Introduction

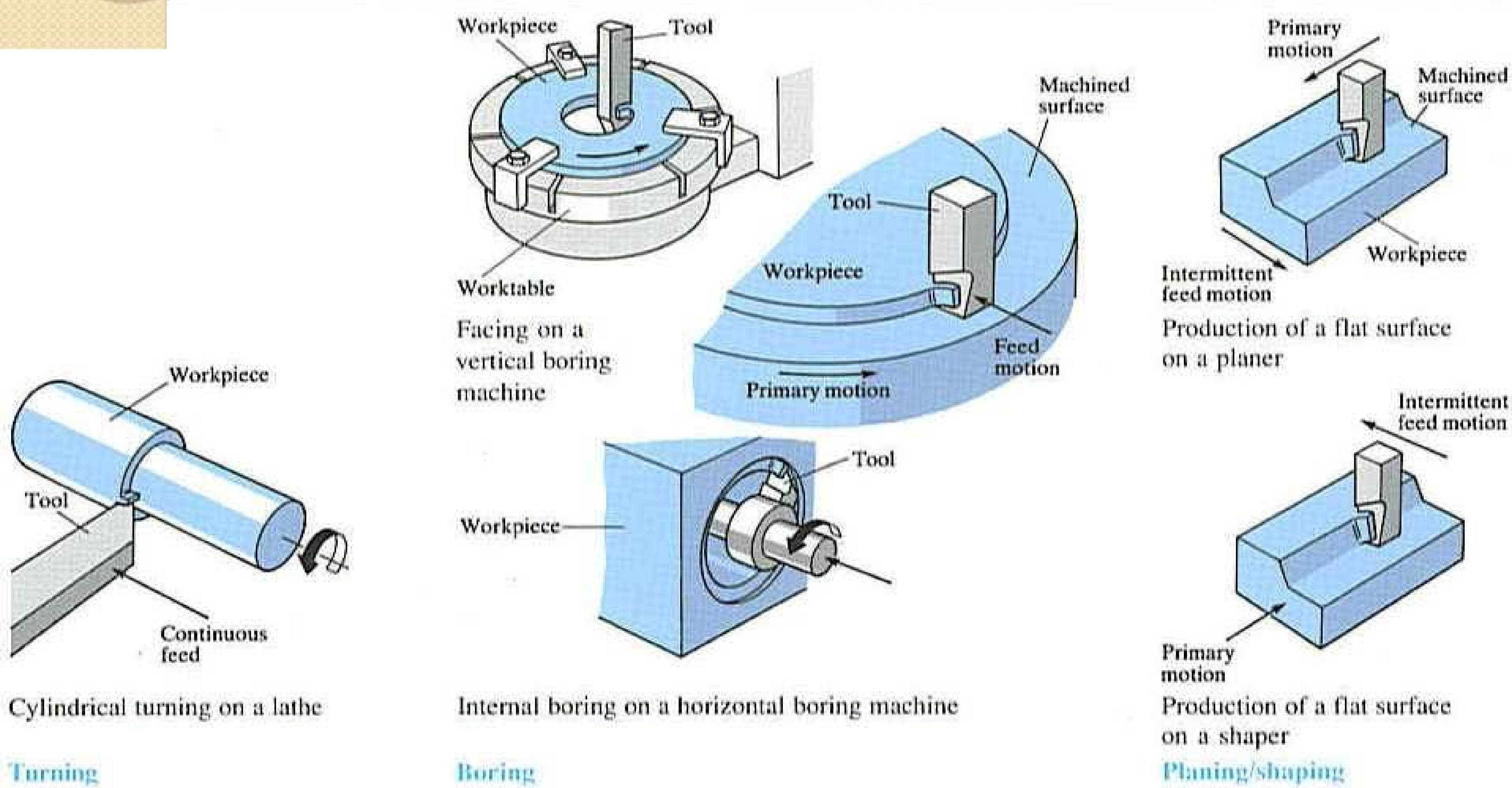
❑ Objectives

- This chapter aims to provide basic backgrounds of different types of machining processes and highlights on an understanding of important parameters which affects machining of metals with their chip removals.
- Metal cutting or Machining is the process of producing workpiece 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.
- The major drawback of the process is loss of material in the form of chips. In this chapter. we shall have a fundamental understanding of the basic metal process.

Introduction

Single point Cutting Tool

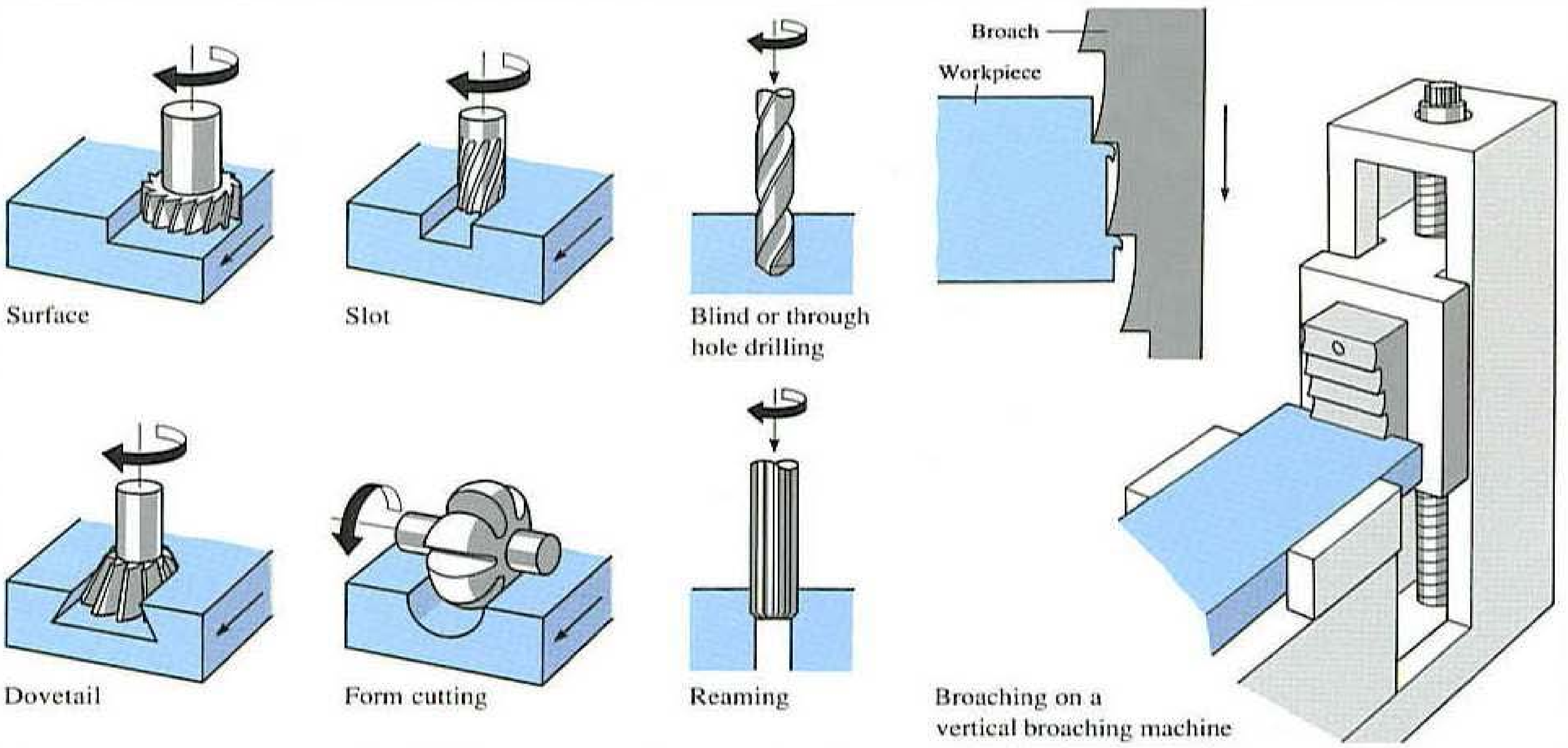
- Removal of the metal from the workpiece by means of cutting tools which have one major cutting edge.



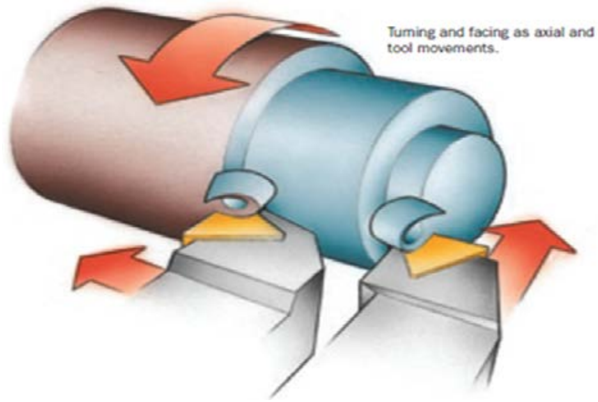
Introduction

Multi- point Cutting Tool

- Removal of the metal from the workpiece by means of cutting tools which have more than one major cutting edge.



Single point Cutting Tool



Turning and facing as axial and radial tool movements.

A ***chip of material*** is removed from the surface of the workpiece.

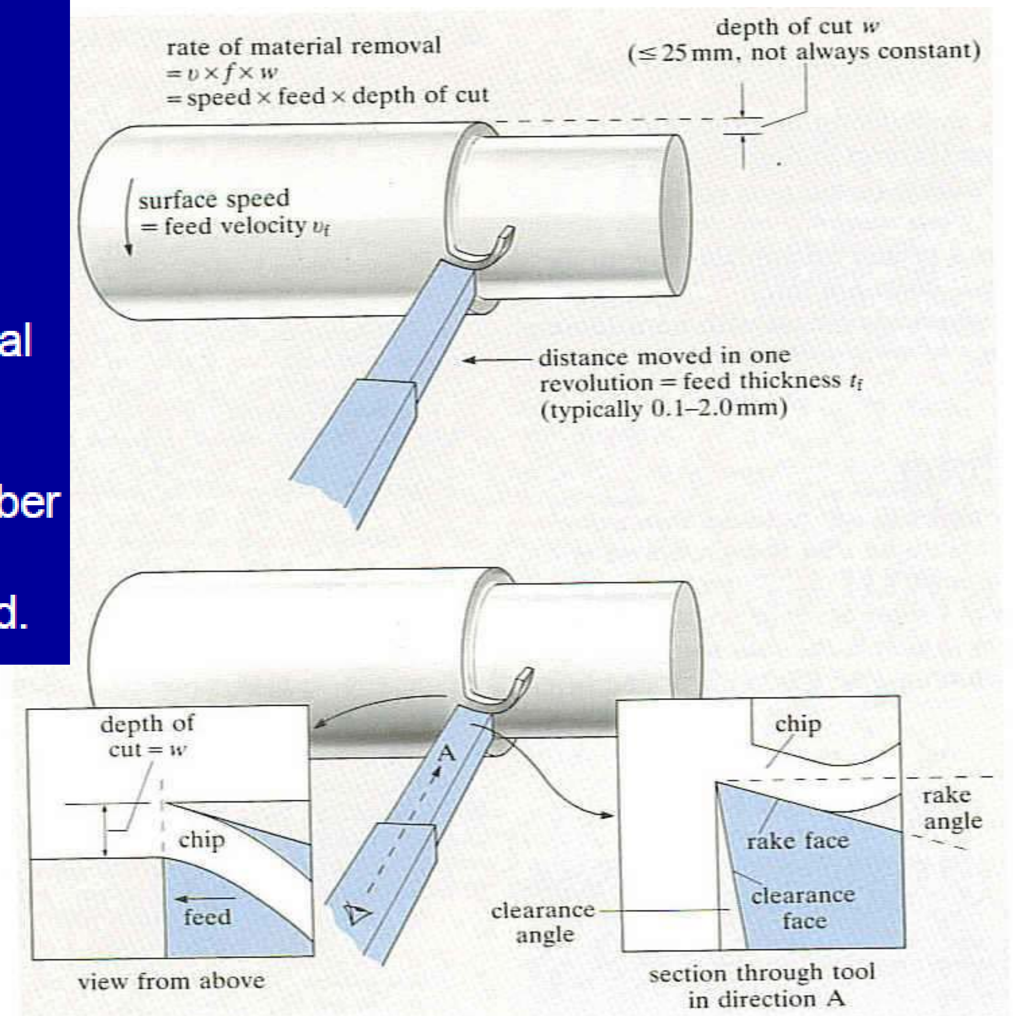
Principal parameters:

- the cutting speed, ***v***
- the depth of cut, ***w or d***
- the feed, ***f***.

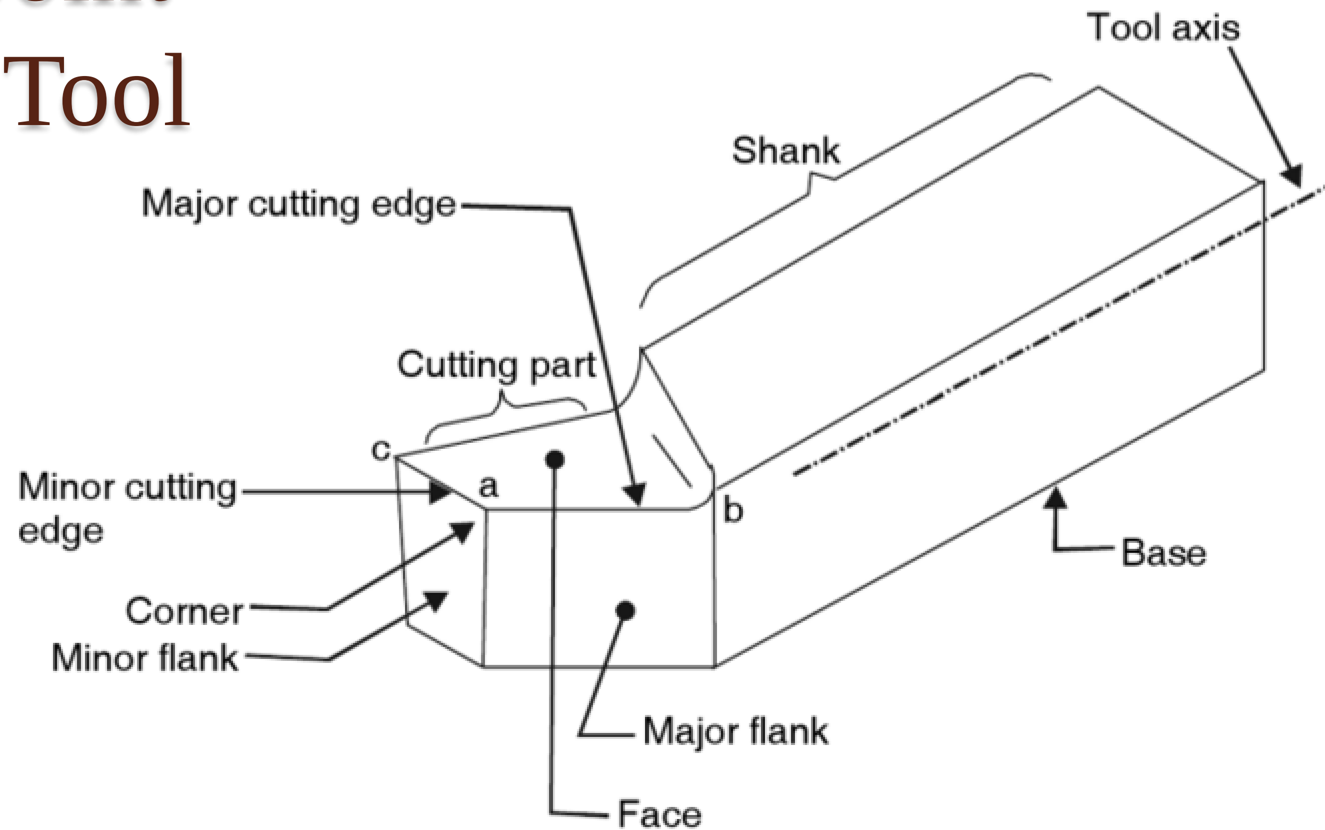
Time requires to turn a cylindrical surface of length L_w,

$$t = \frac{L_w}{f n_w}$$

Where n_w is the number of revolutions of the workpiece per second.



Single point Cutting Tool



Shank. It is the main body of the tool.

Flank. The surface or surfaces below and adjacent to the cutting edge is called flank of the tool.

Face. The surface on which the chip slides is called the face of the tool.

Heel. It is the intersection of the flank and the base of the tool.

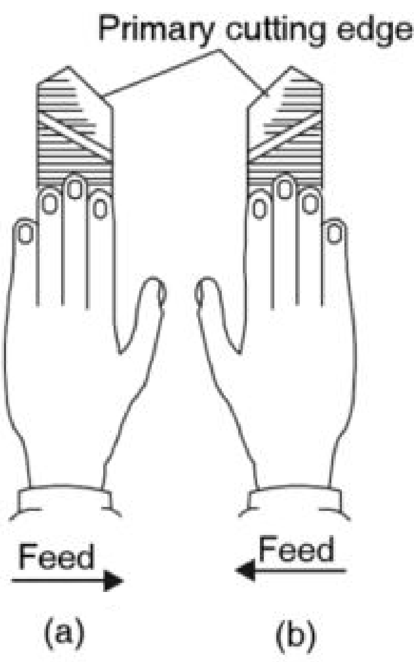
Nose. It is the point where the side cutting edge and end cutting edge intersect.

Single point Cutting Tool

Cutting edge. It is the edge on the face of the tool which removes the material from the workpiece. The total cutting edge consists of side cutting edge (major cutting edge), end cutting edge (minor cutting edge and the nose).

A single point cutting tool may be either right–or left hand cut tool depending on the direction of feed. In a right cut tool, the side cutting edge is on the side of the thumb when the right hand is placed on the tool with the palm downward and the fingers pointed towards the tool nose .

Such a tool will cut when fed from right to left as in a lathe in which the tool moves from tailstock to headstock. A left-cut tool is one in which the side cutting edge is on the thumb side when the left hand is applied . Such a tool will cut when fed from left to right.



Left and Right Cut Tools.

The various types of surfaces and planes in metal cutting are explained below , in which the basic turning process is shown.
The three types of surfaces are :

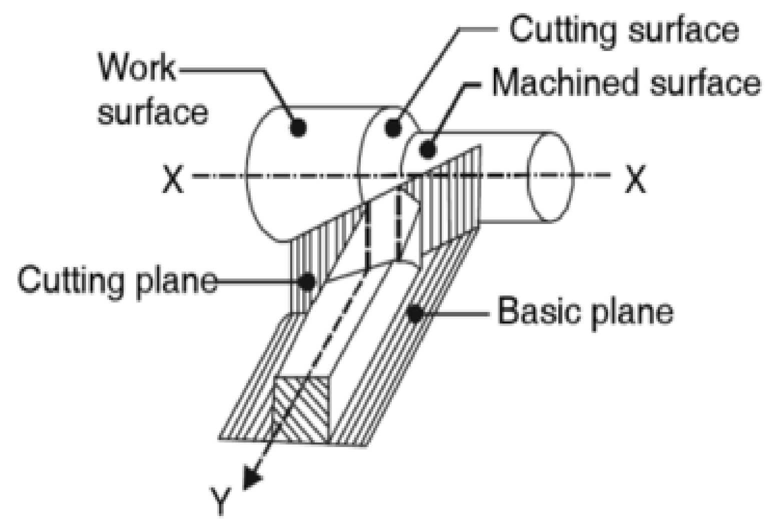
1. the work surface, from which the material is cut.
2. the machined surface which is formed or generated after removing the chip.
3. the cutting surface which is formed by the side cutting edge of the tool.

Single point Cutting Tool

The references from which the tool angles are specified are the 'cutting plane' and the 'basic plane' or the 'principal plane'. The cutting plane is the plane tangent to the cutting surface and passing through and containing the side cutting edge. The basic plane is the plane parallel to the longitudinal and cross feeds, that is, this plane lies along and normal to the longitudinal axis of the workpiece. In a lathe tool, the basic plane concides with the base of the tool.

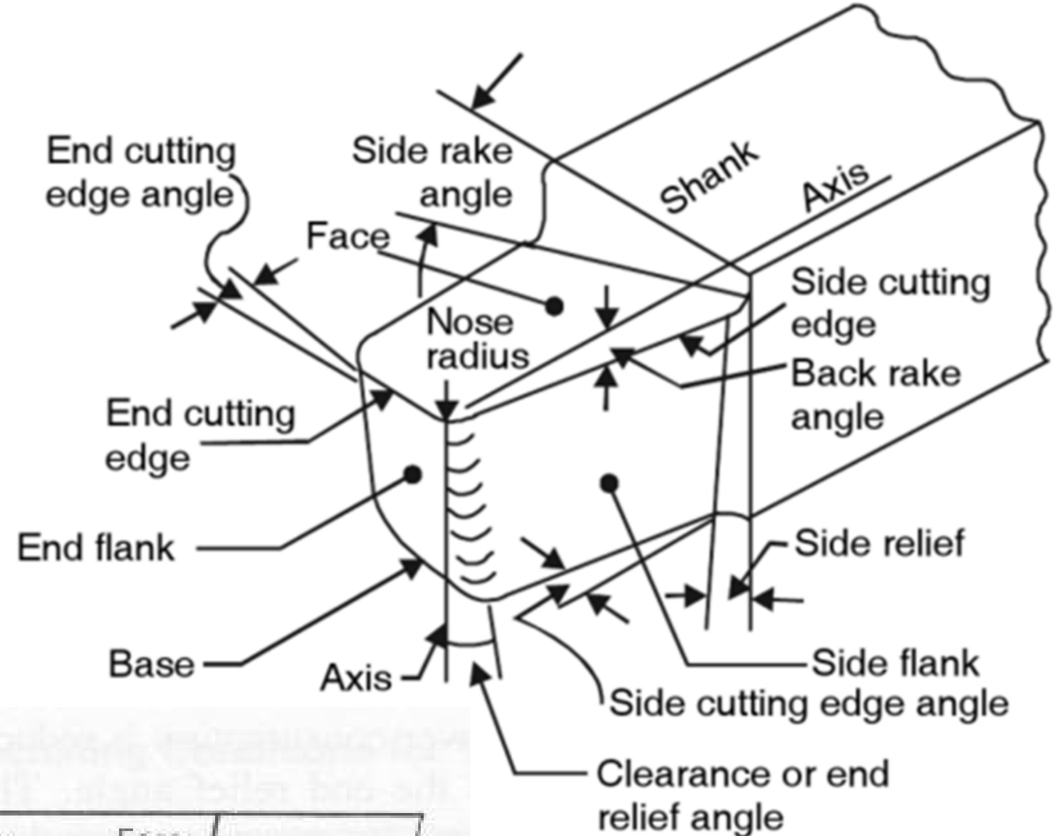
Designation of Cutting Tools. By designation or nomenclature of a cutting tool is meant the designation of the shape of the cutting part of the tool. The two systems to designate the tool shape, which are widely used, are :

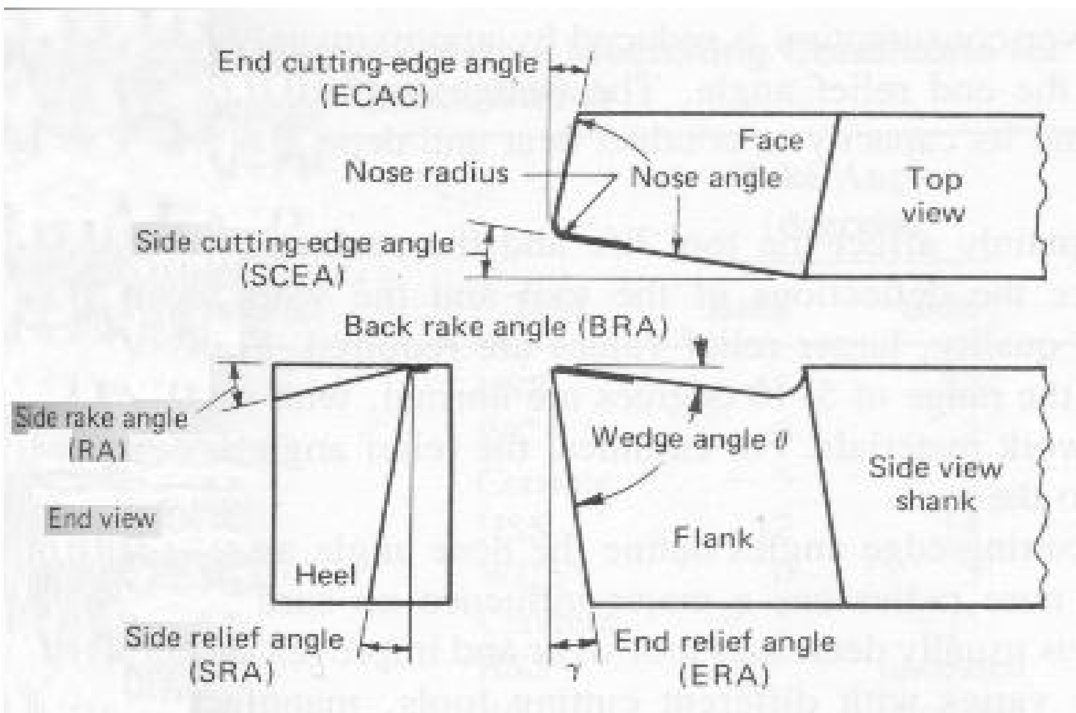
1. American Standards Association System (ASA) or American National Standards Institute (ANSI).
2. Orthogonal Rake System (ORS).



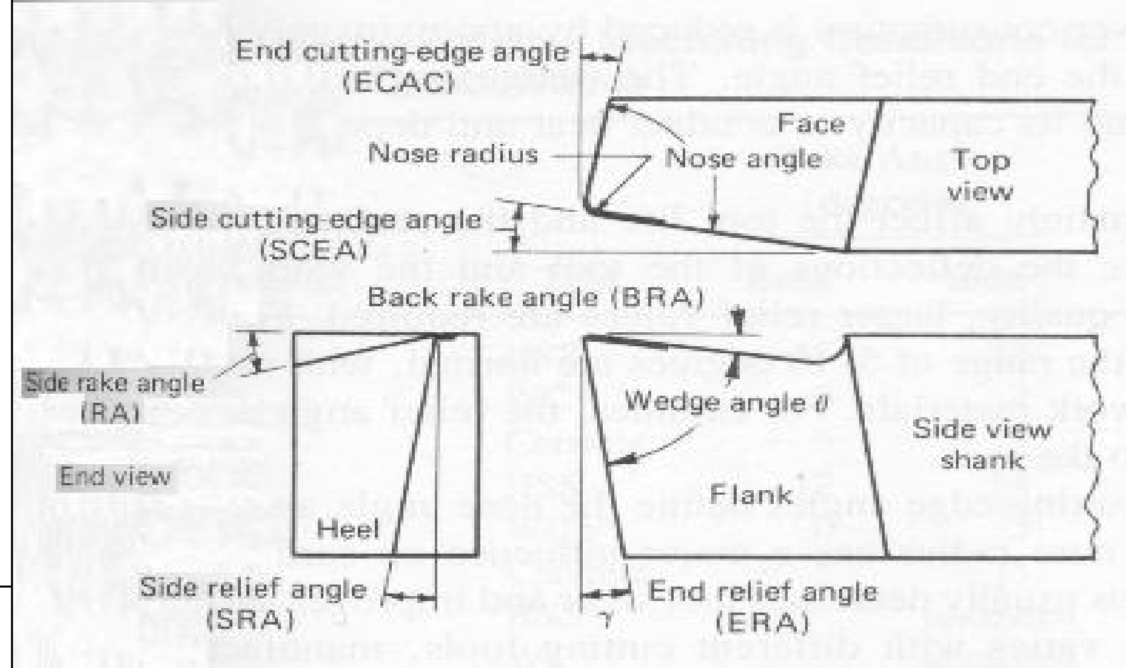
Principal Surfaces and Planes in Metal Cutting.

Angles in Single point Cutting Tool





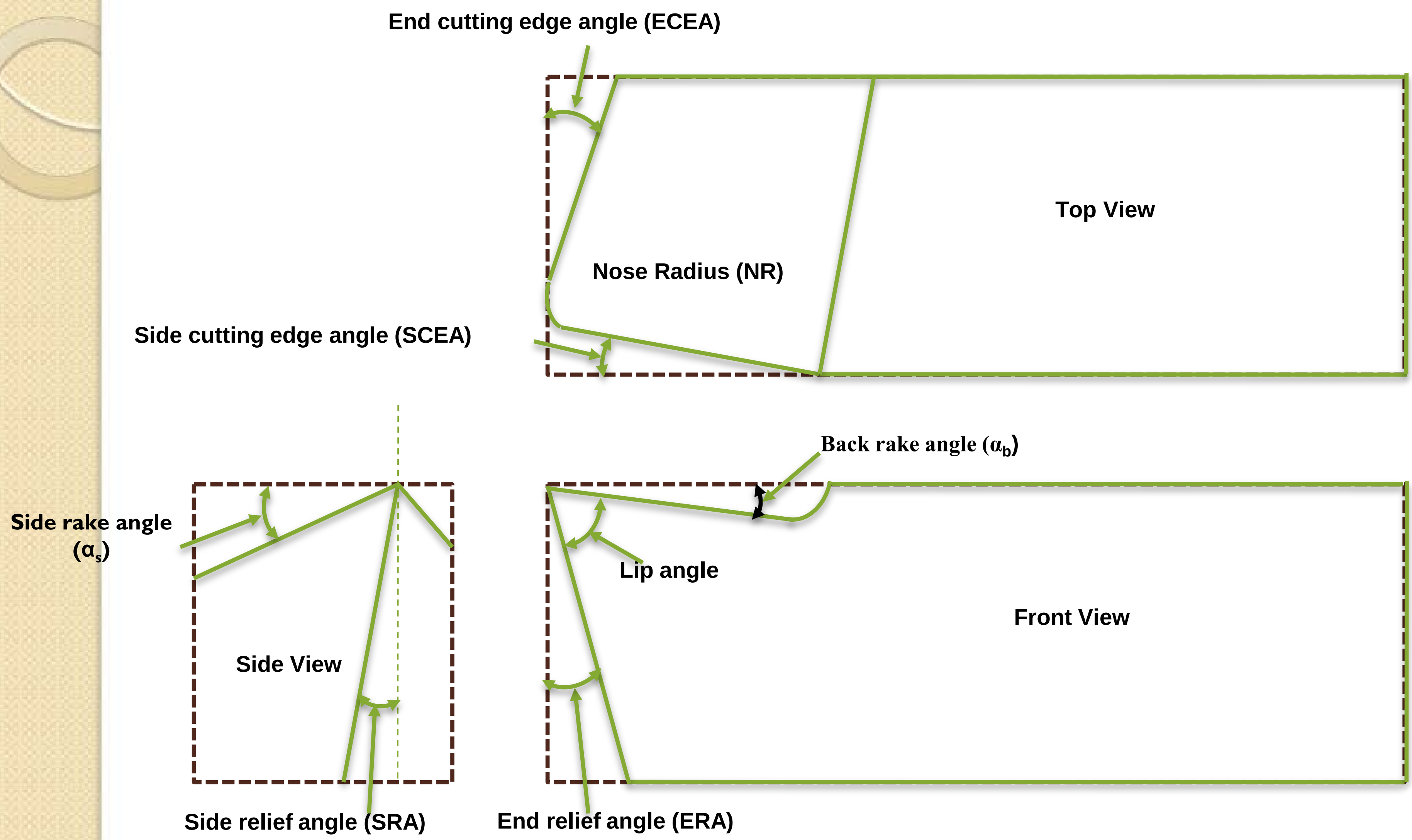
Angles in Single point Cutting Tool



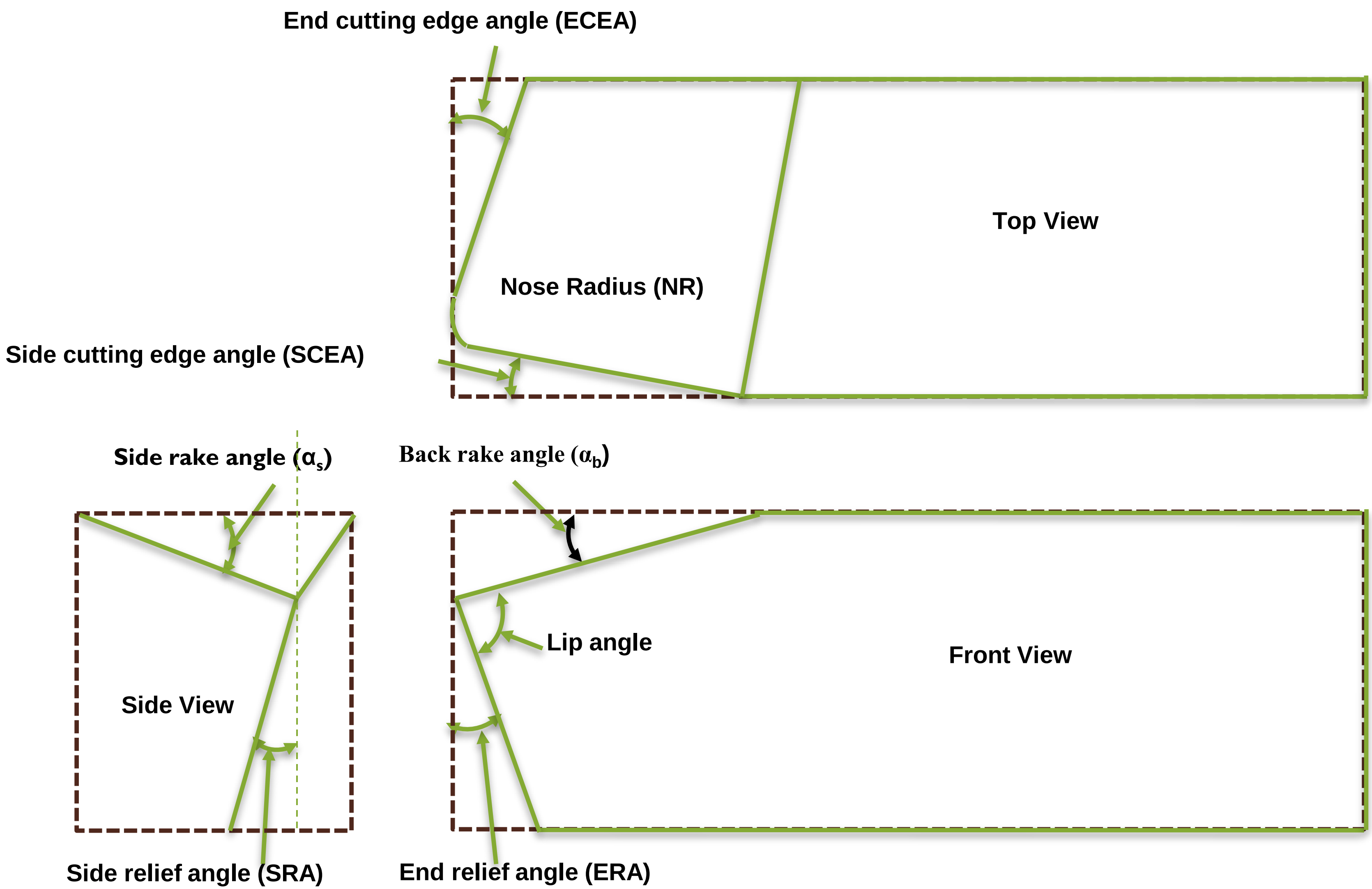
Angle				
Side Cutting Edge Angle	Side cutting edge	&	Side of tool shank	
End Cutting Edge Angle	End cutting edge	&	Normal to the tool shank	
Side Relief angle	Portion of side flank Immediately below Side cutting flank	&	Line perpendicular to Base of tool	Measured at Right angle to Side flank
End Relief angle	Portion of end flank Immediately below End cutting flank	&	Line perpendicular to Base of tool	Measured at Right angle to End flank
Back Rake angle	Face of the tool	&	Line parallel to Base of tool	Measure in a plane Through side cutting edge
Side Rake angle	Face of the tool	&	Line parallel to Base of tool	Measure in a plane Perpendicular to base & side cutting edge

Importance of Angles in Single point Cutting Tool

Geometry of positive rake single point cutting tool



Geometry of negative rake single point cutting tool



Rack Angle

- Side rake angle and Back rake angle combine to form the effective rake angle.
- It also called true rake angle.
- It has two major function

1. Its influence on tool strength

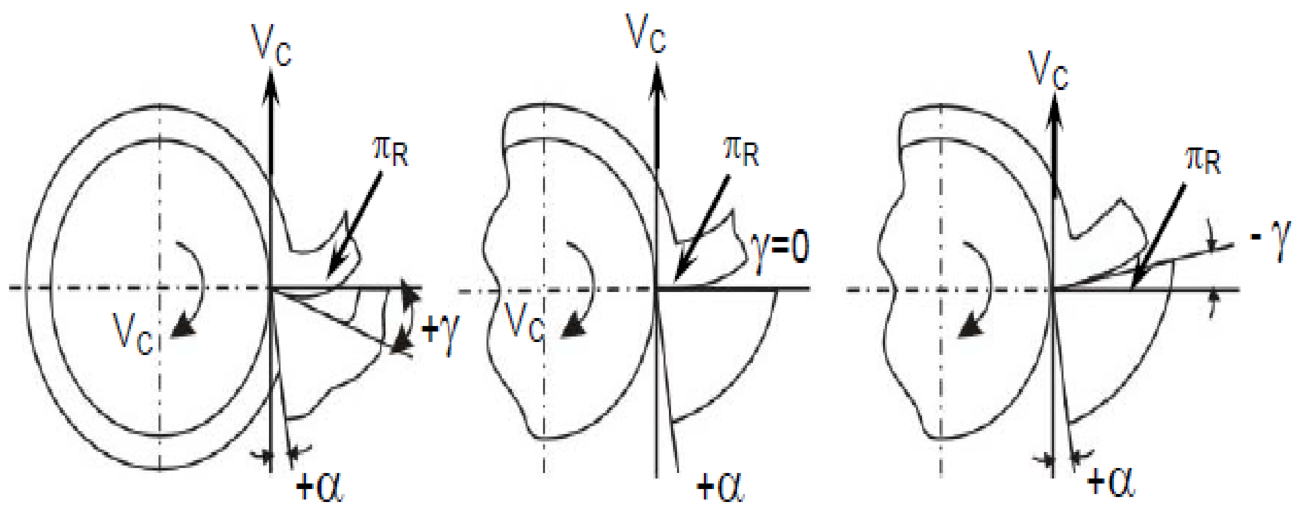
- Negative rake angle increase strength

2. Its influence on cutting pressure

- Positive rake angle reduce cutting force by allowing chips to flow freely

- Rake angle is provided for ease of chip flow and overall machining.

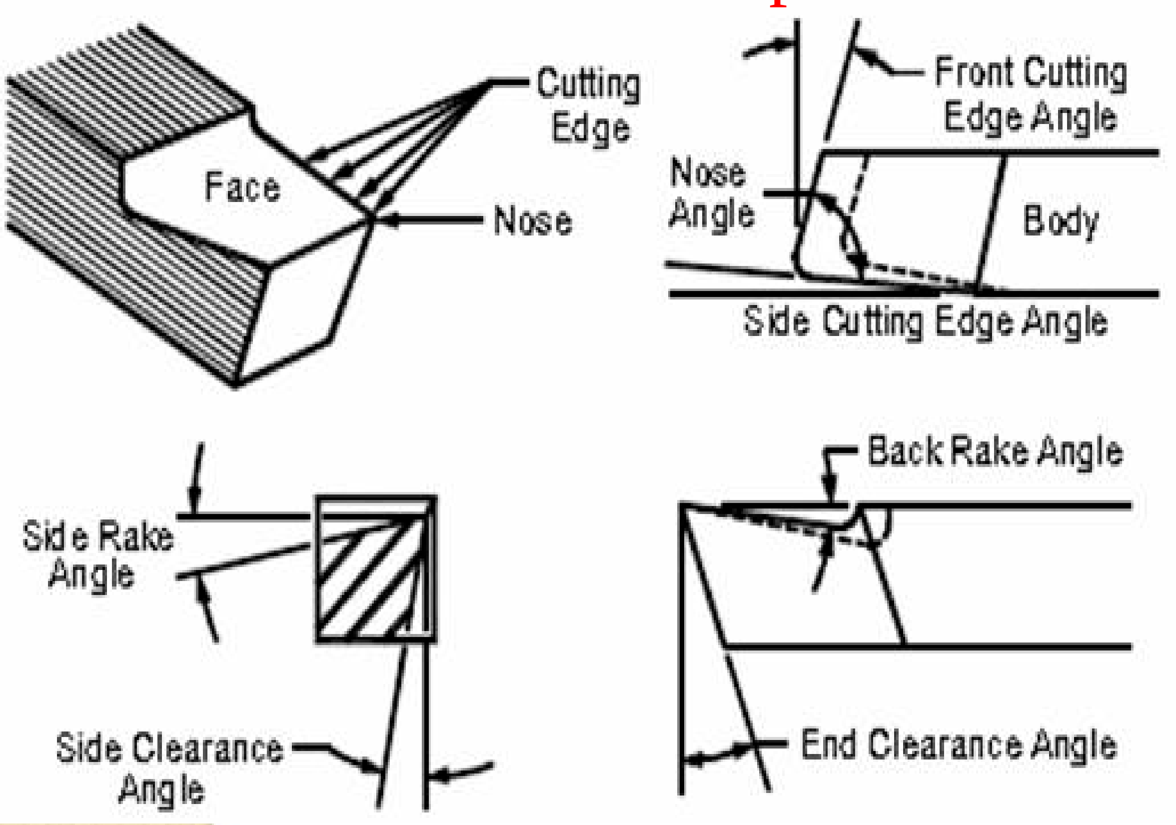
- Rake angle may be positive, or negative or even zero.
- Positive rake – helps reduce cutting force and thus cutting power requirement.
- Negative rake – to increase edge-strength and life of the tool (eg. carbide tools)
- Zero rake – to simplify design and manufacture of the form tools



(a) positive rake (b) zero rake (c) negative rake

Back Rack Angle

- It's the angle between the face of the tool and line parallel to base of shank in a plane parallel to the side cutting edge
- It affects the ability of the tool to shear the work and form a chip.



Side Rack Angle

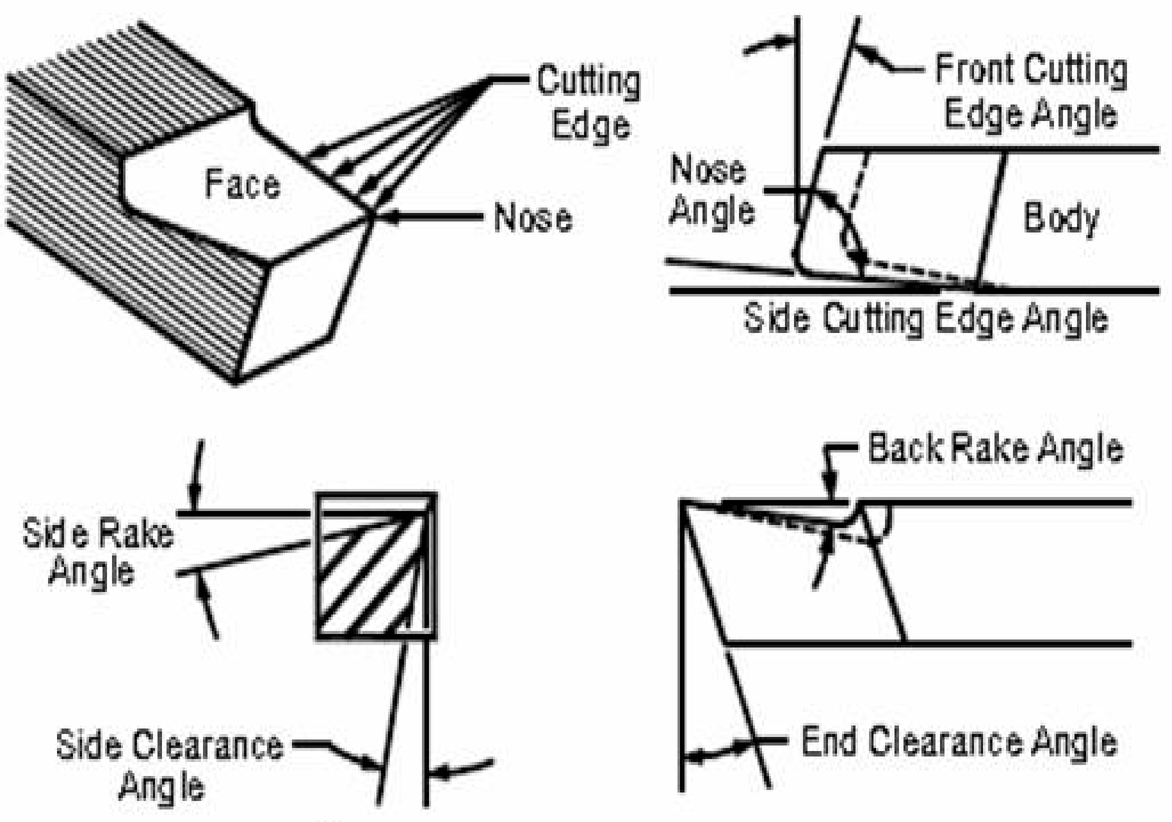
- It's the angle by which the face of the tool is inclined sideways

Rack Angle

- Negative rake are recommended on tool which does not possess good toughness.
- Harder Material like CI cut by smaller rake Angle
- Tool like cemented carbide permit very high speed, at such a high speed rake angle has influence on cutting pressure. under such condition rake angle minimum or negative.
- For more depth of cut, material removal max. it means tool has to withstand severe cutting pressure.

Relief Angle

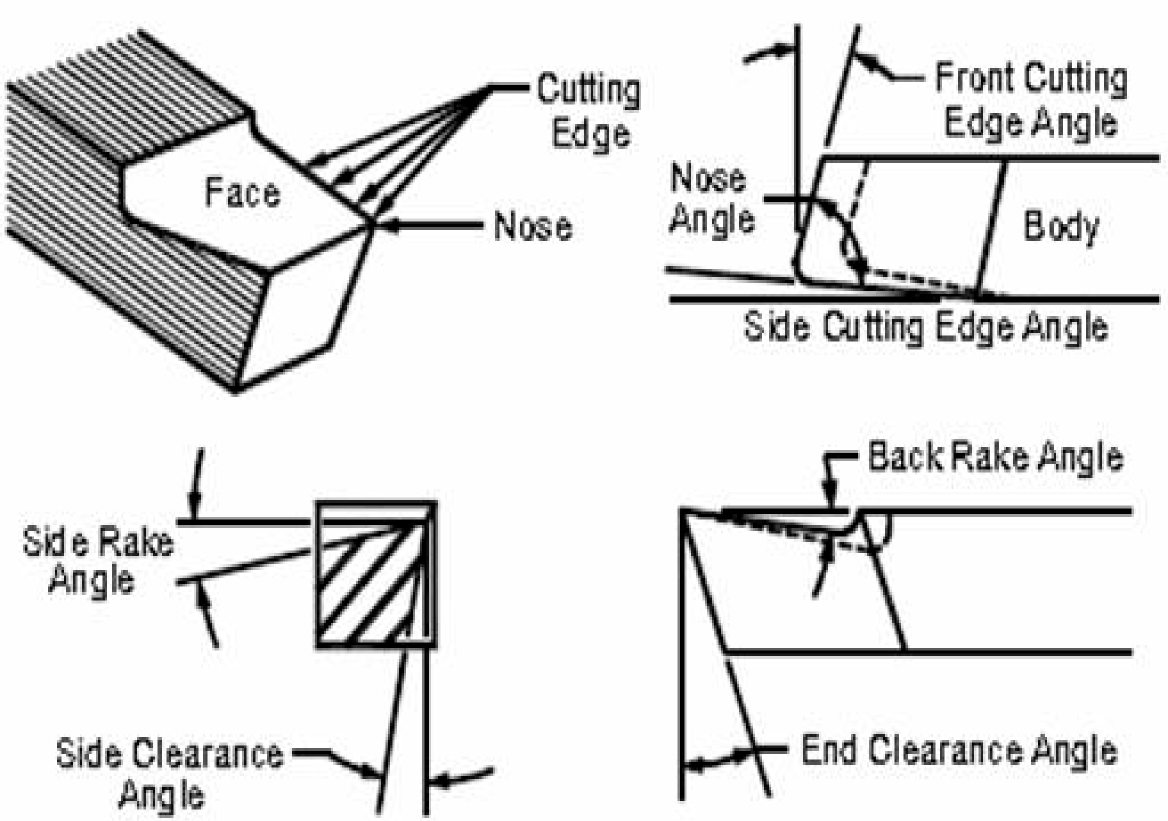
- It minimize rubbing contact between machined surface.
- It helps to eliminate tool brakeage and increase tool life.



- Small angle for machining hard material
- It prevents side flank of tool from rubbing against the work.

Relief Angle

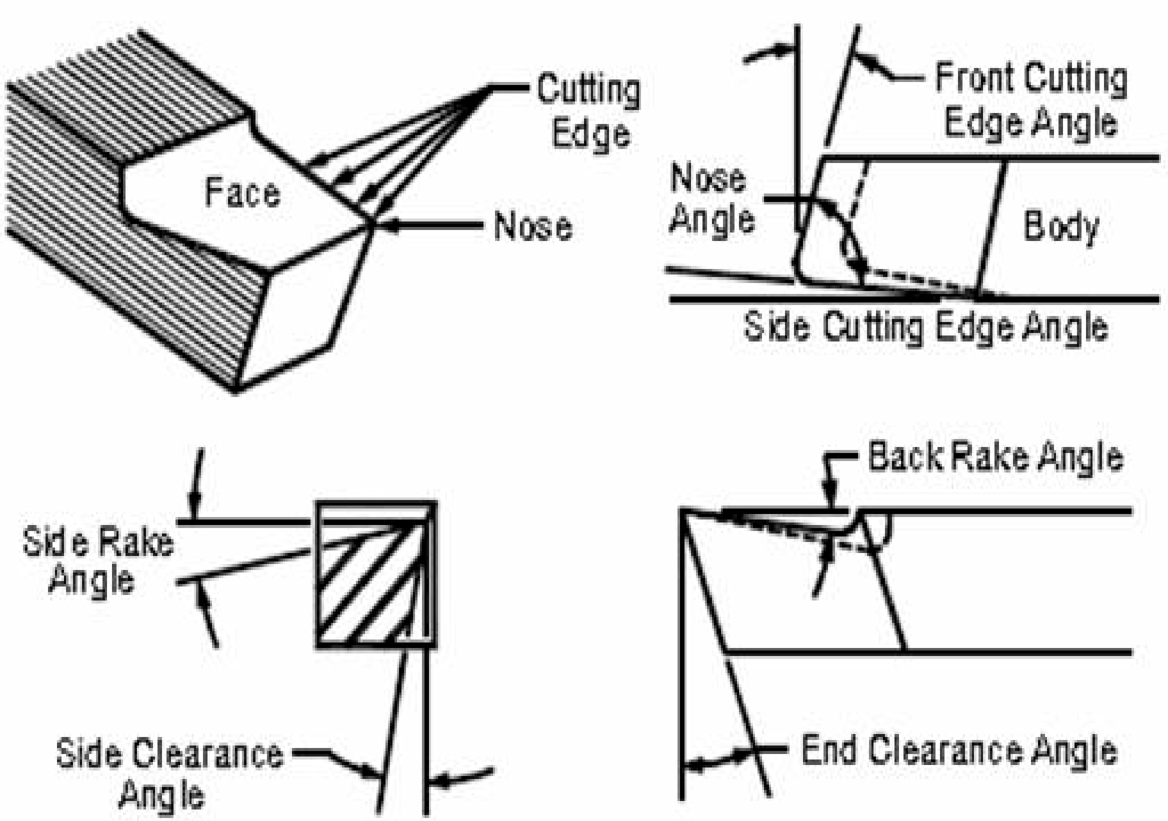
- It prevents side flank of tool from rubbing against the work.



- Increase tool life, for same depth of cut cutting force distributed on wide surface.
- It dissipated heat quickly for having wider cutting edge.

End Cutting Edge Angle

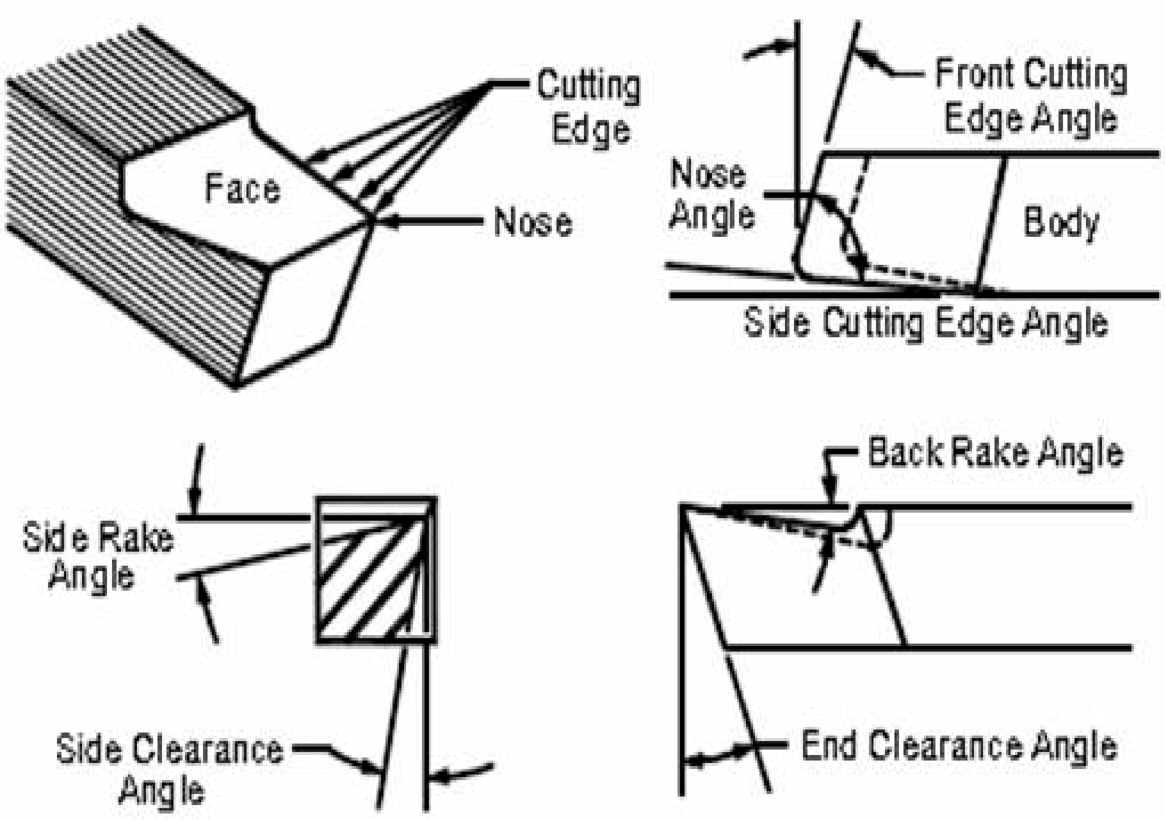
- It prevents front cutting edge of tool from rubbing against the work.



- Large end cutting edge angle unnecessarily weakens of tool.
- 8-15 degrees

Nose Radius

- Grater nose radius provide better surface finish
- All finish tool have grater nose radius than rough tool



- Accumulated heat is less than pointed tool ,which permits higher speed
- Increase tool life

Back rake angle:

•The back rake angle is the angle between the face of the tool and a line parallel to the base of the shank in a plane parallel to the side cutting edge.

•The back rake angle affects the ability of the tool to shear the work material and form chip.

Side Rake Angles:

•It is the angle by which the face of the tool is inclined side ways.

The Rake Angle:

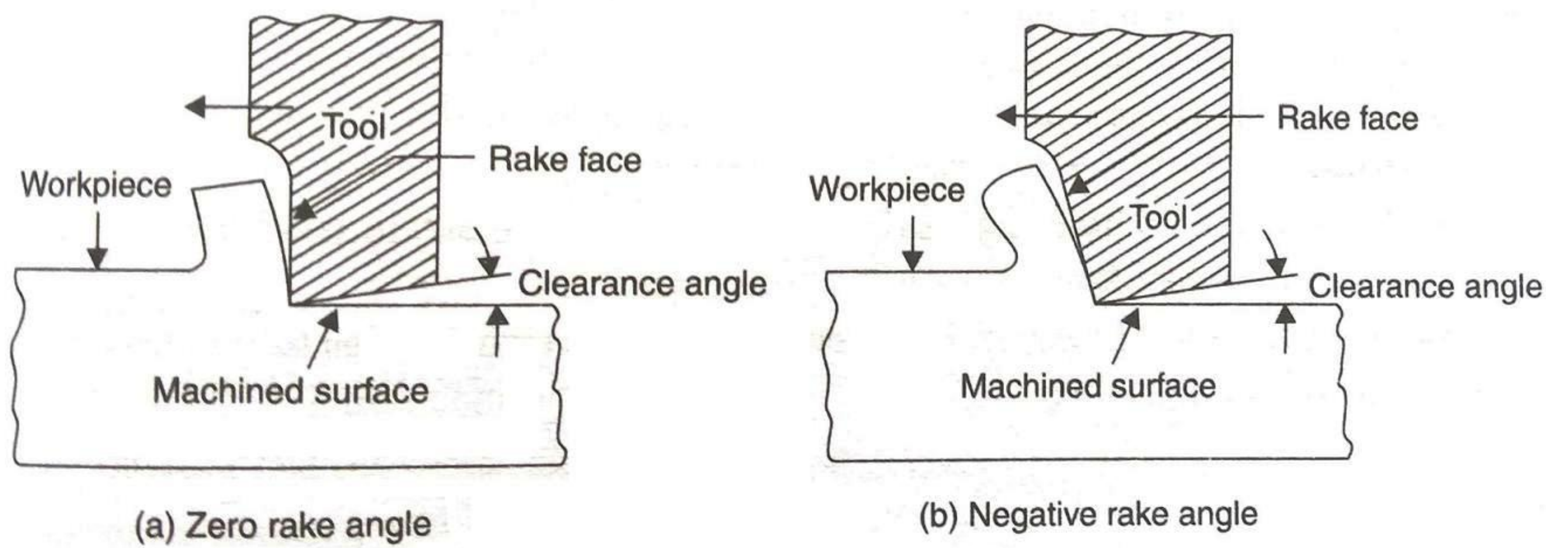
- The side rake angle and the back rake angle combine to form the effective rake angle. This is also called true rake angle or resultant rake angle of the tool.

The Rake Angle:

- The rake angle is always at the topside of the tool.
- The basic tool geometry is determined by the rake angle of the tool.
- Rake angle has two major effects during the metal cutting process.
- One major effect of rake angle is its influence on tool strength. A tool with negative rake will withstand far more loading than a tool with positive rake.
- The other major effect of rake angle is its influence on cutting pressure. A tool with a positive rake angle reduces cutting forces by allowing the chips to flow more freely across the rake surface.

The rake angle has the following function:

- It allows the chip to flow in convenient direction.
- It reduces the cutting force required to shear the metal and consequently helps to increase the tool life and reduce the power consumption. It provides keenness to the cutting edge.
- It improves the surface finish.



Tool cutting at different rake angles.

Positive Rake:

- Positive rake or increased rake angle reduces compression, the forces, and the friction, yielding a thinner, less deformed and cooler chip.
- But increased rake angle reduces the strength of the tool section, and heat conduction capacity.
- Some areas of cutting where positive rake may prove more effective are, when cutting tough, alloyed materials that tend to work-harden, such as certain stainless steels, when cutting soft or gummy metals, or when low rigidity of work piece, tooling, machine tool, or fixture allows chatter to occur.
- The shearing action and free cutting of positive rake tools will often eliminate problems in these areas.

Negative Rake:

- To provide greater strength at the cutting edge and better heat conductivity, zero or negative rake angles are employed on carbide, ceramic, polycrystalline diamond, and polycrystalline cubic boron nitride cutting tools.
- These materials tend to be brittle, but their ability to hold their superior hardness at high temperature results in their selection for high speed and continuous machining operation.
- Negative rakes increases tool forces but this is necessary to provide added support to the cutting edge. This is particularly important in making intermittent cuts and in absorbing the impact during the initial engagement of the tool and work.
- Negative rakes are recommended on tool which does not possess good toughness (low transverse rupture strength). Thus negative rake (or small rake) causes high compression, tool force, and friction, resulting in highly deformed, hot chip.

Relief Angles:

- Relief angles are provided to minimize physical interference or rubbing contact with machined surface and the work piece.
- Relief angles are for the purpose of helping to eliminate tool breakage and to increase tool life.
- If the relief angle is too large, the cutting tool may chip or break. If the angle is too small, the tool will rub against the work piece and generate excessive heat and this will in turn, cause premature dulling of the cutting tool.
- Small relief angles are essential when machining hard and strong materials and they should be increased for the weaker and softer materials.
- A smaller angle should be used for interrupted cuts or heavy feeds, and a larger angle for semi-finish and finish cuts.

Side relief angle:

- The Side relief angle prevents the side flank of the tool from rubbing against the work when longitudinal feed is given.
- Larger feed will require greater side relief angle.

End relief angle:

- The End relief angle prevents the side flank of the tool from rubbing against the work.
- A minimum relief angle is given to provide maximum support to the tool cutting edge by increasing the lip angle.
- The front clearance angle should be increased for large diameter works.

End cutting edge angle:

- The function of end cutting edge angle is to prevent the trailing front cutting edge of the tool from rubbing against the work. A large end cutting edge angle unnecessarily weakens the tool.
- It varies from 8 to 15 degrees.

Side cutting edge angle:

The following are the advantages of increasing this angle:

- It increases tool life as, for the same depth of cut; the cutting force is distributed on a wider surface.
- It diminishes the chip thickness for the same amount of feed and permits greater cutting speed.
- It dissipates heat quickly for having wider cutting edge.
- The side cutting edge angle of the tool has practically no effect on the value of cutting force or power consumed for a given depth of cut & feed.
- Large side cutting edge angles are likely to cause the tool to chatter.

Nose radius:

The nose of a tool is slightly rounded in all turning tools.

The function of nose radius is as follows:

- Greater nose radius clears up the feed marks caused by the previous shearing action and provides better surface finish.
- All finish turning tool have greater nose radius than rough turning tools.
- It increases the strength of the cutting edge, tends to minimize the wear taking place in a sharp pointed tool with consequent increase in tool life.
- Accumulation heat is less than that in a pointed tool which permits higher cutting speeds.

Tool Designation (ASA System)

Tool Designation. The tool designation or tool signature, under ASA system is given in the order given next :

Back rake, Side rake, End relief, Side relief, End cutting edge angle, Side cutting edge angle, and nose radius that is,

$$\alpha_b - \alpha_s - \theta_e - \theta_s - C_e - C_s - R$$

If tool designation is : $8 - 14 - 6 - 6 - 6 - 15 - \frac{1}{8}$, it means that,

$\alpha_b = 8°$ $\alpha_s = 14°$

$\theta_e = 6°$ $\theta_s = 6°$

$C_e = 6°$ $C_s = 15°$ $R = \frac{1''}{8}$.

- In ASA system of tool angles. the angles are specified independently of the position of the cutting edge. therefore. does not give any indication of the behavior of the tool in practice.
- Therefore. in actual cutting operation. we should include the side cutting edge (principal cutting angle) in the scheme of reference planes. Such a system is known as Orthogonal rake system (ORS).

Tool Signature

For example a tool may designated in the following sequence:

8-14-6-6-6-15-1

1. Back rake angle α_b is 8
2. Side rake angle α_s is 14
3. End relief angle θ_e is 6
4. Side relief angle θ_s is 6
5. End cutting Edge angle C_e is 6
6. Side cutting Edge angle C_s is 15
7. Nose radius **R** is 1 mm

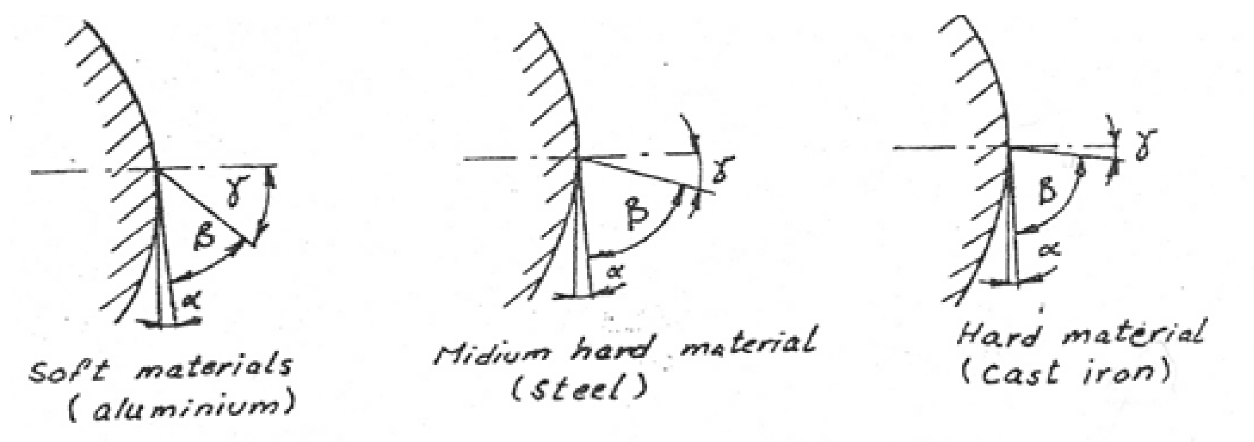
Tool Geometry

Tool	Abbreviation	Angle Recommended
Back rake	BR	12°
Side rake	SR	12°
End relief	ER	10°
Side relief	SRF	10°
End cutting edge angle	ECEA	30°
Side cutting edge angle	SCEA	15°
Nose radius	NR	$\frac{1}{32}$ in.

α Clearance angle: Is the angle included by the tool flank and a plane containing the main motion. Its purpose is to decrease the friction between the tool and the work piece

β Rake angle: Is the angle included by the tool face and a plane perpendicular to the main motion. It helps the cutting and the chip formation .

γ Wedge angle: Is the angle included by the tool face and flank. Its size depends mainly on the work piece material. If it is too big than required , the tool will need high force to penetrate the work piece. At the same time , if it is too small , it will weaken the tool and cause its rapid failure.



Cutting speed :

The cutting speed (v) is the speed at which the cutting edge travels relative to the machined surface of the work piece .

Feed rate :

The feed rate (f) is the distance advanced by the cutting tool relative to the machined surface in a direction which is usually normal to the cutting speed. Its units can be
-> mm/cycle, mm/min, mm/rev, mm/stroke or mm/tooth depending on the type of the machining operation and the tool used.

Depth of cut:

The depth of cut (t) is the normal distance from the original surface before machining to the machined surface

Cutting-Tool Materials

- Lathe toolbits generally made of five materials
  - High-speed steel
  - Cast alloys (such as stellite)
  - Cemented carbides
  - Ceramics
  - Cermets
- More exotic finding wide use
  - Borazon and polycrystalline diamond

Lathe Toolbit Properties

- Hard
- Wear-resistant
- Capable of maintaining a red hardness during machining operation
  - Red hardness: ability of cutting tool to maintain sharp cutting edge even when turns red because of high heat during cutting
- Able to withstand shock during cutting
- Shaped so edge can penetrate work

High-Speed Steel Toolbits

- May contain combinations of tungsten, chromium, vanadium, molybdenum, cobalt
- Can take heavy cuts, withstand shock and maintain sharp cutting edge under red heat
- Generally two types (general purpose)
  - Molybdenum-base (Group M)
  - Tungsten-base (Group T)
- Cobalt added if more red hardness desired

Cemented-Carbide Toolbits

- Capable of cutting speeds 3 to 4 times high-speed steel toolbits
- Low toughness but high hardness and excellent red-hardness
- Consist of tungsten carbide sintered in cobalt matrix
- Straight tungsten used to machine cast iron and nonferrous materials (crater easily)
- Different grades for different work

Coated Carbide Toolbits

- Made by depositing thin layer of wear-resistant titanium nitride, titanium carbide or aluminum oxide on cutting edge of tool
  - Fused layer increases lubricity, improves cutting edge wear resistance by 200%-500%
  - Lowers breakage resistance up to 20%
  - Provides longer life and increased cutting speeds
- Titanium-coated offer wear resistance at low speeds, ceramic coated for higher speeds

Ceramic Toolbits

- Permit higher cutting speeds, increased tool life and better surface finish than carbide
  - Weaker than carbide used in shock-free or low-shock situation
- Ceramic
  - Heat-resistant material produced without metallic bonding agent such as cobalt
  - Aluminum oxide most popular additive
  - Titanium oxide or Titanium carbide can be added

Diamond Toolbits

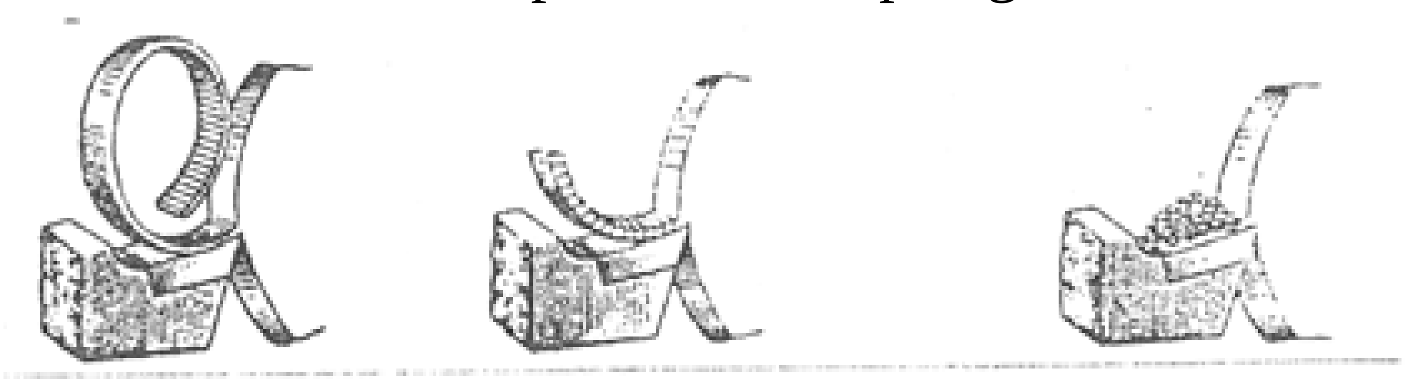
- Used mainly to machine nonferrous metals and abrasive nonmetallics
- Single-crystal natural diamonds
  - High-wear but low shock-resistant factors
- Polycrystalline diamonds
  - Tiny manufactured diamonds fused together and bonded to suitable carbide substrate

Chip Formation

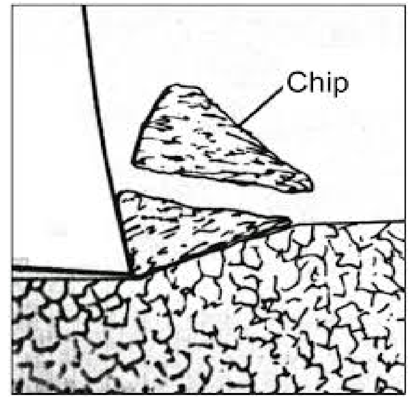
- Every convectional machining process involves the formation of chips. Chip formation is a complex phenomenon where a force is applied to work piece to remove the material from the work piece. The metal is sheared along the shear plane, which makes an angle Ø with the direction of tool travel because of shearing action.

Chip Formation

- The shape and size of the chips obtained depends on the types of the material to be cut and other cutting conditions. It also indicates the type and quality of pieces. The following three basic types of the chips are produced in any convectional machining process.
- I. Segmental or Discontinuous chip.
- II. Continuous chip.
- III. Continuous chip with built-up edge.



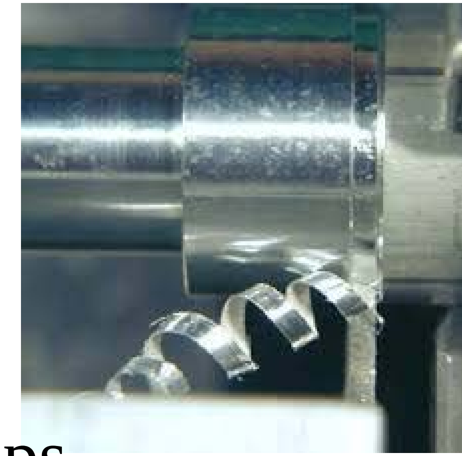
Discontinuous Chip:



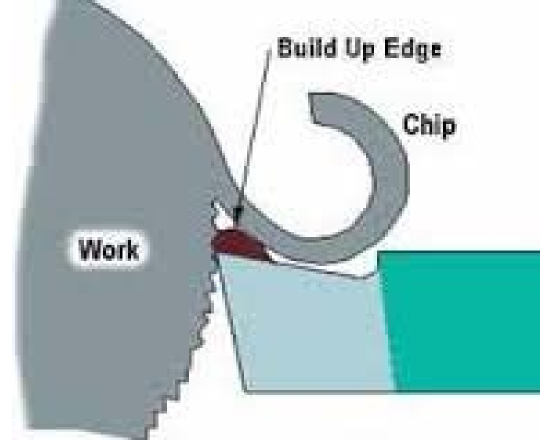
- This type of chips consist of separate, plastically deformed segments which loosely where to each other or completely unconnected. These are produced by actual fracture of the metal ahead of the cutting edge. The fracture of the metal take place when the magnitude of the compression forces reaches the fracture limits of the metal.
- Facture affecting the segmental chip:
- 1.) Brittle material (C.I., Brass, Casting etc)
- 2.) Low speed and high depth of cut. while cutting ductile material.
- 3.) Small rake angles too ductile material, segmental chips.

Continuous Chip:

- This type of chips produced when material ahead of the too continuously deforms without fracture and flows off the rake face in the form of continuous segment. The following factors are responsible for the continuous chip.
- 1. Ductile material like Steel, Copper, Aluminum etc.
- 2. High cutting speed.
- 3. Large rake angle.
- 4. Sharp cutting edge.
- 5. Efficient cutting fluid.
- 6. Low friction between tool face & chips.



Continuous chip with Built Up Edge:



- This type of chip is similar to continuous chip except that a built up edge is formed on the nose of the tool. The built of edge is formed owing to the action of welding of chips material on the tool point because of high friction between work material with tool. These types of chips are undesirable because, they result in higher power consumption, poor surface finish, high tool wear and reduction in tool life.

Chip Breakers

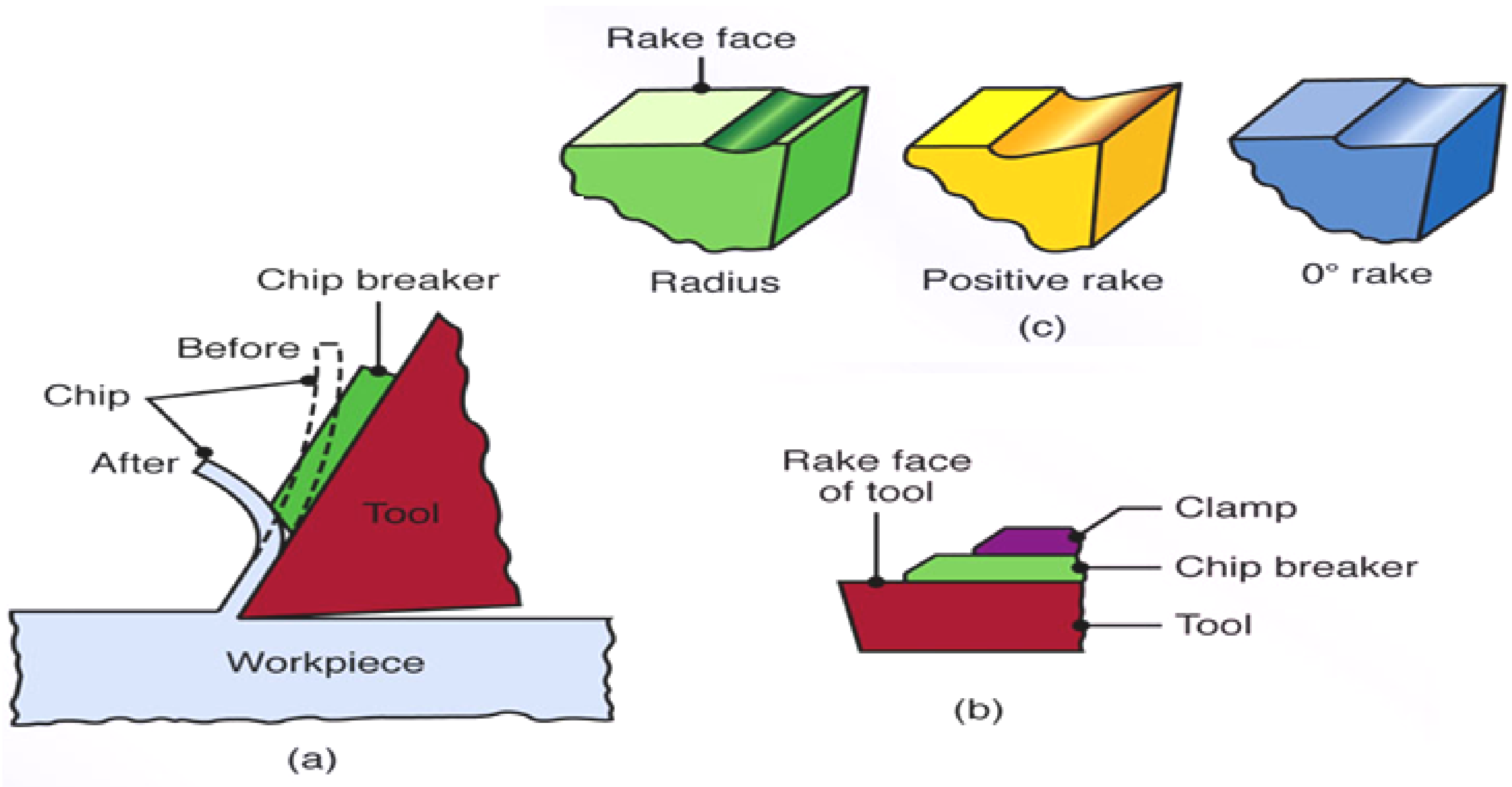


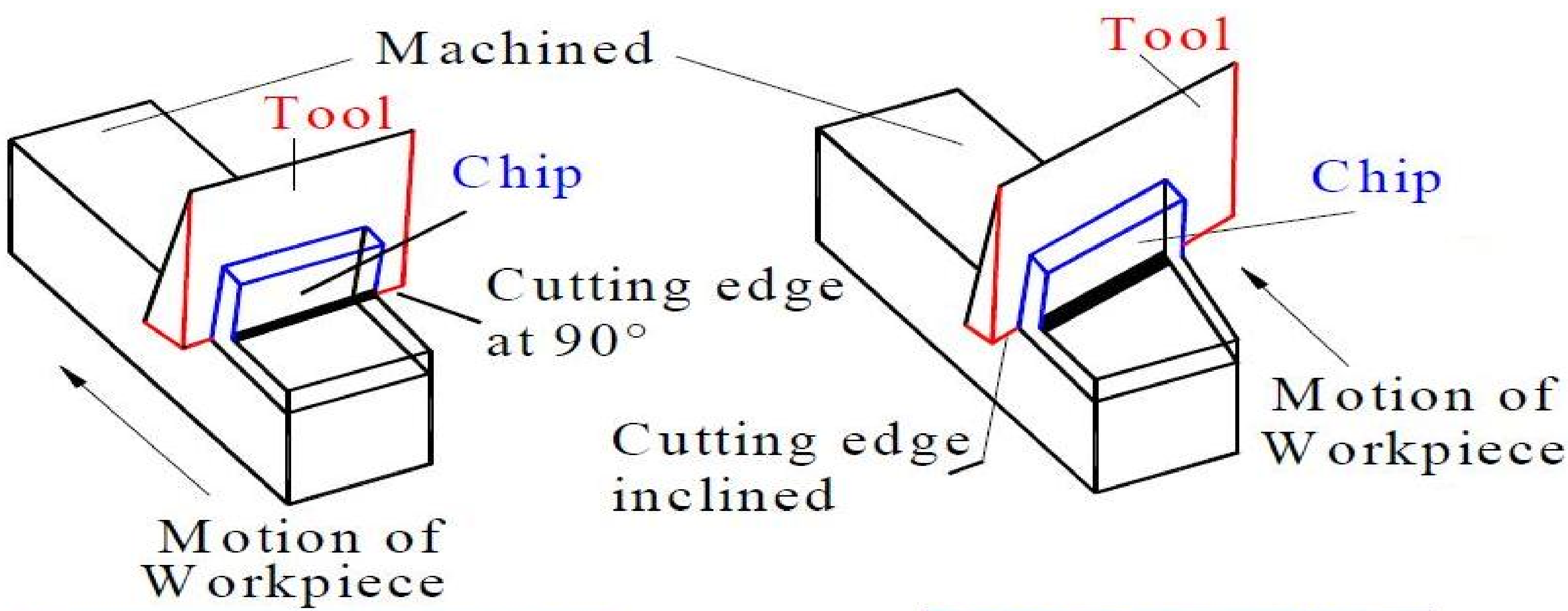
Figure: (a) Schematic illustration of the action of a chip breaker. Note that the chip breaker decreases the radius of curvature of the chip and eventually breaks it.

(b) Chip breaker clamped on the rake face of a cutting tool.

(c) Grooves in cutting tools acting as chip breakers. Most cutting tools used now are *inserts* with built-in chip breaker features.

Orthogonal and Oblique Cutting

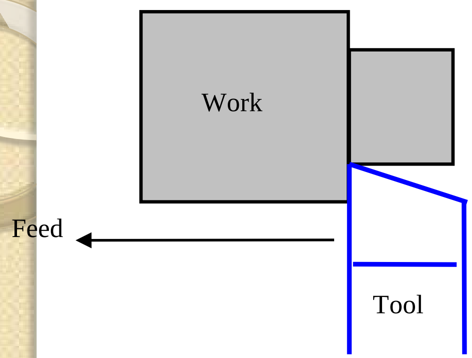
The two basic methods of metal cutting using a single point tool are the orthogonal (2D) and oblique (3D). Orthogonal cutting takes place when the cutting face of the tool is 90^0 to the line of action of the tool. If the cutting face is inclined at an angle less than 90^0 to the line of action of the tool, the cutting action is known as oblique.



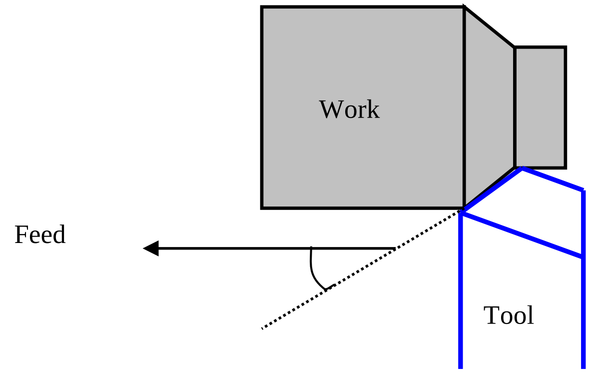
Orthogonal cutting

Oblique cutting

Orthogonal and Oblique Cutting



Orthogonal cutting



Oblique cutting

Orthogonal Cutting:

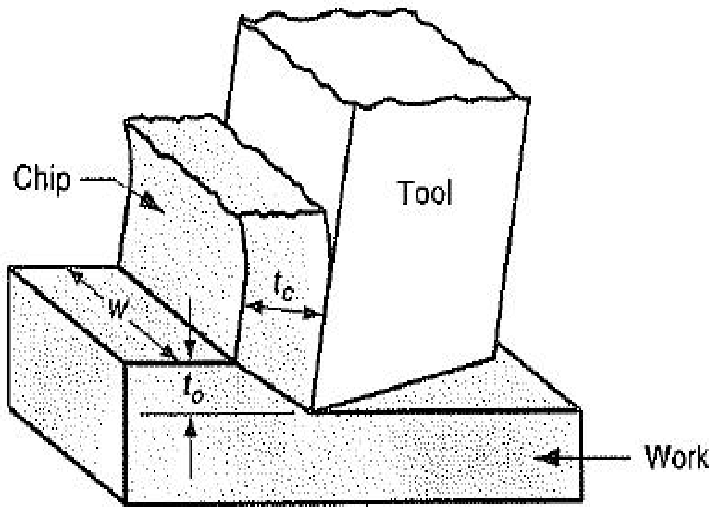
- The cutting edge of the tool remains normal to the direction of tool feed or work feed.
- The direction of the chip flow velocity is normal to the cutting edge of the tool.
- Here only two components of forces are acting: Cutting Force and Thrust Force. So the metal cutting may be considered as a two dimensional cutting.

Oblique Cutting:

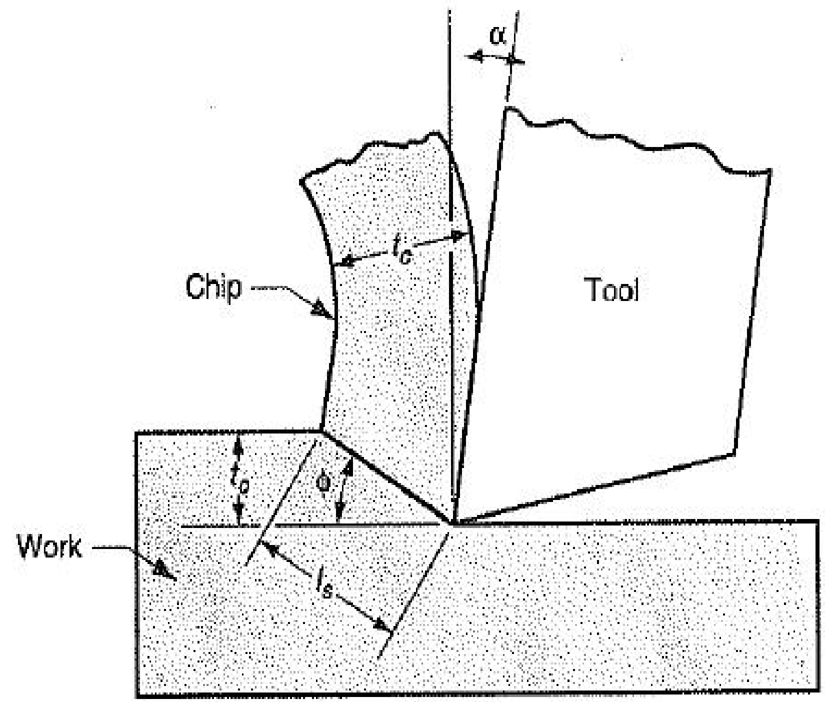
- The cutting edge of the tool remains inclined at an acute angle to the direction of tool feed or work feed.
- The direction of the chip flow velocity is at an angle with the normal to the cutting edge of the tool. The angle is known as chip flow angle.
- Here three components of forces are acting: Cutting Force, Radial force and Thrust Force or feed force. So the metal cutting may be considered as a three dimensional cutting.
- The cutting edge being oblique, the shear force acts on a larger area and thus tool life is increased.

Orthogonal Cutting Model

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



(a)



(b)

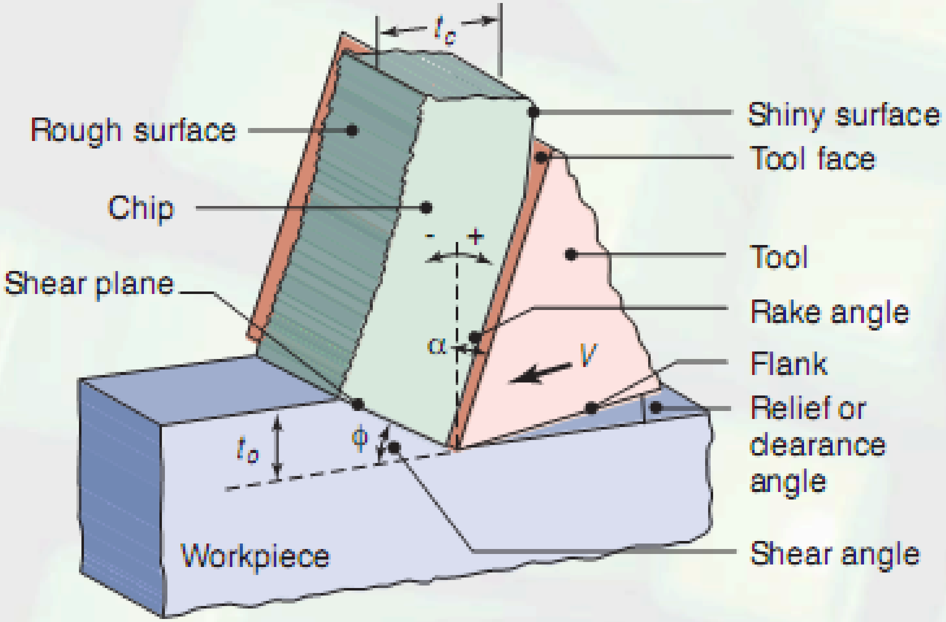
FIGURE Orthogonal cutting: (a) as a three-dimensional process, and

(b) how it reduces to two dimensions in the side view.

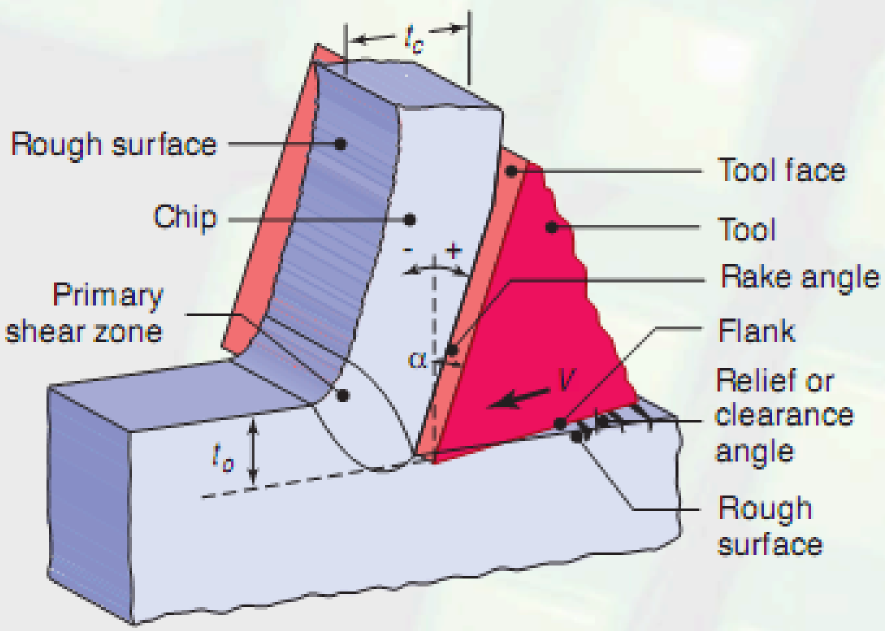
Assumptions in Orthogonal Cutting

- No contact at the flank i.e. the tool is perfectly sharp.
- No side flow of chips i.e. width of the chips remains constant.
- Uniform cutting velocity.
- A continuous chip is produced with no built up edge.
- The chip is considered to be held in equilibrium by the action of the two equal and opposite resultant forces R and R’ and assume that the resultant is collinear.

Two-Dimensional Cutting Process



(a)



(b)

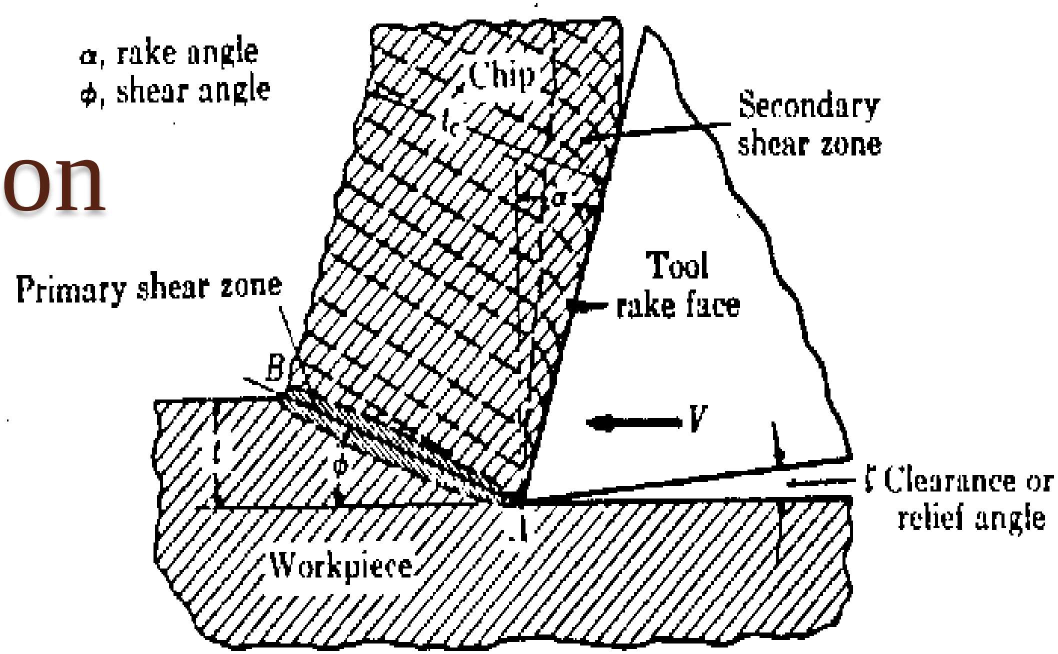
Fig: Schematic illustration of a 2-d cutting process, also called orthogonal cutting:

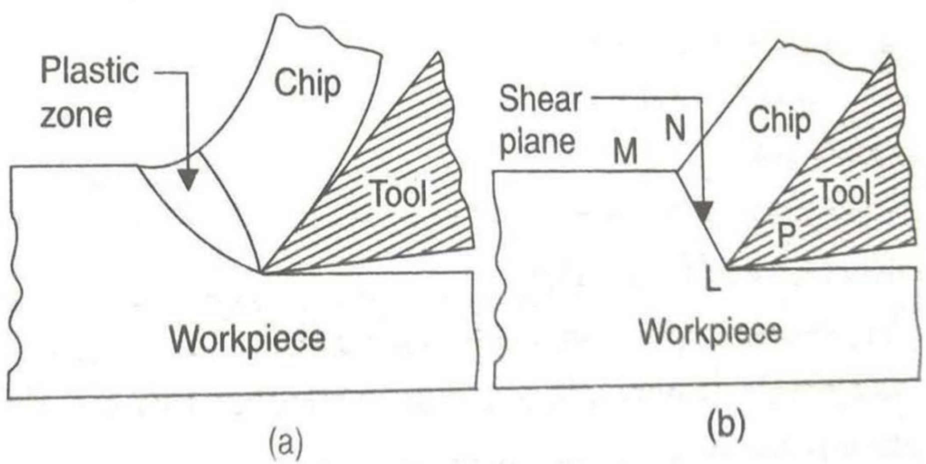
(a) Orthogonal cutting with a well defined shear plane, also known as the Merchant Model.

(b) Orthogonal cutting without a well-defined shear plane.

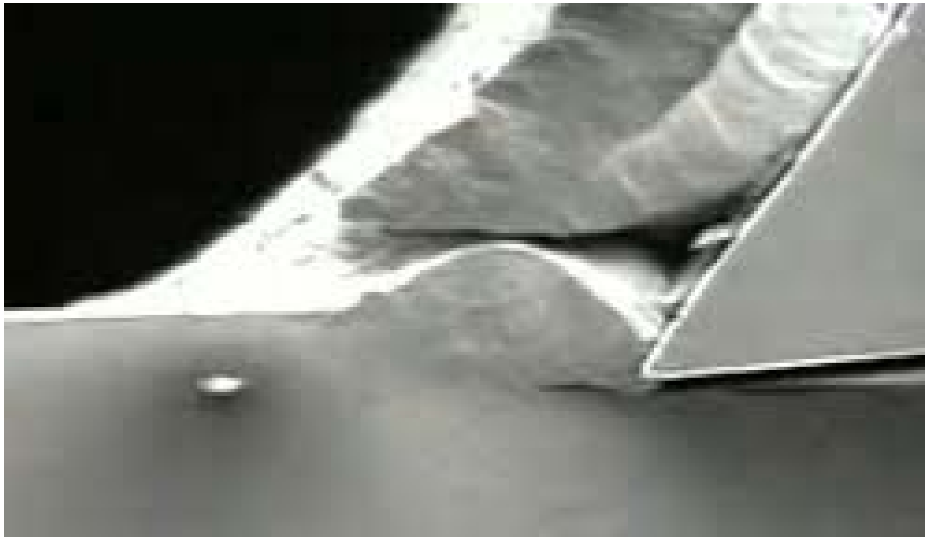
Note that the tool shape, depth of cut, t_o, and the cutting speed, V, are all independent variables.

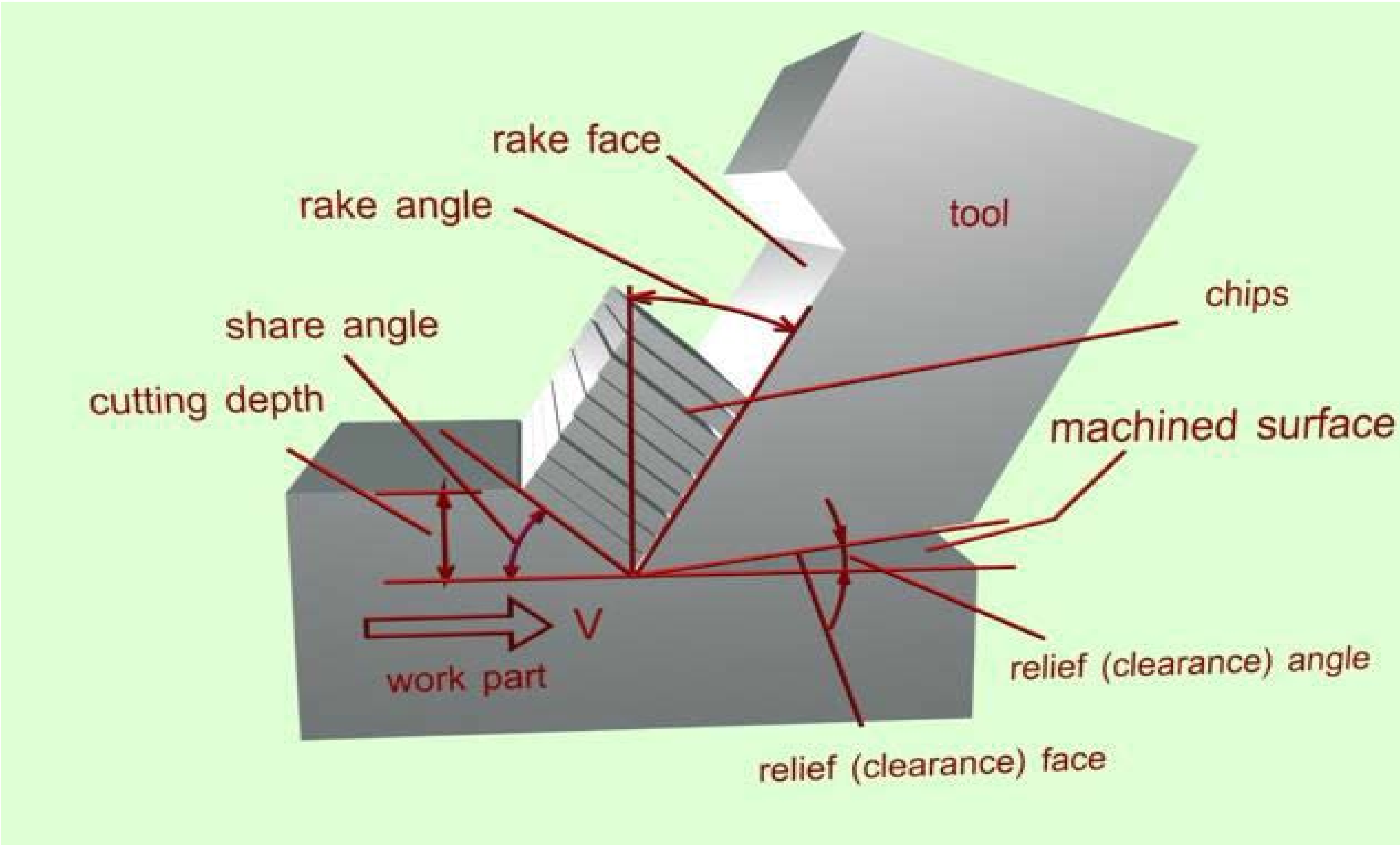
Chip Formation

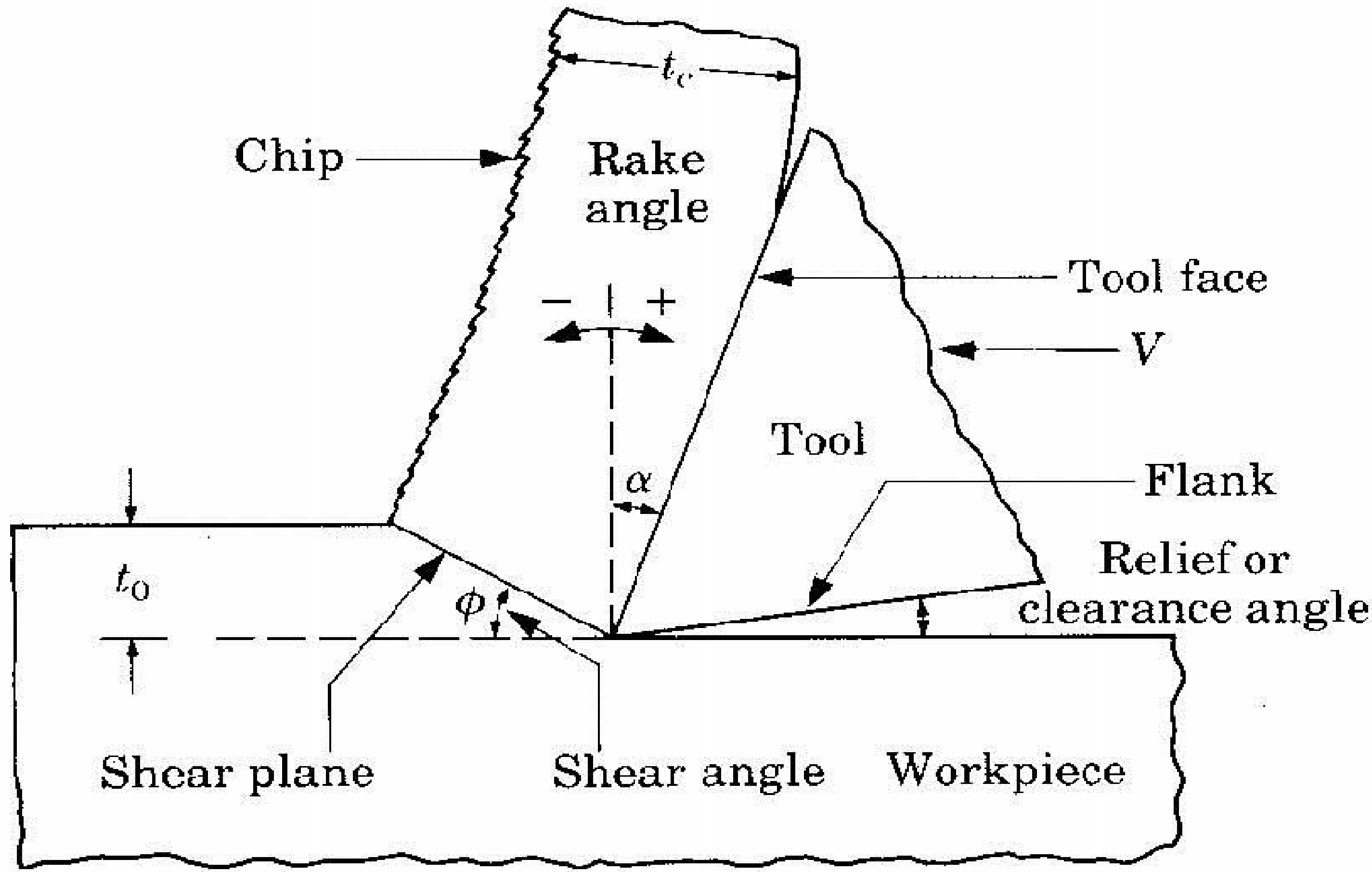




Chip formation.

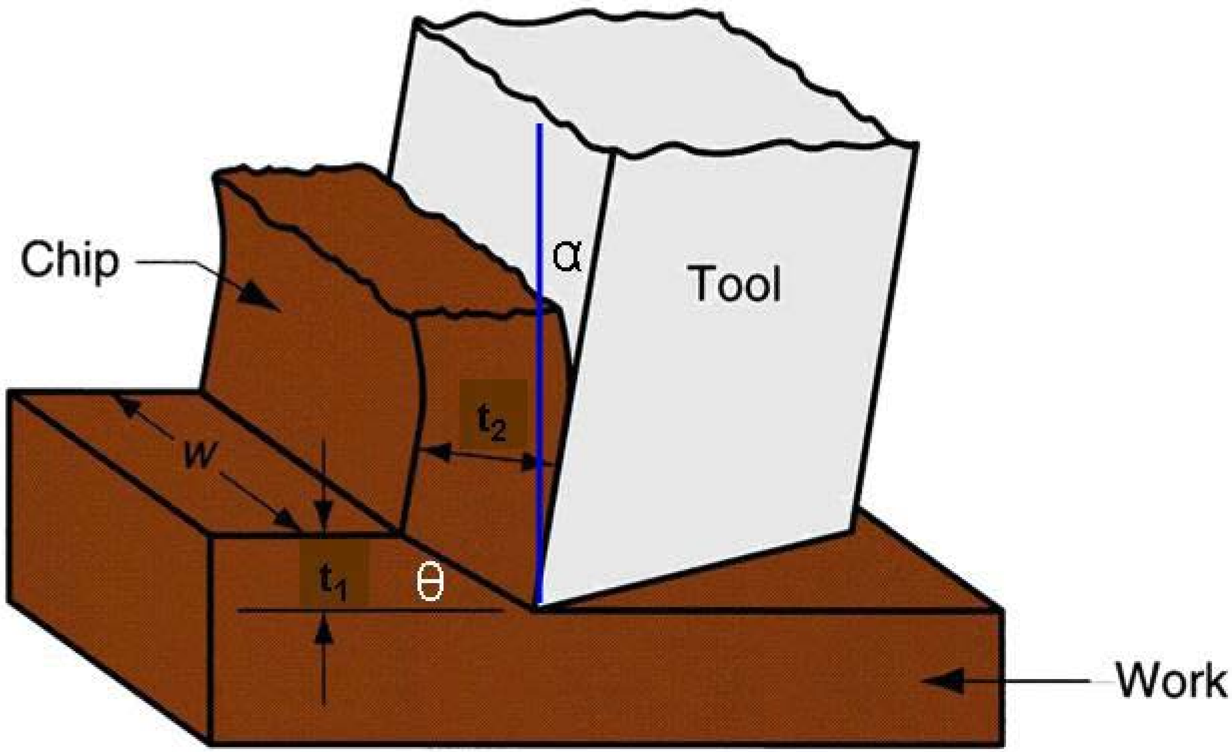



rake face
rake angle
tool
chips
share angle
cutting depth
machined surface
V
work part
relief (clearance) angle
relief (clearance) face


t_c
Chip
Rake
angle
Tool face
V
Tool
Flank
α
Relief or
clearance angle
t_0
φ
Shear plane
Shear angle
Workpiece

Orthogonal cutting model:

- t1 = un deformed chip thickness
- t2 = deformed chip thickness (usually t2 > t1)
- α = rake angle
- If we are using a lathe, t1 is the feed per revolution.



Chip thickness ratio (or) cutting ratio

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

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