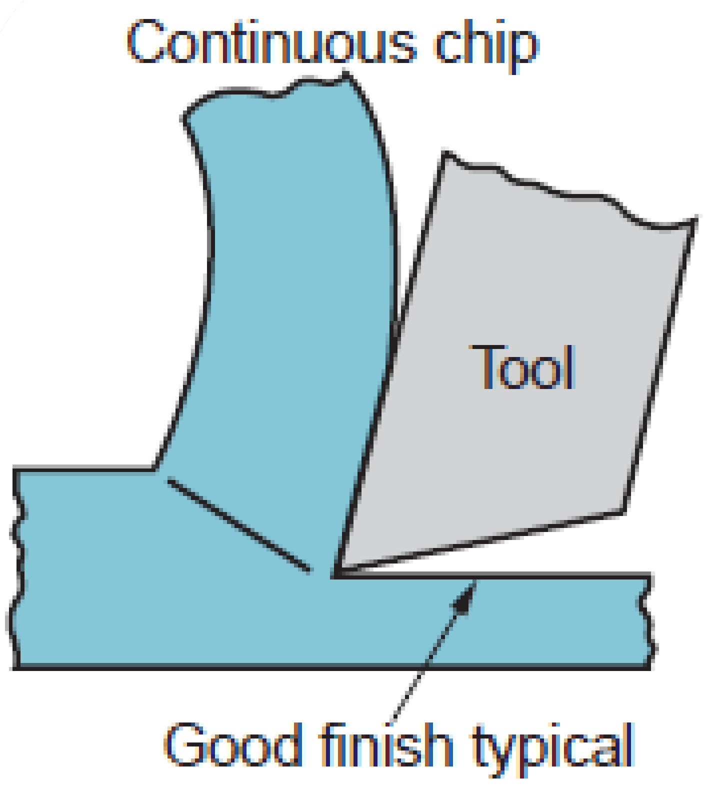
Discontinuous and segmented chips

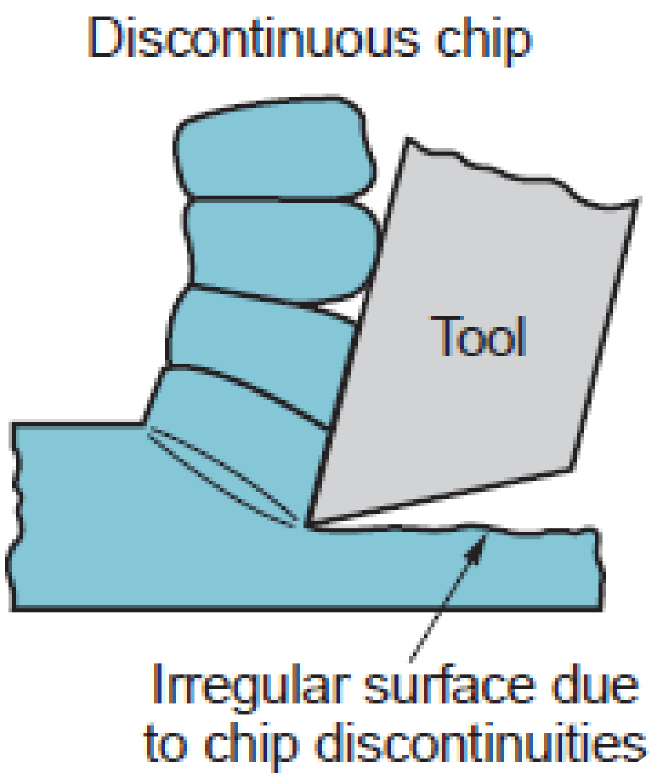
Continuous chips with built-up-edges

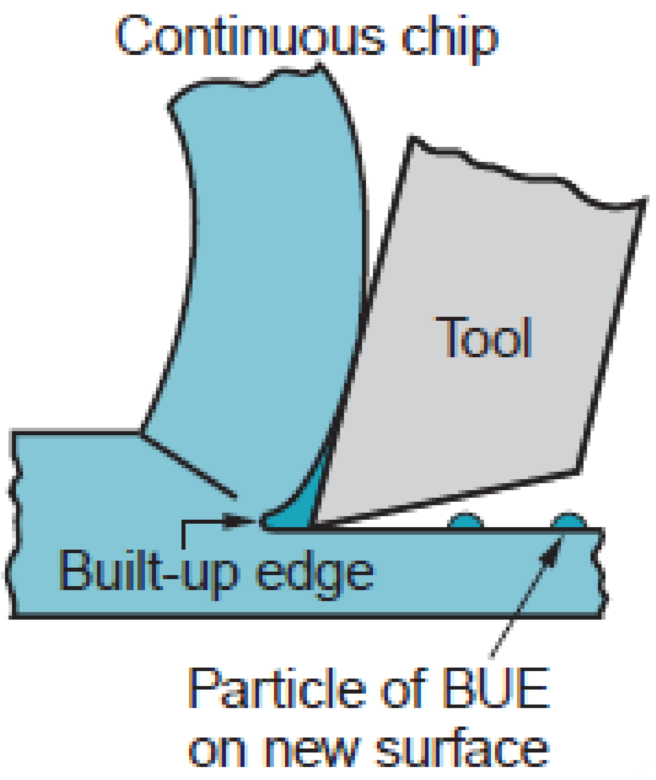
- During machining tough steels such as alloy steels, tool steels etc., larger cutting forces are required.
- This produces a lot of heat at the tool-work interface.
- The high heat generated causes the compressed metal adjacent to the tool nose to get welded to it in the form of metal lumps.
- The extra metal welded to the nose or point of the tool is called built-up-edge. As the chip slides up the tool, the built-up-edge is broken and carried away with the chip, while rest of it adheres to the surface of the work piece making it rough.



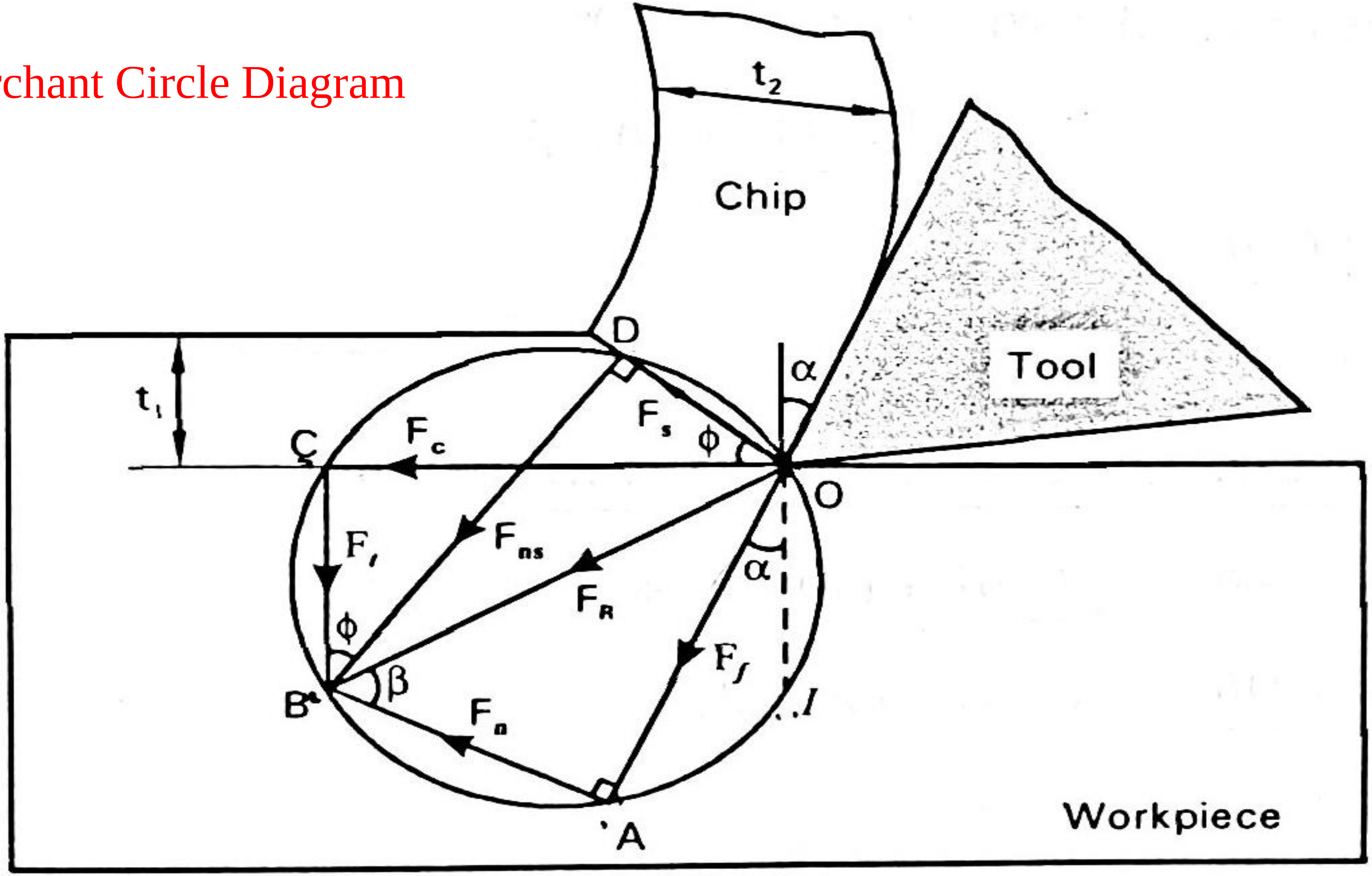
Continuous chips with built-up-edges


Continuous chip
Tool
Good finish typical

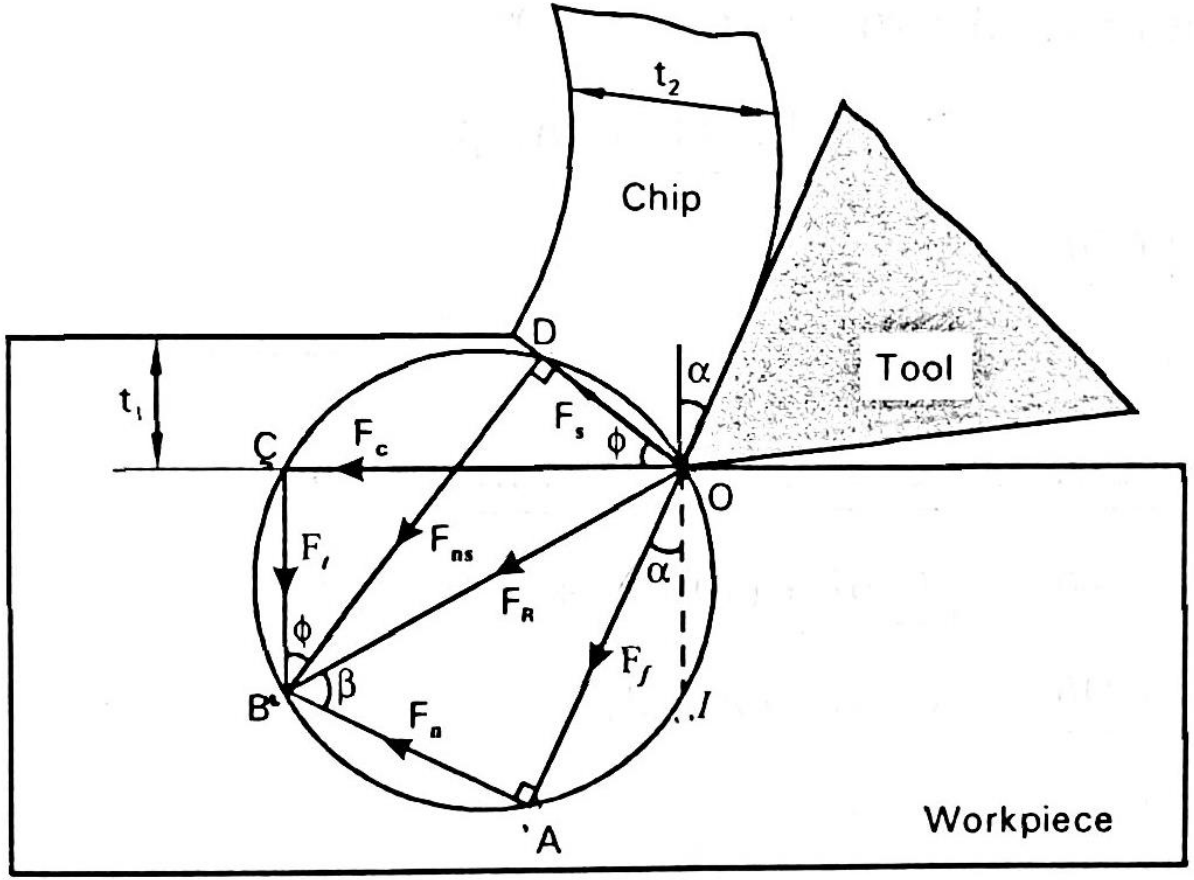

Discontinuous chip
Tool
Irregular surface due to chip discontinuities


Continuous chip
Tool
Built-up edge
Particle of BUE on new surface

Merchant Circle Diagram



Merchant Circle Diagram



α = Rake angle

ϕ = Shear angle

β = Friction angle

F_f = Frictional force along tool face

F_n = Normal force to the tool face

F_s = Shear force

F_{ns} = Force normal to the shear force

F_c = Horizontal cutting force

F_t = Thrust force

F_R = Resultant force

Step 1: To find various angles

From triangle AOB,

$$\beta + 90 + \angle AOB = 180^0$$

$$\therefore \angle AOB = 90 - \beta$$

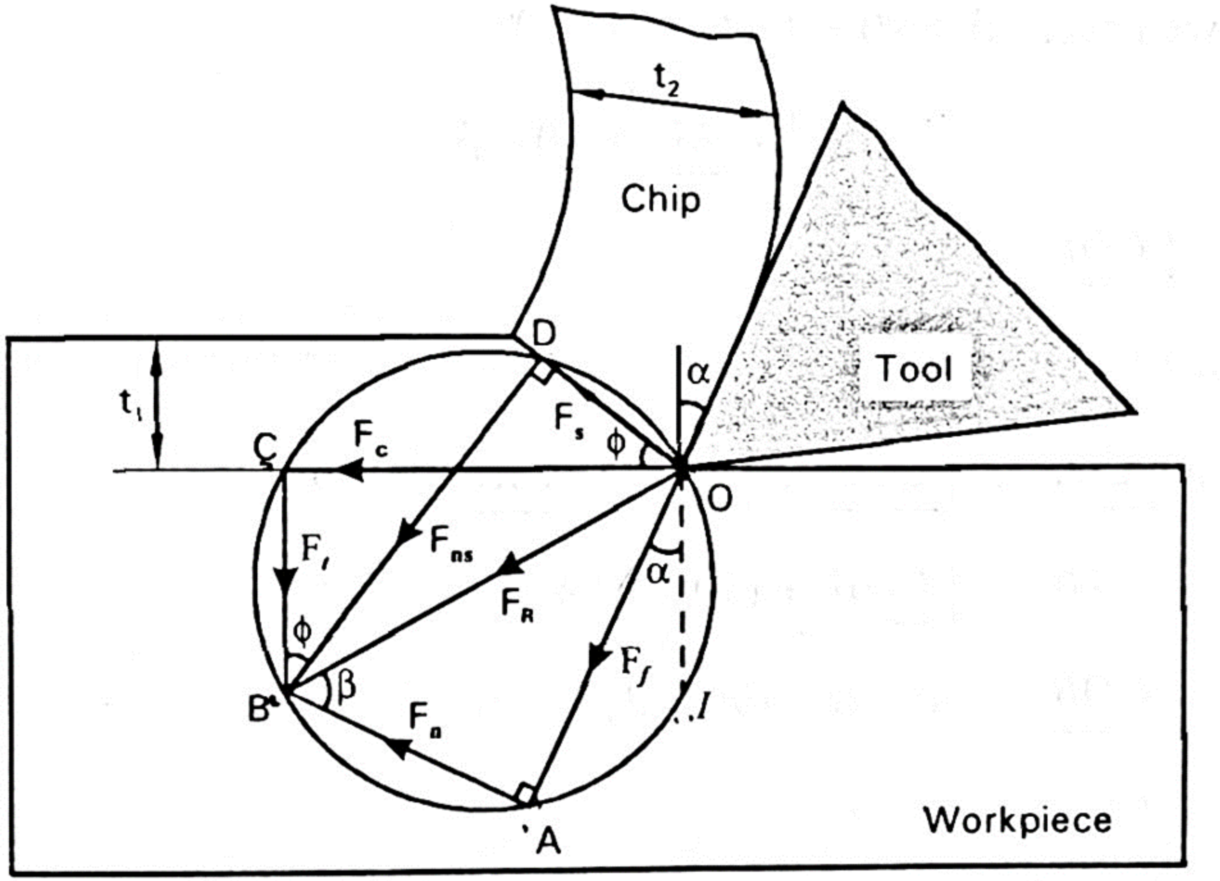
$\angle COB = ?$

It is clear that, $\angle COI = 90^0$

But $\angle COI = \angle COB + \angle AOB + \angle AOI$

$$90^0 = \angle COB + (90 - \beta) + \alpha$$

$$\angle COB = \beta - \alpha$$



Step 2: To calculate various forces

From triangle COB, $\cos(\beta - \alpha) = \dfrac{F_c}{F_R}$

$$\therefore F_c = F_R \cos(\beta - \alpha)$$

also, $\sin(\beta - \alpha) = \dfrac{F_t}{F_R}$

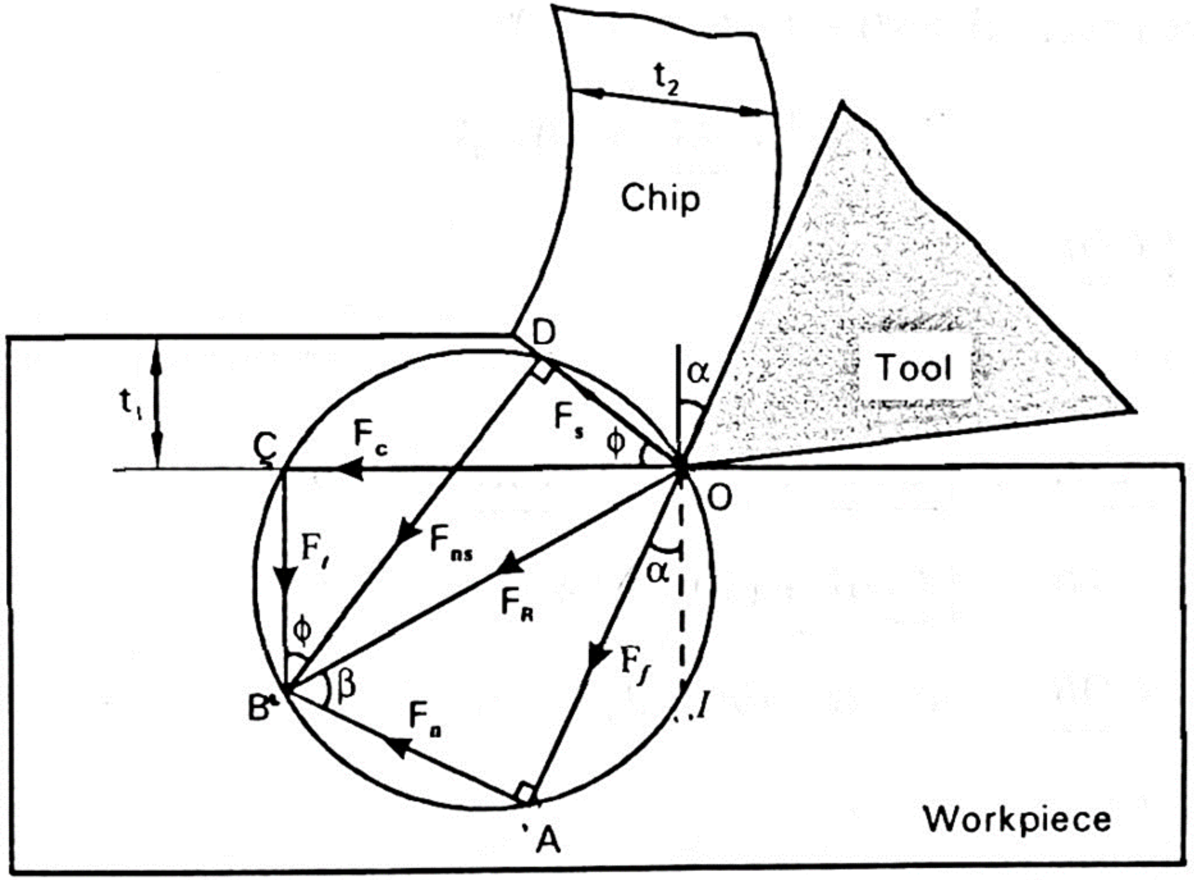
$$\therefore F_t = F_R \sin(\beta - \alpha)$$

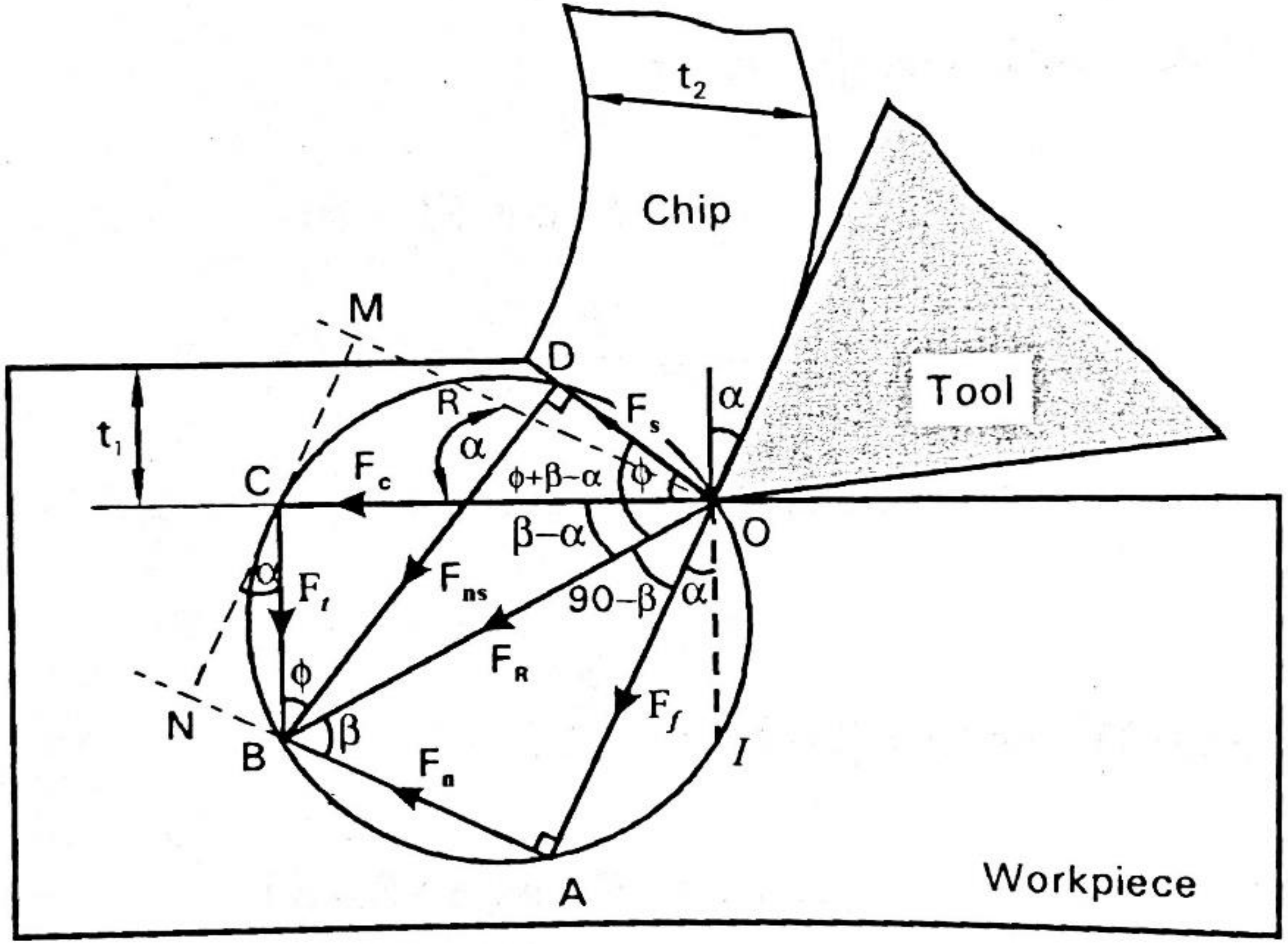
From triangle DOB, $\cos(\phi + \beta - \alpha) = \dfrac{F_s}{F_R}$

$$\therefore F_s = F_R \cos(\phi + \beta - \alpha)$$

also, $\sin(\phi + \beta - \alpha) = \dfrac{F_{ns}}{F_R}$

$$\therefore F_{ns} = F_R \sin(\phi + \beta - \alpha)$$




t2
Chip
Tool
M
D
R
Fs
α
t1
C
Fc
φ+β−α
φ
O
β−α
Fns
90−β
α
Ft
FR
Ff
φ
N
B
β
Fn
I
A
Workpiece

To find F_f =?

From the diagram $F_f = OA = MN$

$$\therefore\ F_f = MN = MC + CN \quad .... (1)$$

From triangle MOC, $\sin\alpha = \dfrac{MC}{OC} = \dfrac{MC}{F_C}$

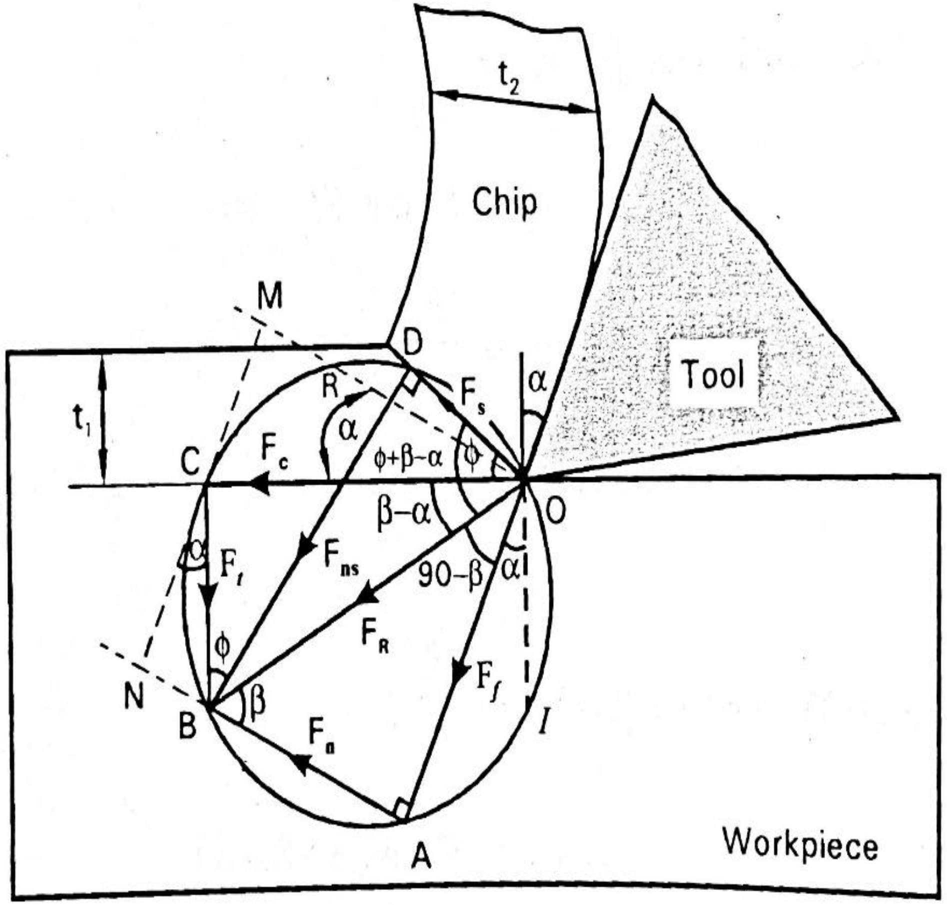
$$\therefore\ MC = F_C \sin\alpha \quad .... (2)$$

From triangle CNB, $\cos\alpha = \dfrac{CN}{CB} = \dfrac{CN}{F_t}$

$$\therefore\ CN = F_t \cos\alpha \quad .... (3)$$

Substituting (2) and (3) in (1)

$$F_f = F_c.\sin\alpha + F_t.\cos\alpha$$



To find F_n =?

From the diagram $F_n = AB = OR$

$$\therefore F_n = OR = OM - MR \quad .... (4)$$

From triangle MOC, $\cos\alpha = \frac{OM}{OC} = \frac{OM}{F_C}$

$$\therefore OM = F_C \cos\alpha \quad .... (5)$$

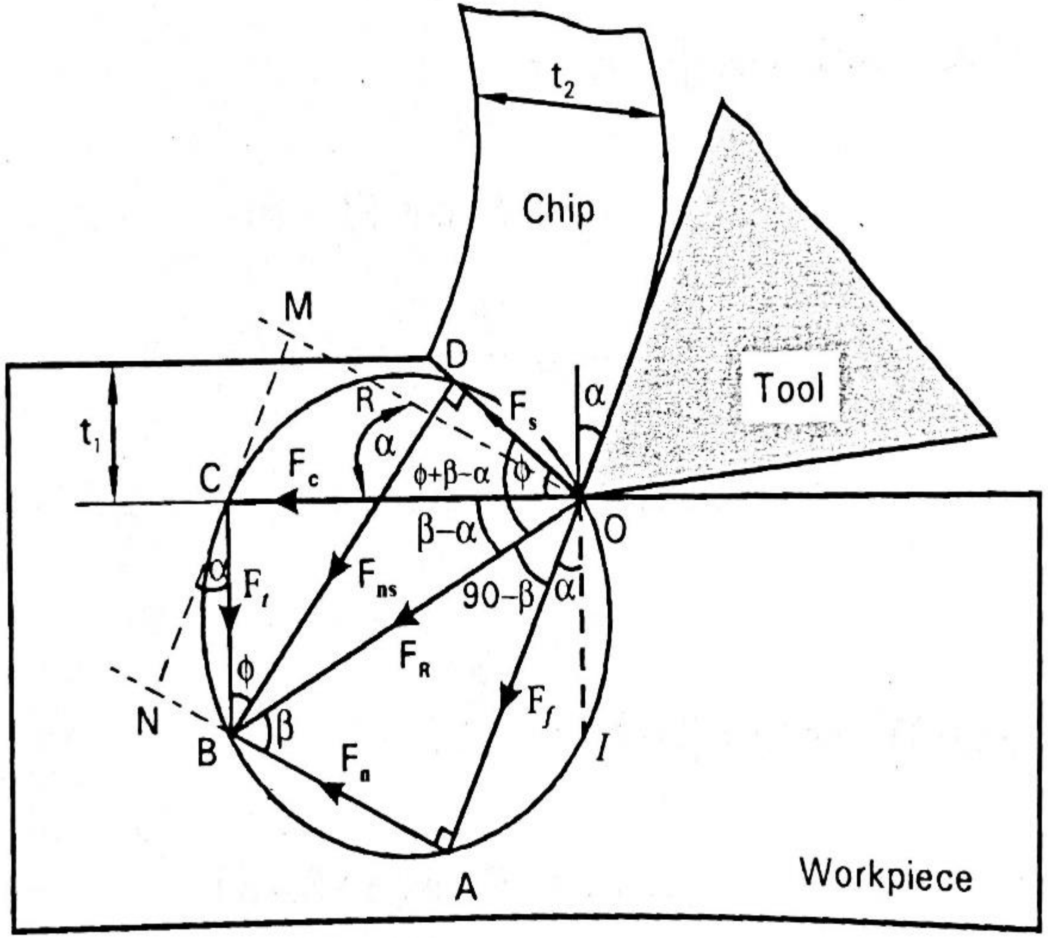
But MR = NB

From triangle CNB, $\sin\alpha = \frac{NB}{BC} = \frac{NB}{F_t}$

$$\therefore NB = F_t \sin\alpha \quad .... (6)$$

Substituting (5) and (6) in (4)

$$F_n = F_c.\cos\alpha - F_t.\sin\alpha$$



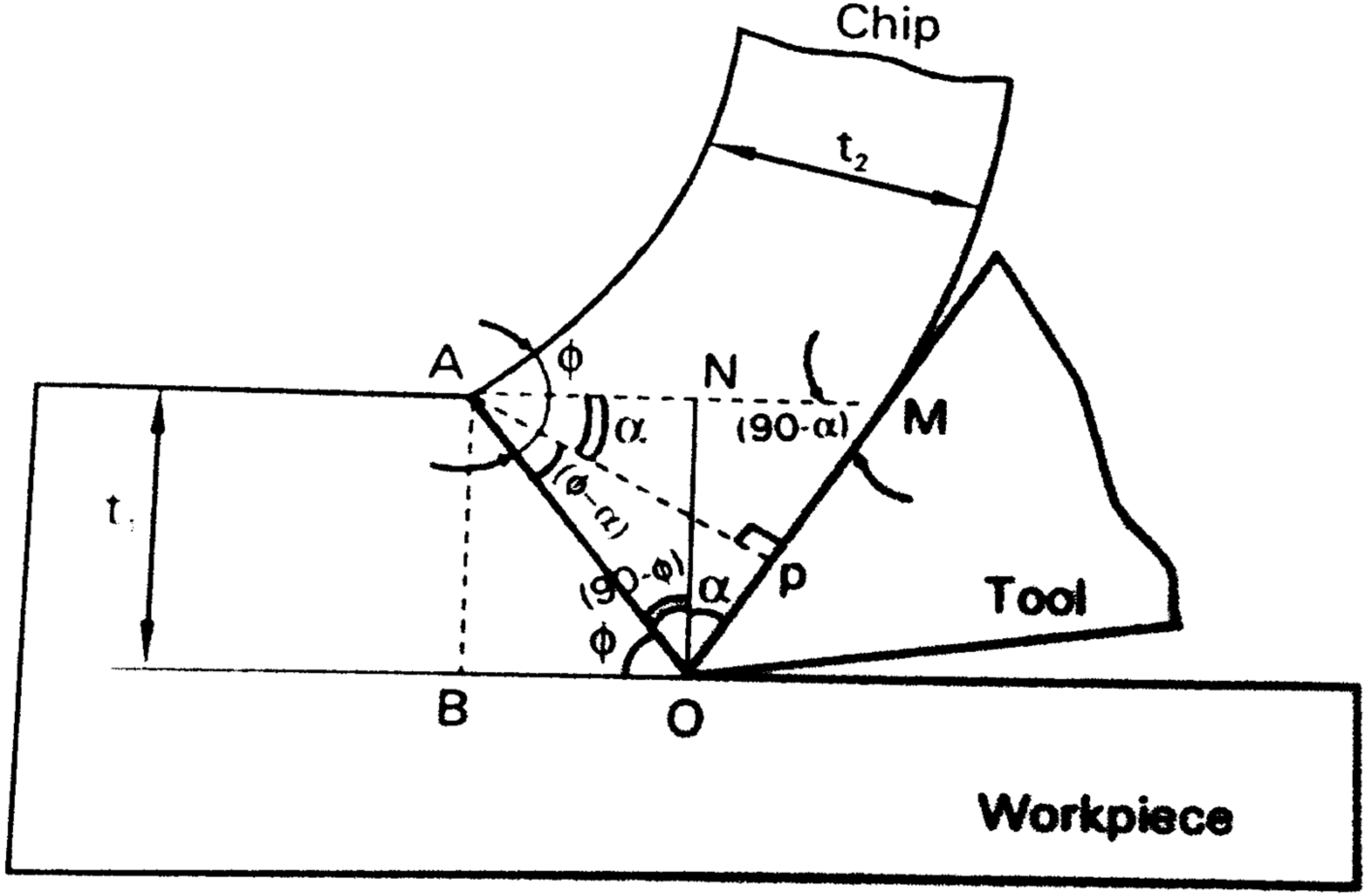
Step 3: To calculate co-efficient of friction

w.k.t $F_f = \mu F_n$

$$\therefore \mu = \frac{F_f}{F_n}$$

$$\therefore \mu = \frac{F_c \sin\alpha + F_t \cos\alpha}{F_c \cos\alpha + F_t \sin\alpha}$$

Shear angle and chip thickness ratio:



From ΔOAB, $\sin\phi = \dfrac{AB}{AO}$

$$AO = \frac{AB}{\sin\phi} = \frac{t_1}{\sin\phi} \quad \ldots\ldots (1)$$

From ΔPAO, $\cos(\phi-\alpha) = \dfrac{AP}{AO}$

$$AO = \frac{AP}{\cos(\phi-\alpha)} = \frac{t_2}{\cos(\phi-\alpha)} \quad \ldots\ldots (2)$$

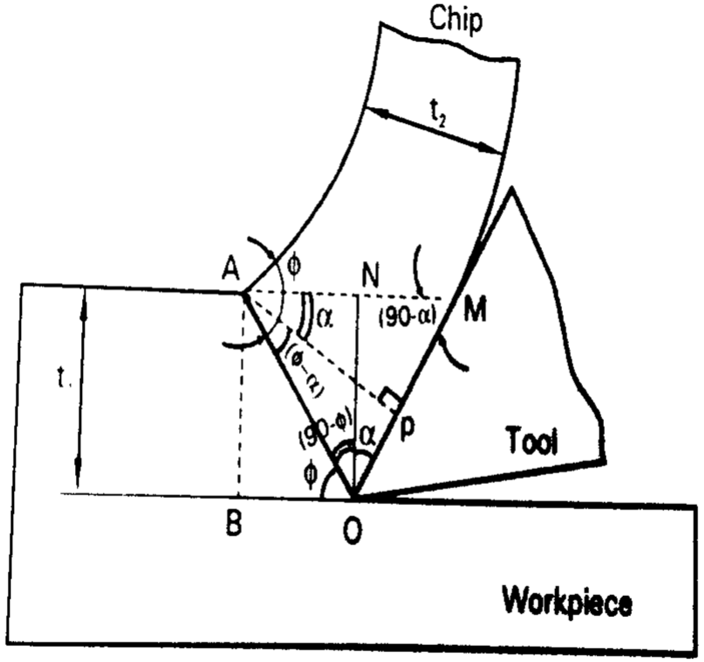
From equation (1) and (2)

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

or $\dfrac{t_1}{t_2} = \dfrac{\sin\phi}{\cos(\phi-\alpha)}$

But $\dfrac{t_1}{t_2} = r =$ Chip thickness ratio

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



w.k.t $\cos(A-B) = \cos A \cos B + \sin A \sin B$

$$\therefore\ r = \frac{\sin\phi}{\cos\phi\cos\alpha + \sin\phi\sin\alpha} \quad ......(3)$$

dividing both sides of the equation (3) by r

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

$$1 = \frac{\sin\phi}{r\cos\phi\left(\cos\alpha + \dfrac{\sin\phi\sin\alpha}{\cos\phi}\right)}$$

$$1 = \frac{\tan\phi}{r(\cos\alpha + \tan\phi\sin\alpha)}$$

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

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

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

$$\text{or}\quad \tan\phi = \frac{r\cos\alpha}{(1 - r\sin\alpha)}$$

Cutting tool materials:

Properties of cutting tool materials:

- Hot or Red hardness
- Wear resistance
- Toughness
- Thermal conductivity and specific heat
- Chemical stability and inertness
- Availability and cost

Hot or Red hardness: The ability of the material to resist softening at elevated temperatures is known as hot or red hardness. A cutting tool material should have high value of hardness to resist temperature generated during metal cutting.

Wear resistance: The material selected for the tool should have high resistance to wear to ensure longer tool life.

Toughness: Toughness describes a material's resistance to fracture. Hence, the material selected for the tool should be tough enough to withstand the external sudden shocks or impact forces without fracture.

Thermal conductivity and specific heat: A tool material should have a high thermal conductivity and specific heats, because it can readily absorb the heat generated at the cutting zone and conduct it away.

Chemical stability and inertness: The chemical stability and inertness with respect to the workpiece material should be high, so that any adverse reactions contributing to tool wear are avoided.

Availability and cost: The material selected for the manufacture of cutting tool should be easily available and with low cost.

Types of Cutting tool materials

- High Speed Steel (HSS)
- Carbides
- Coated Carbides
- Ceramics
- Cubic Boron Nitride (CBN)

High Speed Steel (HSS): High speed steel is an alloyed steel with 14 – 22% tungsten, as well as cobalt, molybdenum, chromium and vanadium.

It is so called because tools manufactured from HSS materials cut about four times faster than the carbon steel tools.

With proper heat treatment, the alloying elements play a significant role in developing high hardness, strength and other properties necessary for the tool.

HSS is used in all types of cutters: single/multiple point tools and rotary tools. Also, HSS tools retain hardness up to about 600^0C, but softens rapidly at higher temperatures.


12 x 12 x 100 mm
12 x 12 x 100 mm
12 x 12 x 100 mm
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12 x 12 x 100 mm

Carbides: Cemented tungsten carbide, often called simple *carbide* is the most common material used for manufacturing cutting tools.

It is produced by powder metallurgy technique by sintering a combination of tungsten carbide powder with powdered cobalt.

The material so obtained possesses high strength, toughness and hardness compared to HSS materials.

The chief advantage of carbide versus HSS is the ability to cut at higher speeds. Carbide tools cut 3-5 times faster than HSS and hence, have replaced HSS in many applications.

Coated Carbides: Cutting with carbide tools is slightly difficult because carbide is more brittle than other tool materials thereby making it susceptible to chipping and breaking.

To increase the life of the carbide tools, they are coated with certain materials like titanium carbide, titanium nitride, ceramics, diamonds etc., and hence are called coated carbides.

Coating provides longer wear resistance and helps to decrease the temperature associated with the cutting process thereby increasing the life of the tool.

Ceramics: Ceramic tools are made by powder metallurgy technique from aluminium oxide or silica nitride compounds mixed with additives like titanium oxide and magnesium oxide to improve cutting properties.

The primary benefit of ceramic materials for manufacturing tools includes high hardness, ability to maintain their properties at extremely high temperatures, high electrical and wear resistance, and chemical inertness.

However, they are extremely brittle in nature and this makes them to be used as inserts in cutting tool applications.


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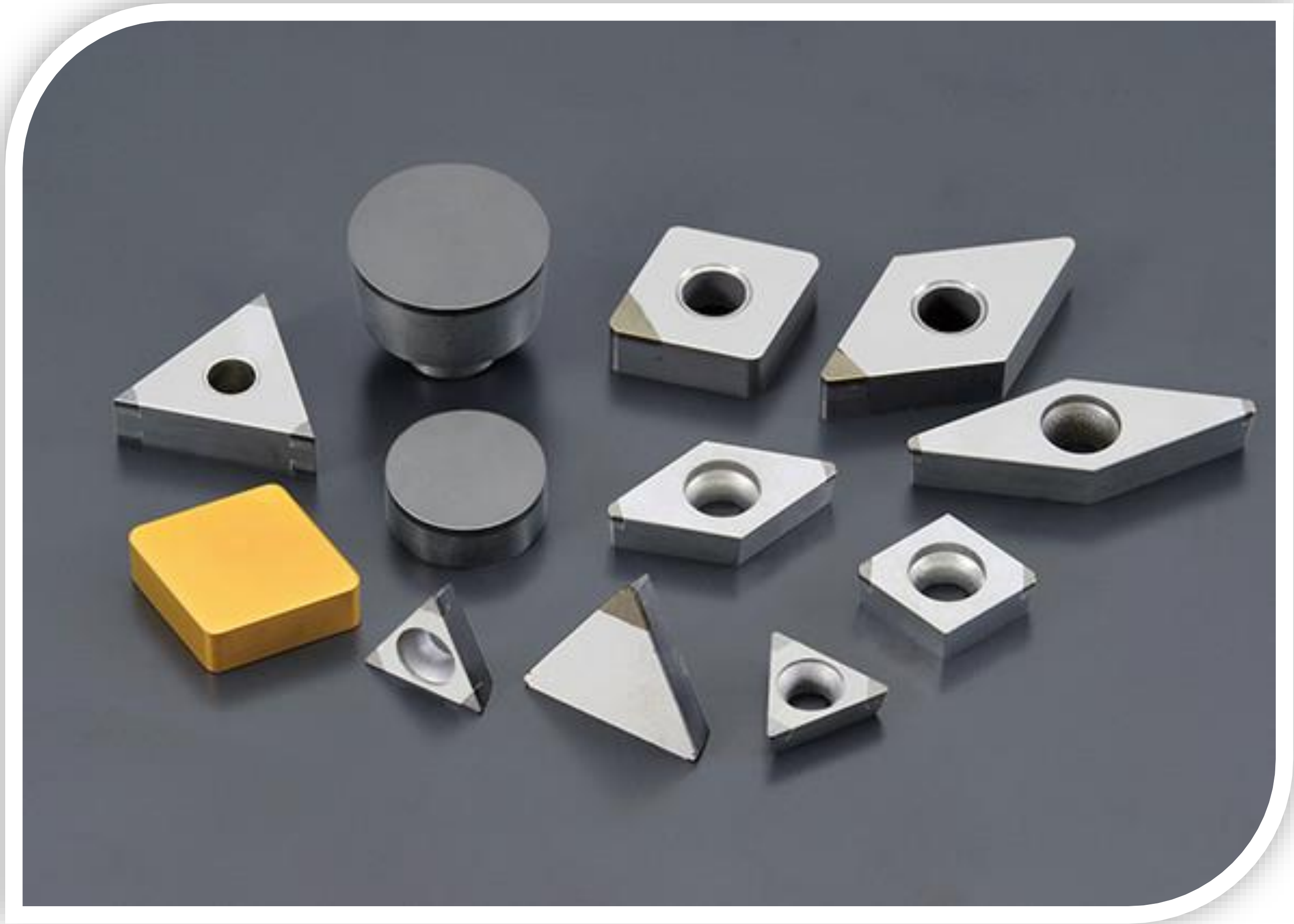
Cubic Boron Nitride (CBN): Boron Nitride, in its natural form has hexagonal, graphite like structure.

When this hexagonal boron nitride is subjected to high-temperature and pressures, the hexagonal structure can be converted to cubic form, and hence is known as cubic boron nitride.

This material in the powder form is sintered at high temperature and pressure with a metal or a ceramic binder phase to get polycrystalline mass to use as a insert in the tool holder.

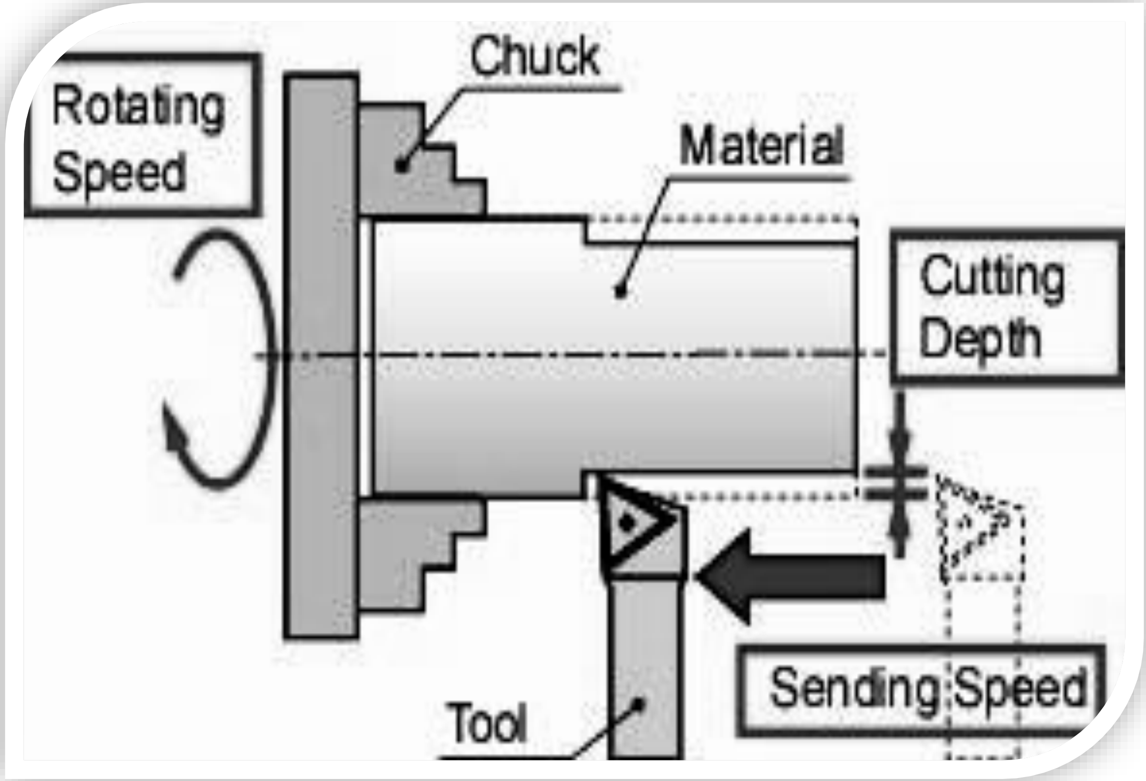
The advantage of CBN is that, it is second in hardness only to diamond. Also, at high temperatures it remains chemically inert to ferrous metals and resists oxidation thereby making it particularly suited for machining hard and difficult to cut materials.



Introduction to basic metal cutting machine Tools –

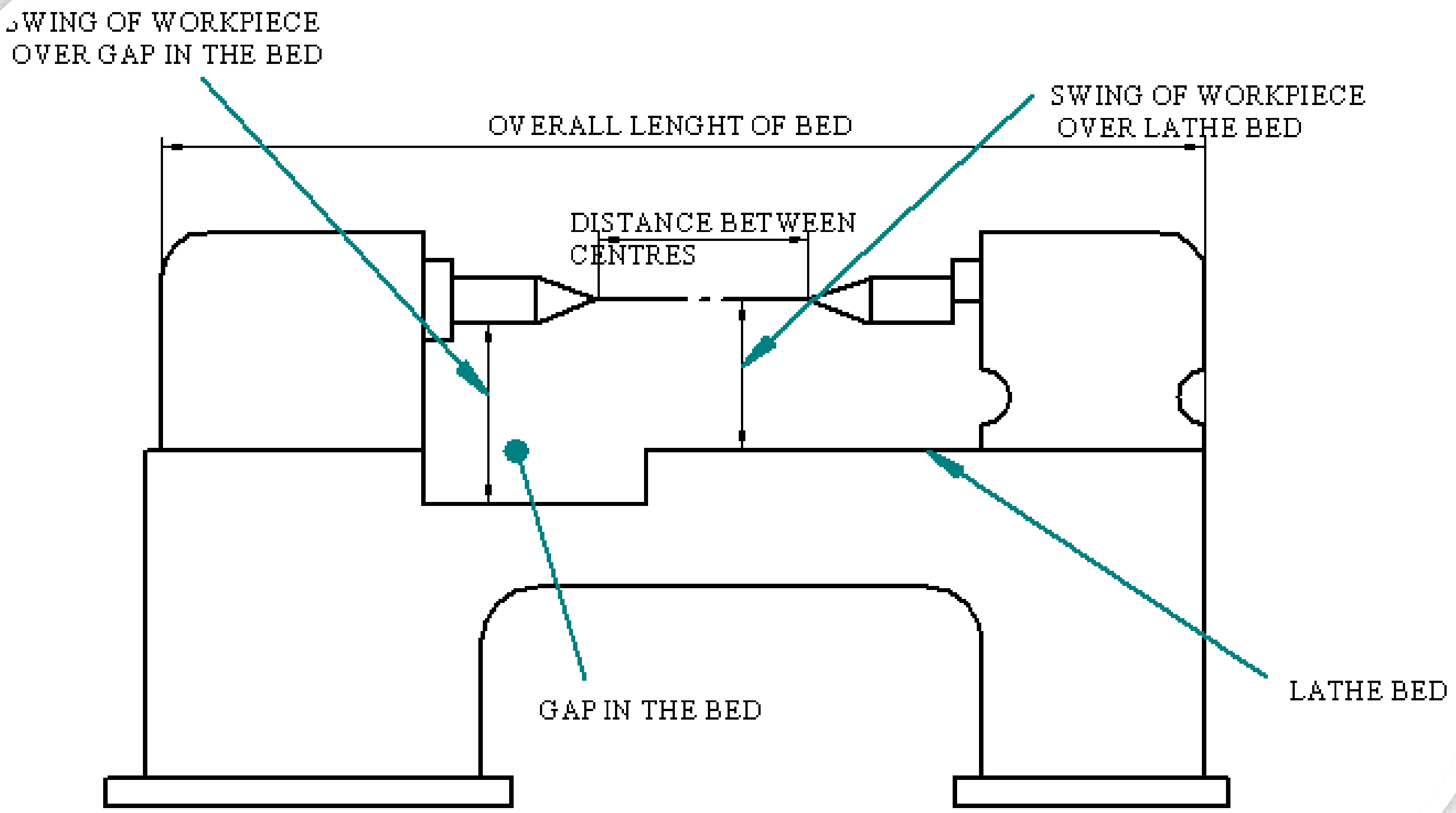
LATHE

LATHE



- The lathe is a machine tool which holds the work piece between two rigid and strong supports called centres or in a chuck.
- The cutting tool is rigidly held and supported in a tool post which is fed against the revolving work.
- The normal cutting operations are performed with the cutting tool fed either parallel or at right angles to the axis of the work.

Specifications of a LATHE



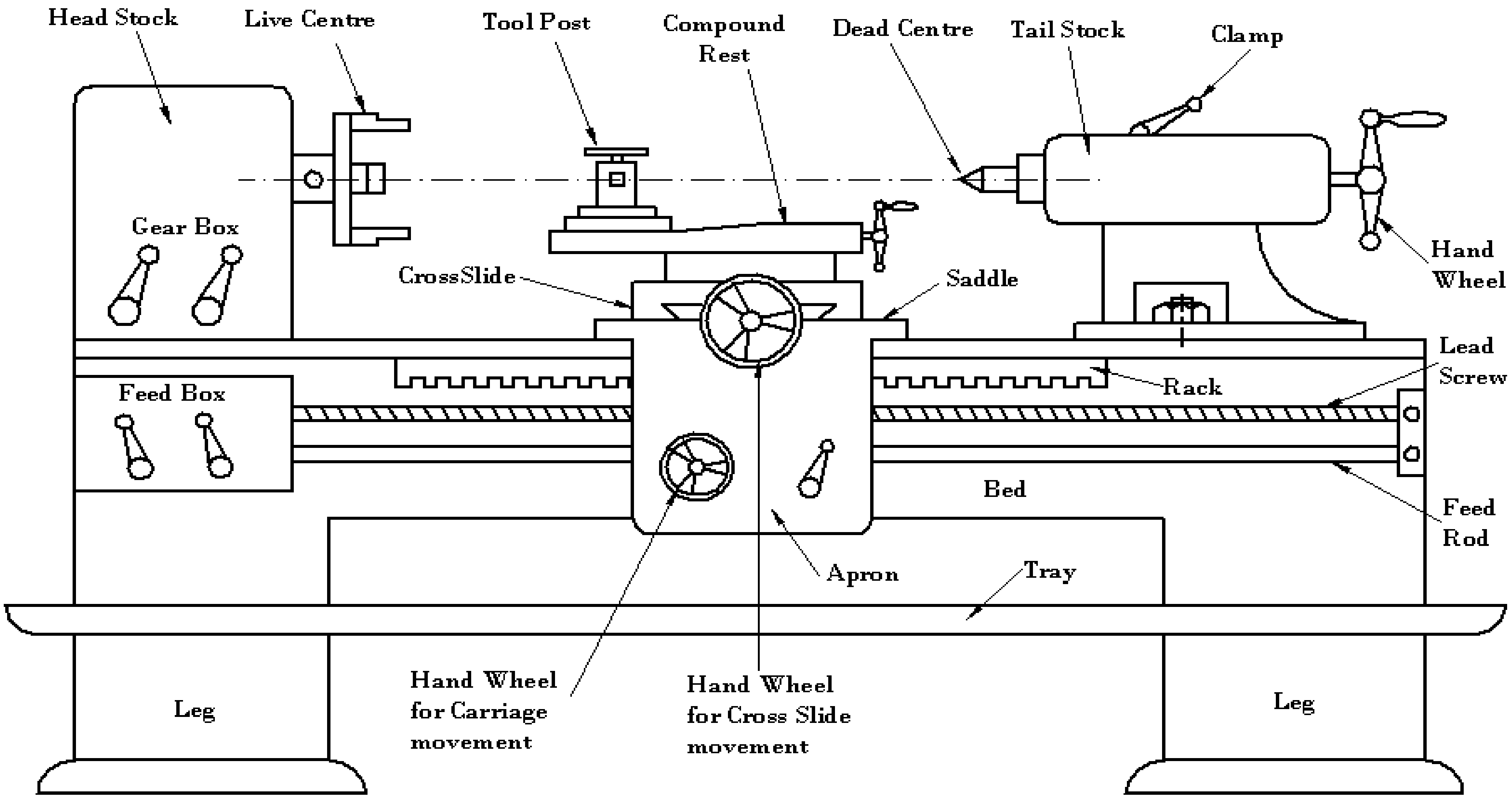
- **Distance between centre** is the maximum length of the job that can be held between the live centre and dead centre.

- **Swing diameter** is the maximum diameter of the work piece can we revolve touching the guideways
- some manufacturers specifying height centre instead of swing diameter

- **height of centres** is the height measured from the bed to the late centre axis
- **length of bed** indicates the approximate floor pace occupied my lathe

- **Range of spindle speeds**

Parts of LATHE

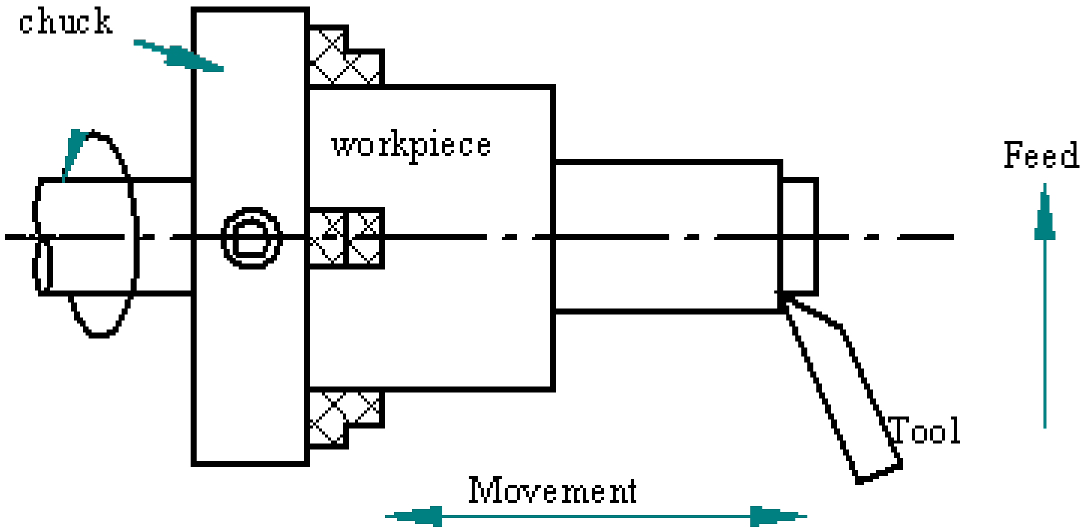


Important elements to work on LATHE

1. **Rotating Speed:** It expresses with the number of rotations (rpm) of the chuck of a lathe. When the rotating speed is high, processing speed becomes quick, and a processing surface is finely finished. However, since a little operation mistakes may lead to the serious accident, it is better to set low rotating speed at the first stage.
2. **Cutting Depth:** The cutting depth of the tool affects to the processing speed and the roughness of surface. When the cutting depth is big, the processing speed becomes quick, but the surface temperature becomes high, and it has rough surface
3. **Sending Speed (Feed):** The sending speed of the tool also affects to the processing speed and the roughness of surface. When the sending speed is high, the processing speed becomes quick. When the sending speed is low, the surface is finished beautiful.

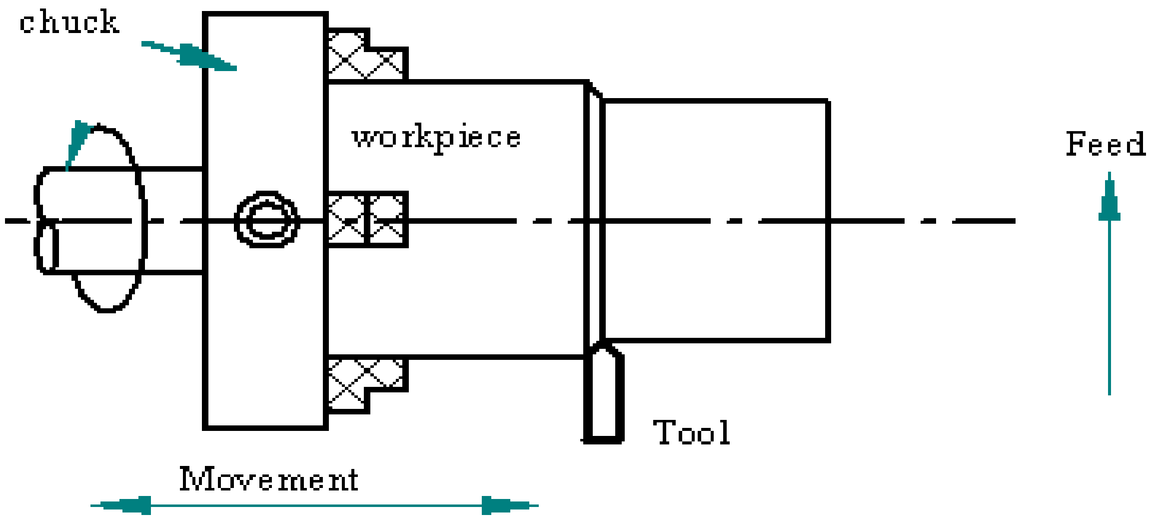
LATHE Operations:

Facing: It is the operation of machining the ends of a workpiece to produce a flat surface with the axis. It involves feeding of the tool perpendicular to the axis of rotation of the workpiece.



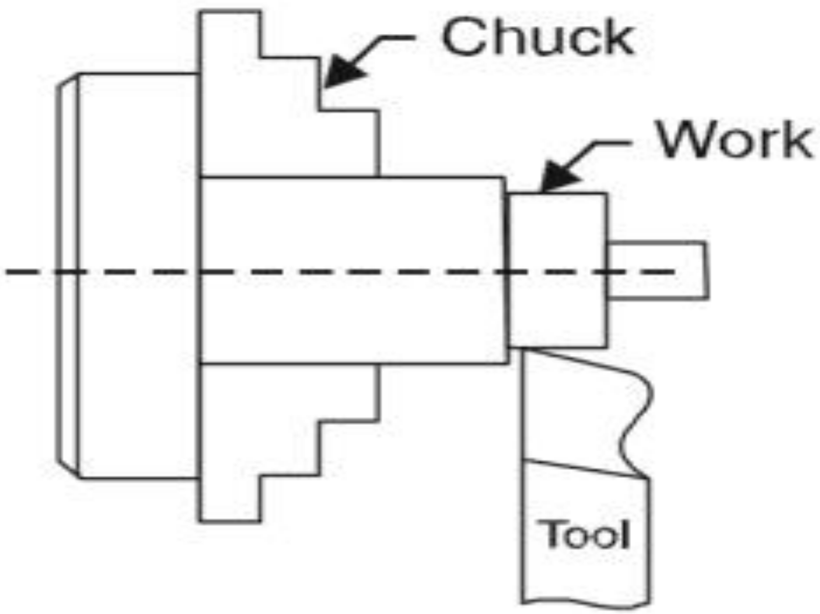
LATHE Operations:

Plain Turning: It is the operation performed for producing a cylindrical surface by removing the excess material from the workpiece. The cutting tool is held in the tool post and fed into the rotating work parallel to the lathe axis.



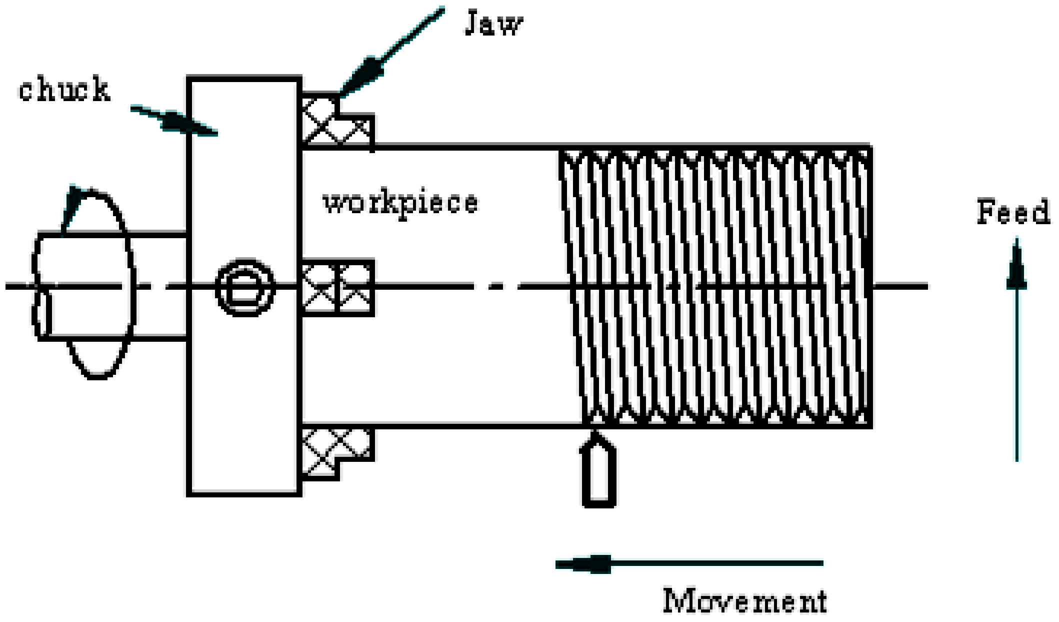
LATHE Operations:

Step Turning: Step turning is also called as shoulder turning. When workpiece of different diameters are turned, the surface formed from one diameter to the other is called as shoulder.



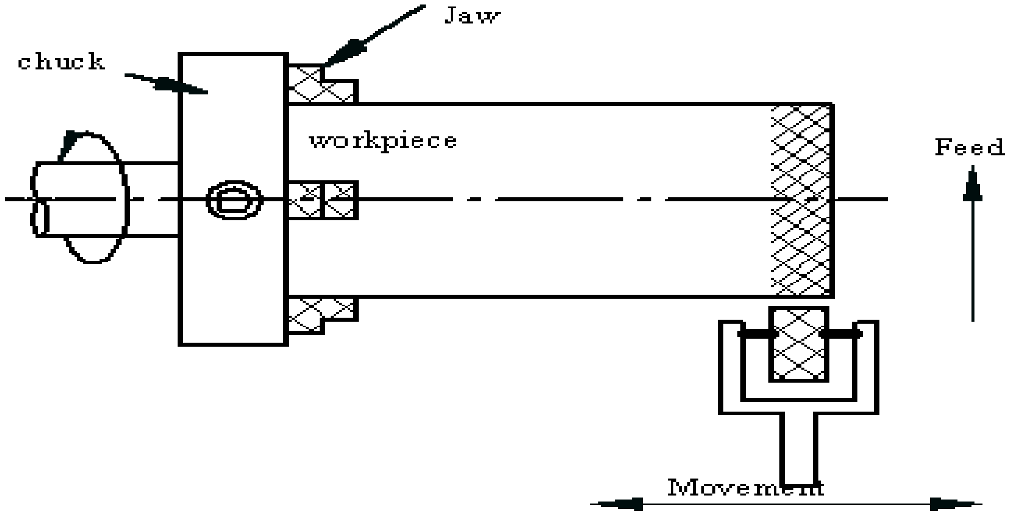
LATHE Operations:

Thread Cutting: A thread is a helical ridge formed on the cylindrical rod surface. By employing V-Shaped cutting tool it is possible to accomplish threads on the work piece.



LATHE Operations:

Knurling: Knurling is an operation performed on the lathe to generate serrated surface on the work piece. This is used to produce a rough surface for griping like the barrel of the micrometre or screw gauge. This is done by a special tool called knurling tool which has a set of hardened roller with the desired serrations.

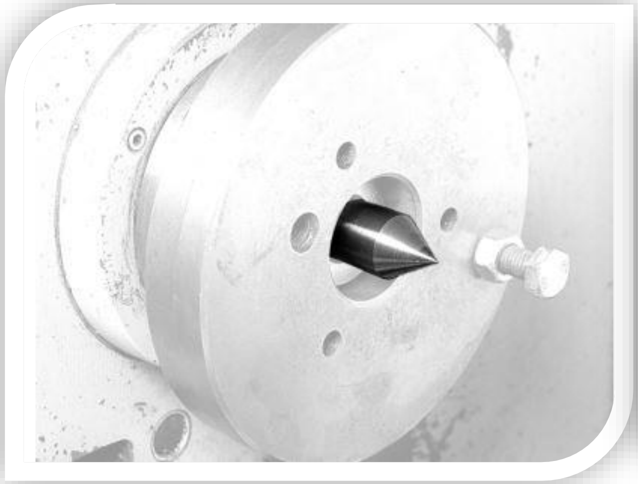


LATHE ACCESSORIES

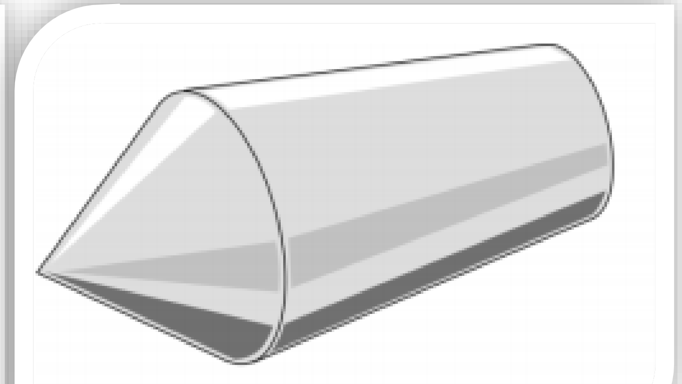
- Lathe Centre
- Lathe chuck
- Lathe dog
- Drive plate
- Face plate
- Mandrel
- Steady rest
- Follower rest

Lathe Centre

- Lathe centres are ideal for supporting long workpieces, such as shafts.
- The workpiece can be taken out of the lathe and flipped end for end without any loss of accuracy, assuming that the centres are in good condition



Live Centre



Solid Dead Centre

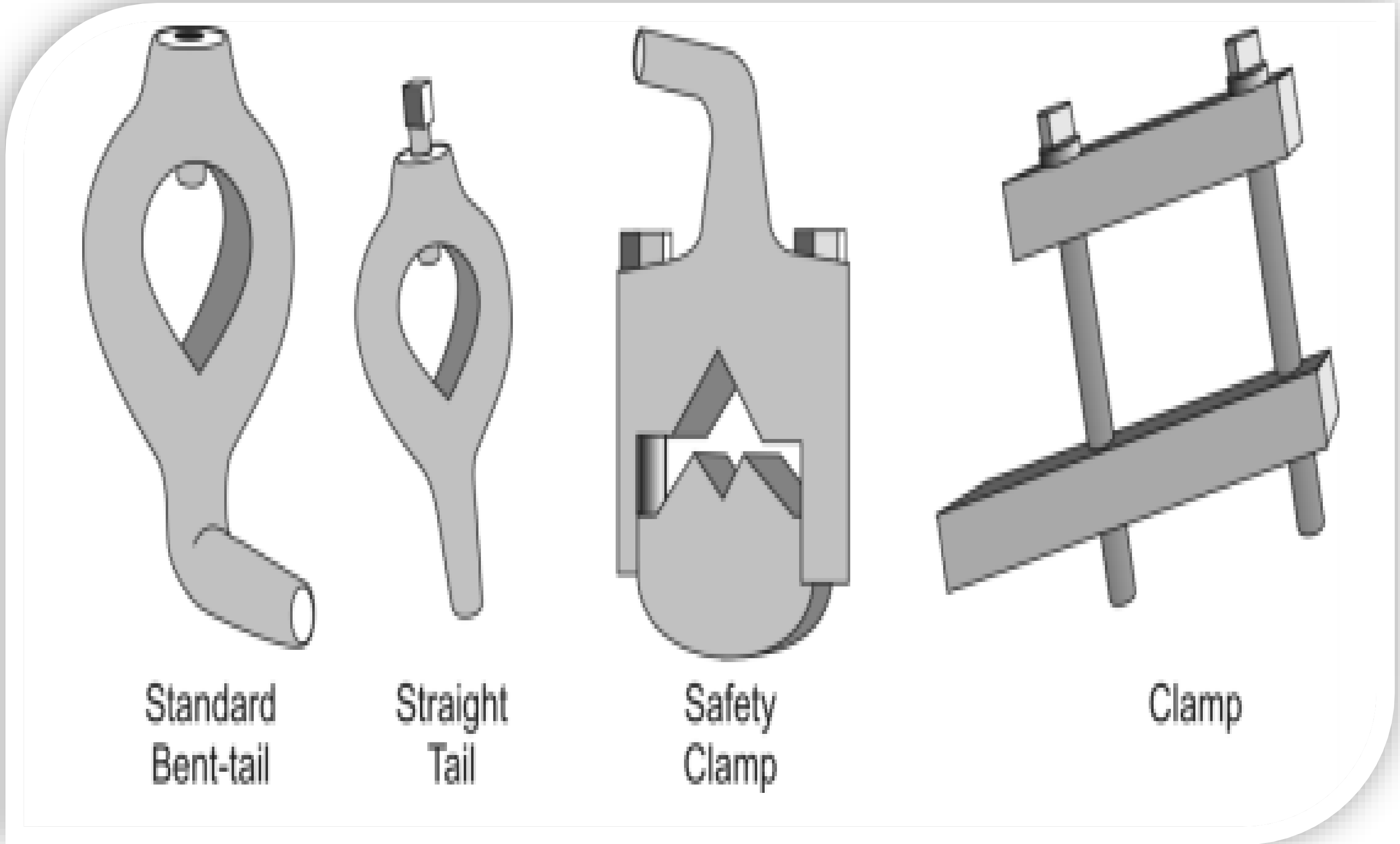
Lathe chuck

Four-jaw independent chuck.

Three-jaw universal chuck.

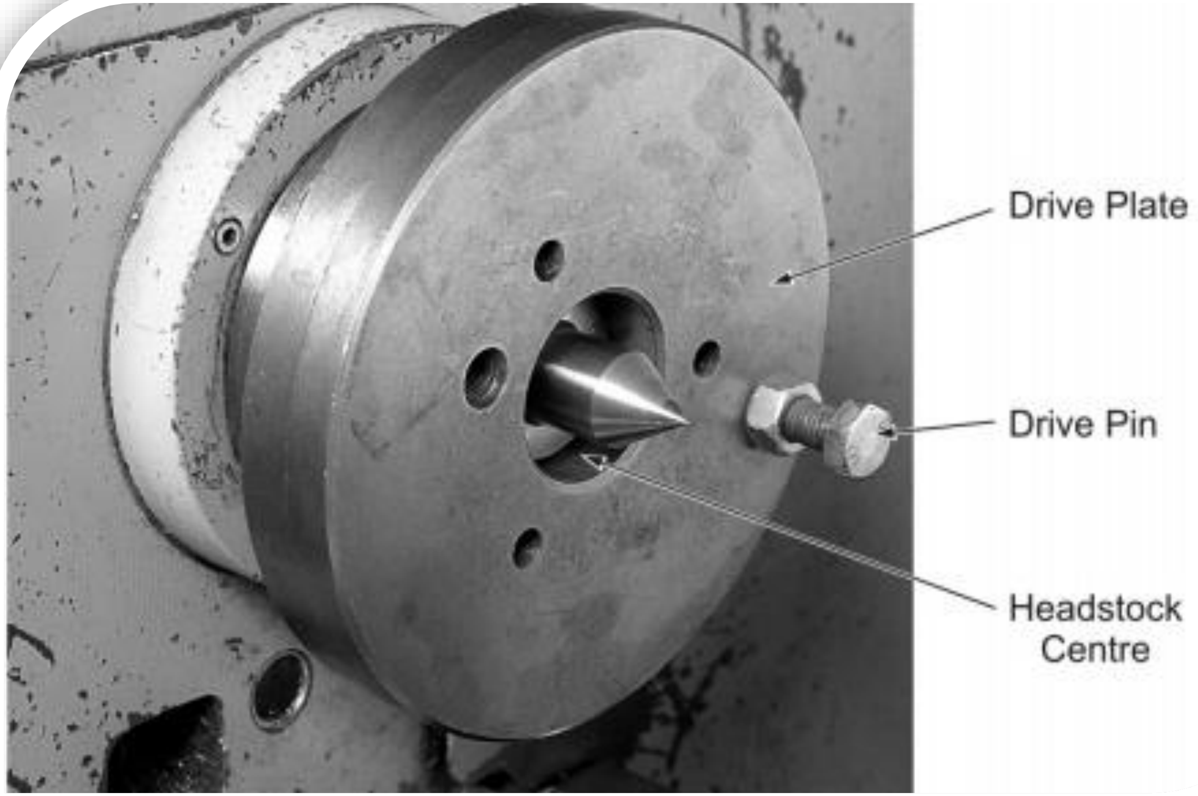
Lathe dog

Lathe dogs are used to transmit drive power from the spindle to a workpiece when it is held between centres (Without a lathe dog, the workpiece stops turning as soon as the cutting tool is applied.



Drive plate

A drive plate is a flat disc that attaches to the spindle nose. It has grooves and pins to engage and turn a lathe dog



Faceplates

- A faceplate is a large disc that may attach to the lathe spindle nose. It is similar to a drive plate, but is larger. Faceplates are used to hold oddly shaped workpieces that cannot be held in a chuck or between centres

Mandrels

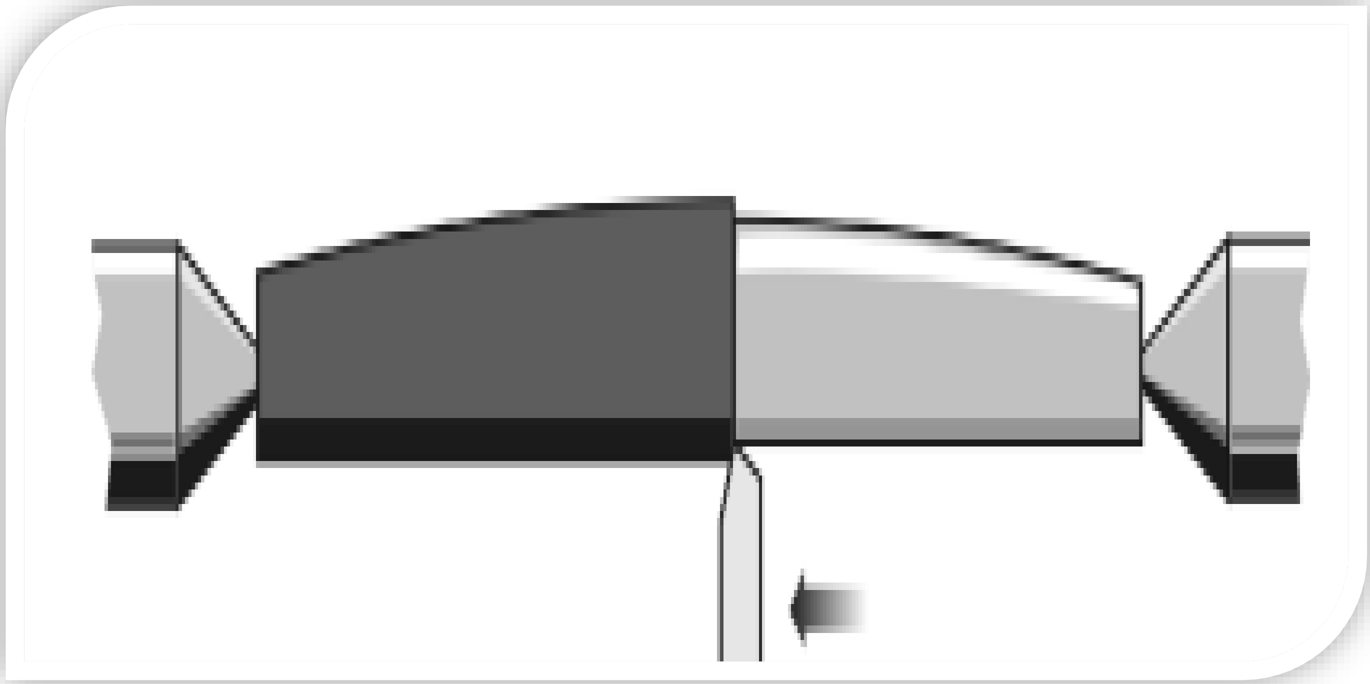
A mandrel is used to grip a workpiece by its bore. Several types of mandrels are available. They are used when gripping a workpiece with jaws could mar the surface. Workpieces are held in mandrels by a shallow solid taper, a tapered sleeve or a nut on the threaded portion.

Steady rest

- Long, thin workpieces present special problems for the lathe operator. A steady rest solves these problems by supporting the workpiece either at the end or in the middle
- A steady rest is an optional piece of equipment supplied with most lathes

Follower Rests

- A long, thin workpiece tends to deflect away from the cutting tool during a cut.
- The deflection is greater in the middle of the workpiece than at either end, which results in a diameter that is not uniform



Thank You