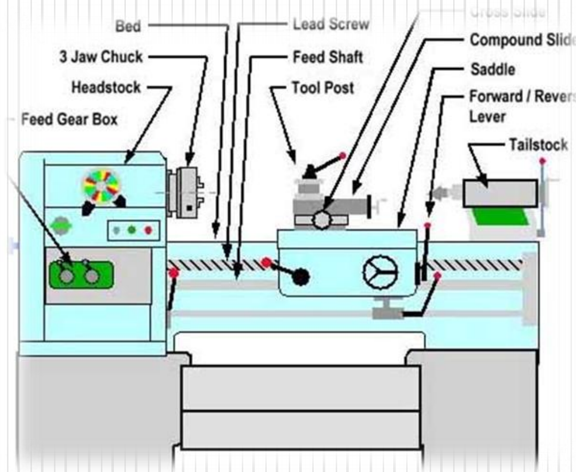
Workshop Practice
TA 102
Lec – 6 & 7 :Theory of Metal Cutting



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Theory of Metal cutting

- **INTRODUCTION:**

The process of manufacturing a component by removing the unwanted material using a machine is known as Machining and when used with metals it is referred to as metal machining or metal cutting.

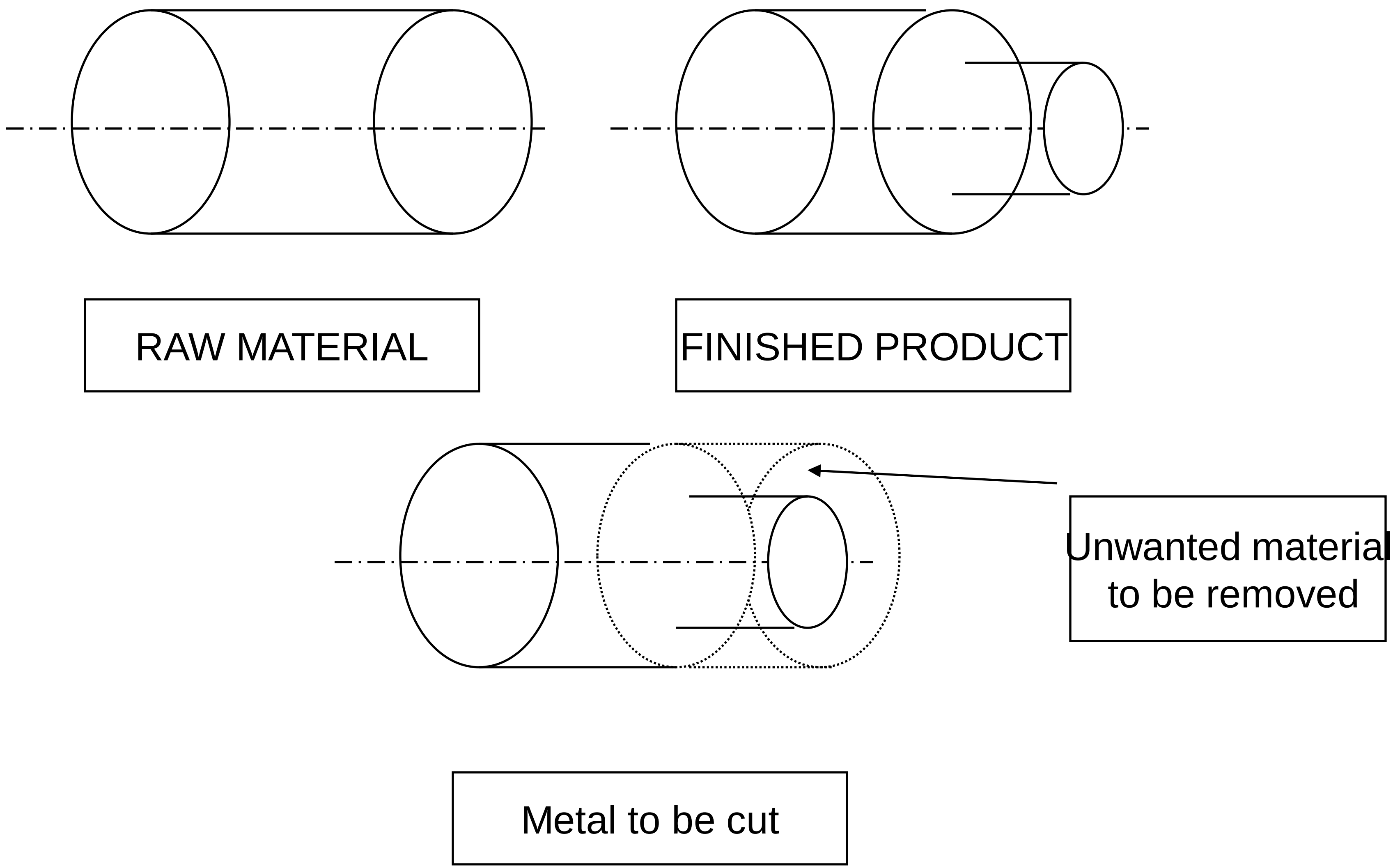
The raw material which is subjected to the process of machining is called work piece or stock.

The unwanted material removed from the raw material to give it the required shape is known as the chip or scrap.

The device used to cut the material is known as cutting tool or simply tool.

" a machine tool is a power driven machine that shapes metals to produce component"

Getting desired shape by metal cutting (machining process)



The metal cutting process (machining) consists of removing a layer of metal from the work piece. The required shape and dimensions of the part with the specified surface finish are obtained by repetitively removing layers of the material from the work piece.

Machining process is necessary for the following reasons

1. Closer dimensional accuracy may be required than is available from casting, forming, or other shaping processes.
2. Some parts are heat treated to improve hardness and wear resistance. Since heat treated parts may undergo distortion, they generally require additional finishing operations, such as grinding, to obtain the desired final dimensions and surface finish.

3. Special surface characteristics or texture which cannot be produced by other means may be required on all or parts of the surfaces of the product. Machining with a diamond cutting tool, for example, makes copper mirrors with very high reflectivity.
4. Machining a part may be economical than manufacturing it by other methods of manufacturing, especially, if the required quantity is small.
5. Shape and/or size of a component may not be suitable for economic production by other methods.

Machine Tools

machine tools are the kind of machines on which the metal cutting or metal forming processes are carried out.

The functions of machine Tool are

- Holding the work piece
- Holding the tool
- Moving the tool or the work piece or both relative to each other and
- Supply energy required to cause the metal cutting

Machine Tools

A machine is a device, which converts some form of input in to output.

A machine tool imparts the required shape to the work piece with the desired accuracy by removing the metal from the work piece in the form of chips.

All machine tools that we use in manufacturing can be broadly classified in to:

1. Metal cutting machine tools
2. Metal forming machine tools

Machine Tools

Machine tools can be classified in to different categories based upon several criteria. some of these are as follows:

Degree of specialization

1. General purpose machine tool like lathe, shaper, milling machine.
2. Special purpose machine tools like gear-cutting (hobbing) machines.

Type of surface produced

1. Cylindrical surface producing machine tools like lathe, drilling machine.
2. Flat surface producing machine tools like milling machine, shaper.

Machine Tools

Type of motion

1. Reciprocating type of machine tools like shaper, planer, slotter.
2. Rotary type of machine tools like lathe, drilling machine, grinding machine.

Degree of Automation

1. Manual control machine tools.
2. Semi – automatic machine tools
3. Automatic machine tools

Duty cycle

1. Light duty machine tools
2. Medium duty machine tools
3. Heavy duty machine tools

Machine Tools

Type of energy used

1. Conventional machine tools that use mechanical energy e.g., lathe, drilling machine, milling machine, shaper.
2. Non-conventional machine tools which may use chemical, electro – discharge energy etc.,

Cutting Tools

Cutting tool is a device used to remove the unwanted material from a given work piece.

1. What is the mechanism of metal cutting and what properties a cutting tool material should possess?
2. What should be its geometry (size, shape and angles) for efficient cutting?
3. How cutting tools are classified ?

Mechanism of metal cutting

Essential Properties of cutting tool are :

- Hard and tough
- Strong
- Heat resistance to maintain hardness at high temperature and
- Wear resistance to prevent fast wear of cutting edge.

TOOL MATERIAL

The performance of a cutting tool material in given machining application is mainly determined by properties such as wear resistance, hot hardness and toughness.

To cater to the need of industry e.g., higher rates of production, good surface finish, close tolerances, etc various tool materials have been developed

TOOL MATERIAL

- Tool steel
- HSS (High speed steel)
- Carbides
- Abrasives
- Diamond
- CBN Cubic Boron Nitride
- Ucon
- Ceramics
- Tipped tools
- Coated tools

Tool steel (TS)

Carbon steel or carbon tools steel is the kind of steels having carbon percentage ranging from **0.8 – 1.5%.**

Tools made from carbon steels can be easily hardened and used for cutting ferrous and non-ferrous metals.

Disadvantages of carbon steel are its less hot hardness (ability of a material to withstand high temperatures) and poor wear resistance. They loose their hardness at around 200 – 250^{0}C Operate at low cutting speeds.

Effect of alloying element on steel

Alloying Element	Effect of alloying element
Mn	**Improves machining ability and such type of steels are known as free coating steels**
Ni	**Improves strength, toughness and resistance to corrosion**
Cr	**Improves strength, toughness and resistance to corrosion**
P	**Causes brittleness and its presence is undesirable**
S	**Reduce hot hardness and its presence is undesirable**
Si	**Makes the steel tough and harder**

High Speed Steel (HSS)

- Alloying steel with tungsten, chromium, molybdenum, etc produce alloy steel known as High speed steel (HSS).
- It can retain hardness up to 600^0C
- It can operate at cutting speeds 2-3 times greater than that of carbon steels.
- HSS can be classified in to three types based on alloying elements and their percentage.

18-4-1 HSS

- This alloy steel contains 18% tungsten, 4% chromium and 1% vanadium.
- This type of steel provides good hot hardness and form stability.
- This type of steel is also known as tungsten based HSS.

8-4-1 HSS

- This alloy steel contains 8% Molybdenum, 4% chromium and 1% vanadium..
- It has excellent toughness and cutting ability.
- This type of steel is also known as Molybdenum based HSS.

Cobalt based HSS

- This steel contains 2-15% cobalt to increase the hot hardness and wear resistance.
- It can operate at very high speeds.
- This steel is also known as super high- speed steel.

Effect of alloying element on HSS

Alloying Element	Effect of alloying element
Tungsten	Increases hot hardness, wear resistance and form stability
Molybdenum	Increases hot hardness, maintains keenness of cutting edge
Vanadium	Increases wear resistance
Cobalt	Increases wear resistance and hot hardness

Carbides

- The basic ingredient of most carbides is tungsten carbide
- Carbides suitable for steel machining consists of 82% tungsten carbide, 10% titanium carbide and 8% cobalt
- Carbides have high hardness over a wide range of temperatures and have relatively high thermal conductivity.

Abrasives

- Abrasives are mainly used for machining harder material and/or where a superior finish is required.
- Abrasive particles are used in the manufacture of grinding wheels.

Diamond

- It is the hardest known material and can be used at cutting speeds about 50 times those used for HSS
- Under proper conditions, diamond can machine 10,000 – 50,000 pieces or some times even 1,00,000 pieces in a single setup where as carbides can machine only 300 – 400 pieces before requiring a re-sharpening or replacement.
- Diamond perform well at highest possible speeds, low feeds and low depth of cut.

Cubic boron nitride (CBN)

- Diamond being a form of carbon is not thermally very stable and at high temperature readily reacts with iron.

Cubic boron nitride has been developed as an alternative to diamond, for machining ferrous materials.

- CBN is the second hardest material known and has red hardness up to 1000^0C

Ucon

- Ucon is an alloy of 50% columbium, 30 % titanium, and 20% tungsten.
- It has excellent thermal shock resistance, high hardness and toughness.
- It gives 3-5 times more tool life than conventional carbides.

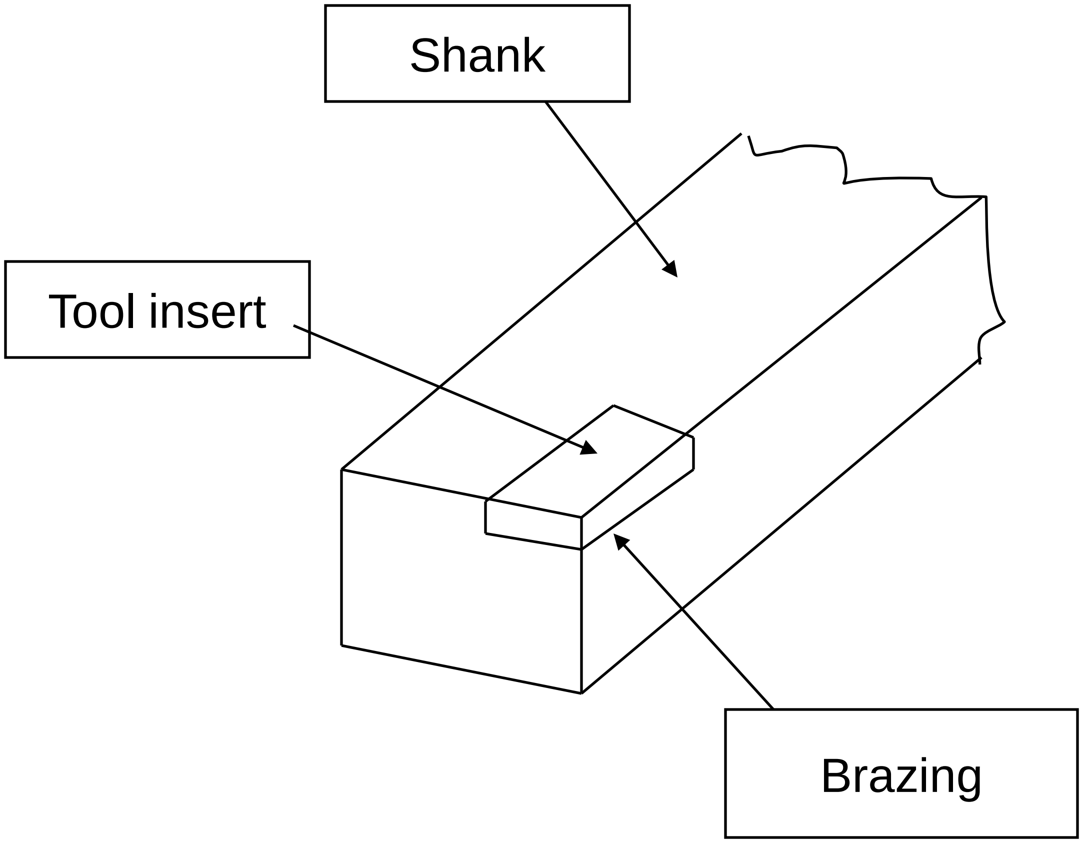
Ceramics

- It is an inexpensive tool material and in many cases, they are efficient substitutes for cemented carbides.
- Their main constituent is aluminium oxide.
- Ceramic tool can cut almost any metal and withstand high heat, but they are very brittle and will not take shock.
- Ceramic tools can give extremely fine finishes to the surface of a material.
- The red hardness of ceramic tool is of the order of 1200^0C.

Tipped Tools

- In case of alloy steel and HSS, the tool is made as one piece. In the case of carbides, CBN and diamond , the tool is not made as single piece owing to increased cost, non availability and difficulty of manufacturing. In these cases, only the cutting edges of the tool are made from these materials and are brazed or clamped to the tool shank.

A tipped tool with tool insert Brazed



Coated Tools

- The performance of HSS tools can be improved by giving coating of carbides over cutting edges .
- Giving a very thin coating of 5-7μm thickness of a carbide material can improve the wear resistance, hardness, hot hardness etc.,
- Coating material used for HSS include titanium, carbide, titanium nitride and so on.

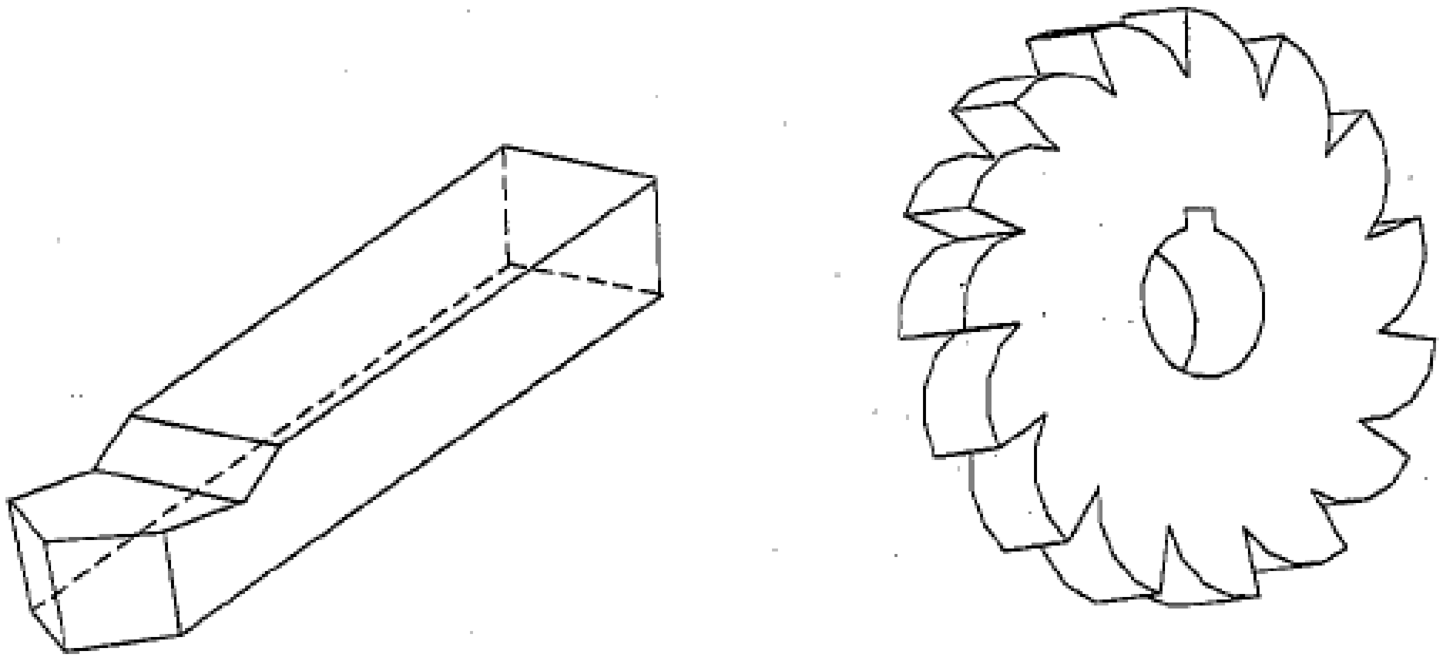
Types of Tools

All the cutting tools used in metal cutting can be broadly classified in to two categories

1. Single point cutting tool
2. Multi point cutting tool

A single point tool has only one cutting edge. These types of tools are used in lathes, shapers and planers.

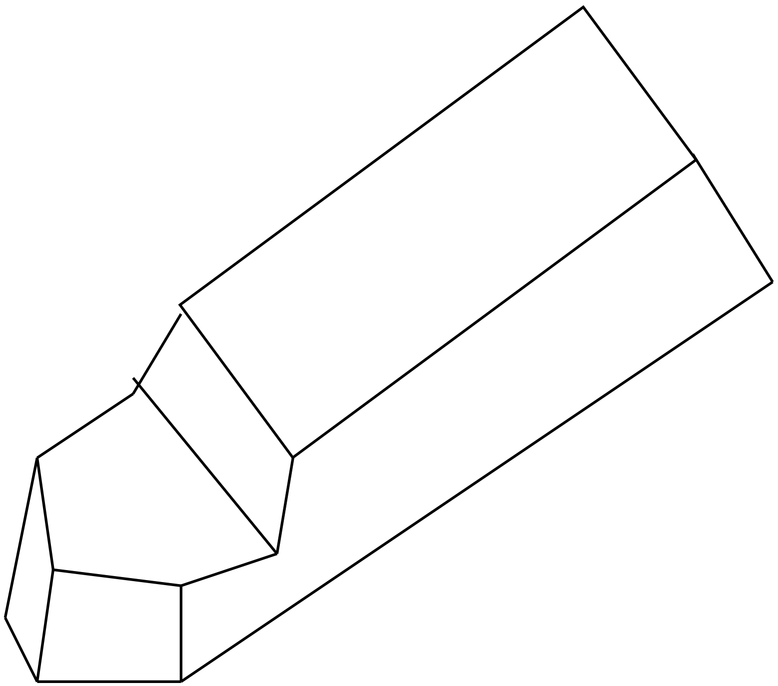
Types of Tools



(a) A single point tool (b) A multipoint tool

Two types of cutting tools.

Types of Tools



single point tool

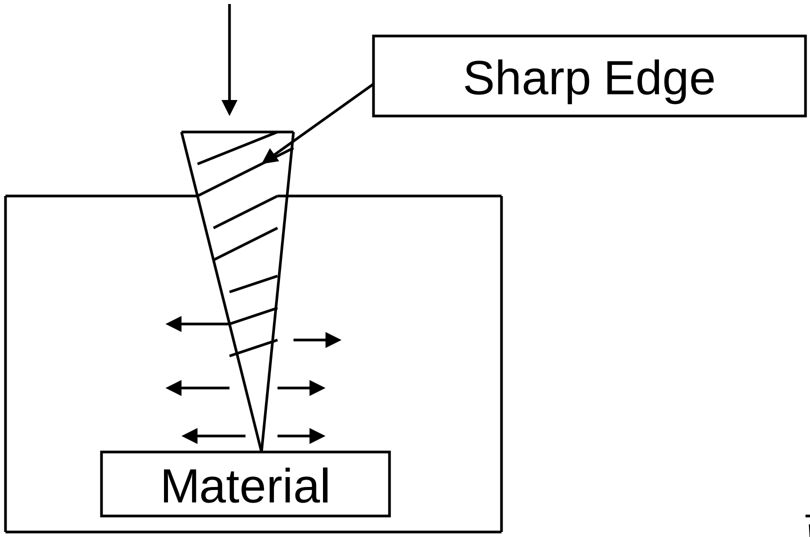
Types of Tools

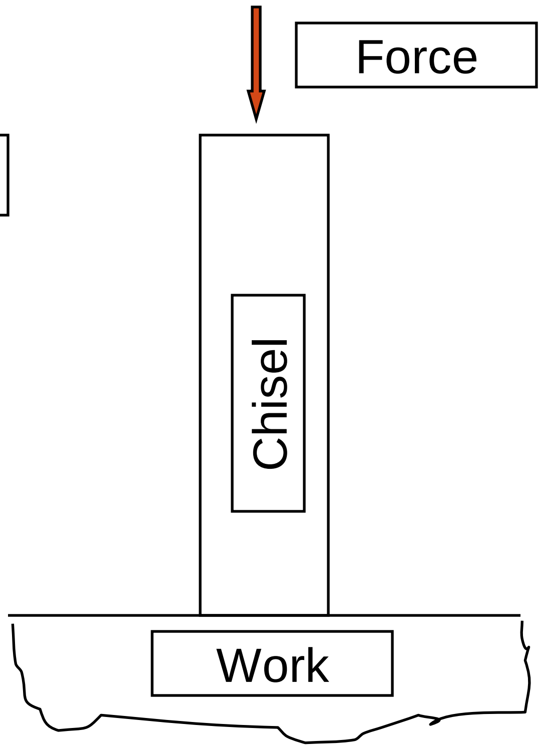
A multi point cutting tools have more than one cutting edge.
Example include milling cutter, drills, reamers.

Multi point cutting Tool

Tool Geometry

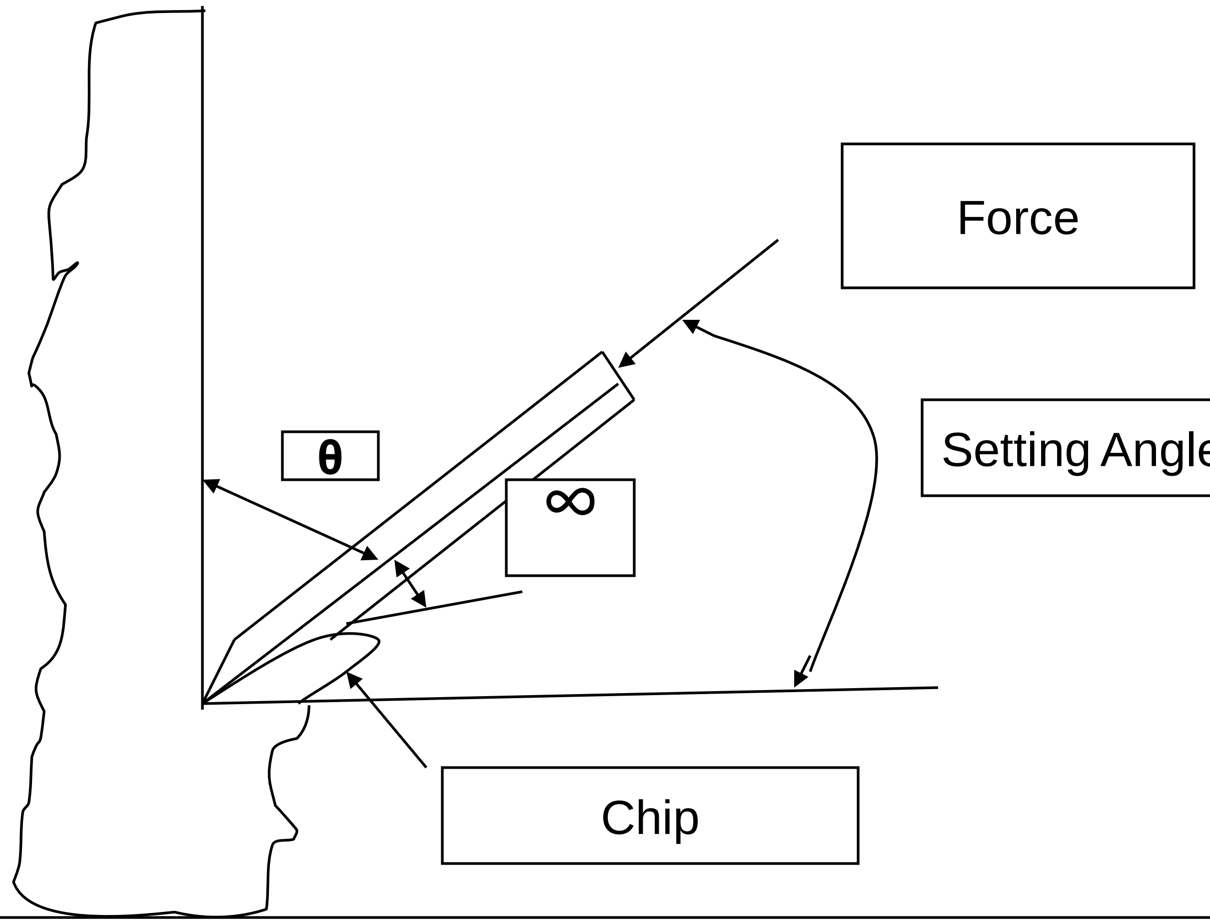
The tool geometry implies the size and shape of the tool.





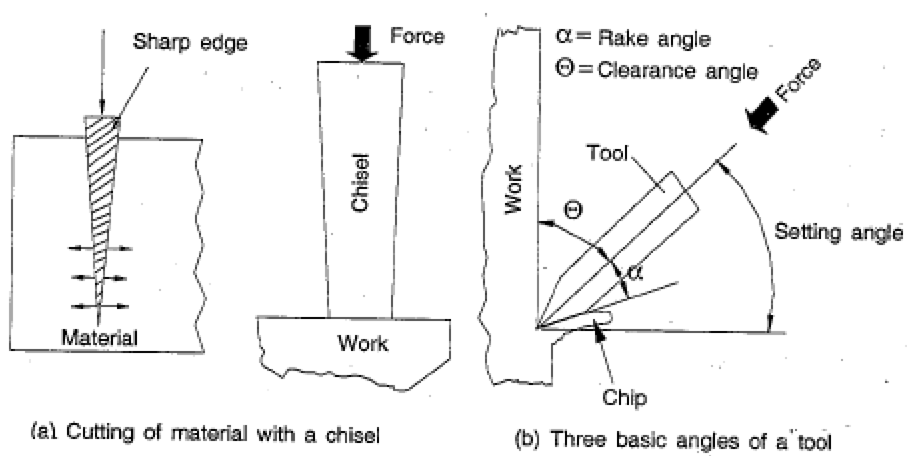
Cutting of material with a Chisel

Three Basic angles of a tool

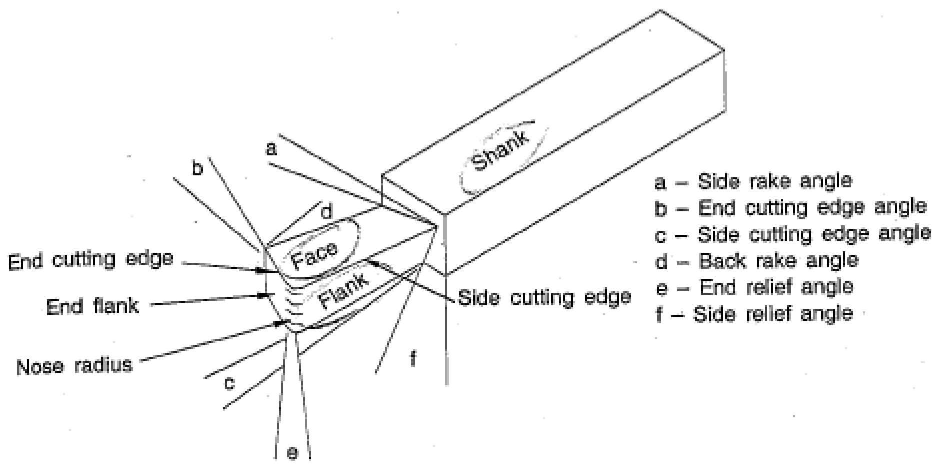


∞ = Rake Angle

Θ = Clearance angle

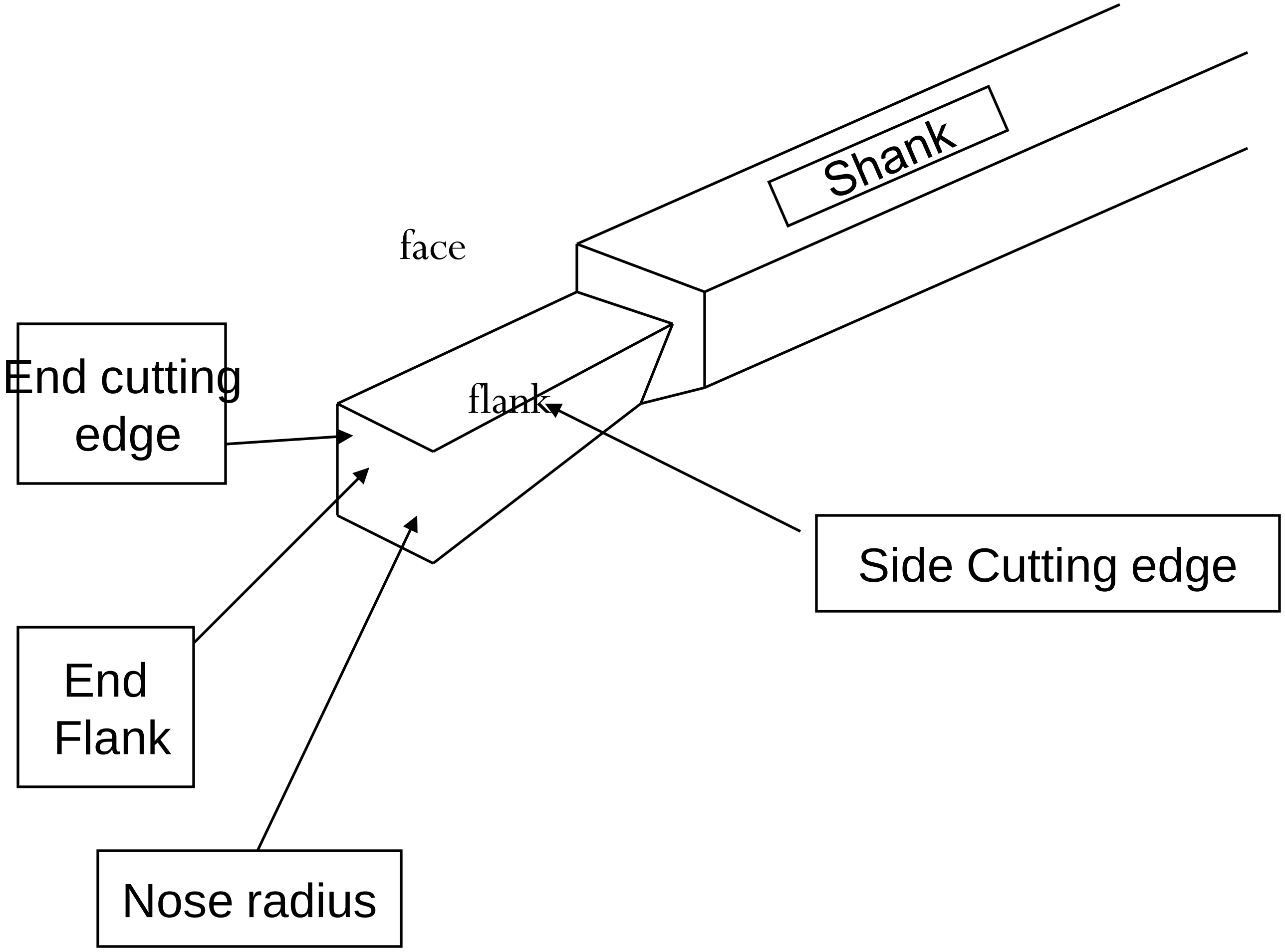


Basic metal cutting and cutting tool geometry.

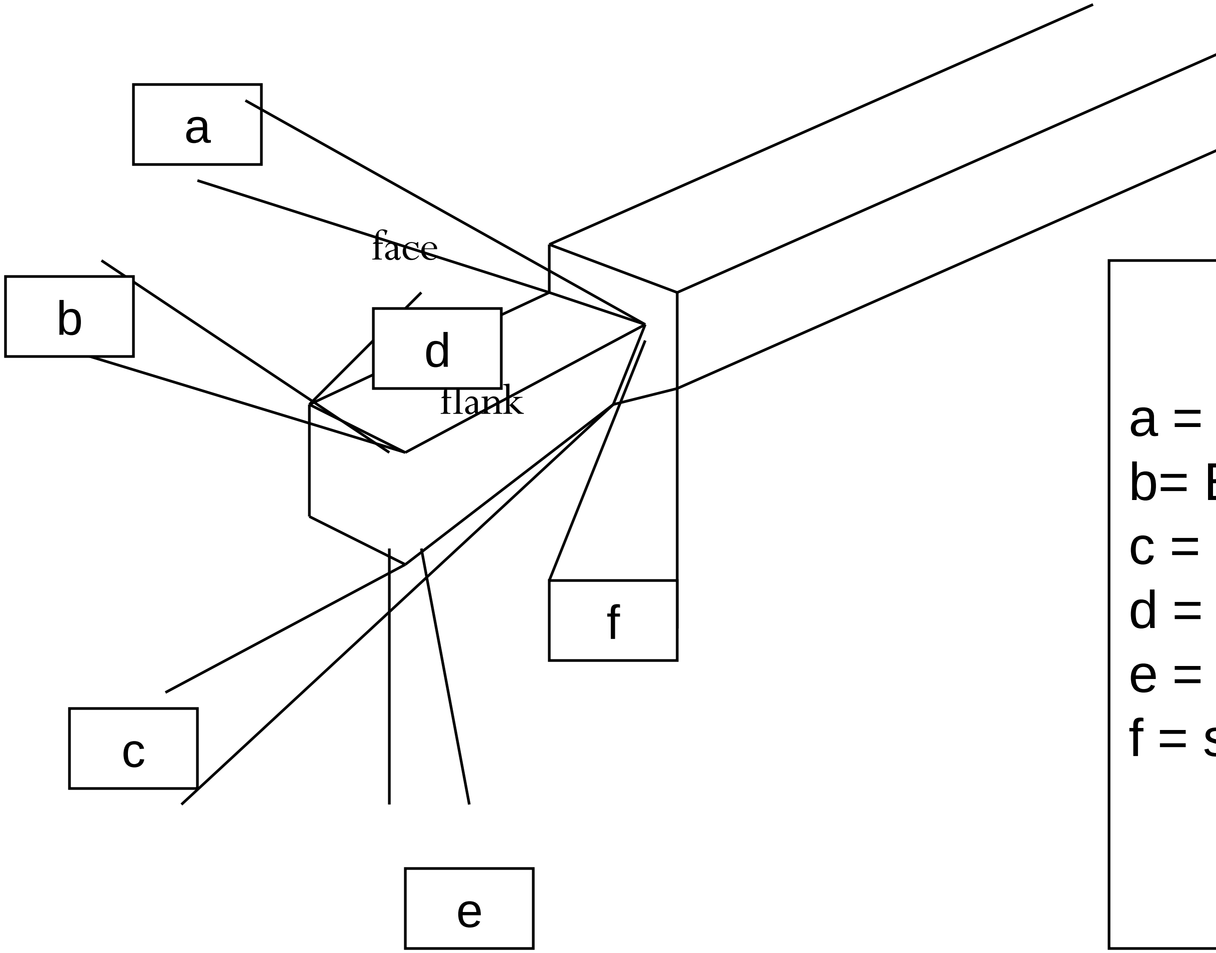


Geometry of single-point turning tool.

Geometry of Single –Point Tool



Geometry of Single –Point Tool



a = side rake angle
b= End cutting edge angle
c = side cutting edge angle
d = Back rake angle
e = End relief angle
f = side relief angle

Single point cutting Tool

- A single point cutting tool consists of a neck which is known as operating end, and the shank or body.
- Shank is used to hold the tool in the tool

post or tool holder.

- The tool neck has the following elements:

Face, Flank, Cutting edges and nose.

Face: it is the surface on which the chip impinges and along which it flows as it is separated from the work.

Flanks: the flanks are two surfaces of the tool facing the work. They are called the side or main flank and the end or auxiliary flank.

Cutting Edge: they are formed by intersections of the face and the flanks. They are called the side or main cutting edge and end cutting edge.

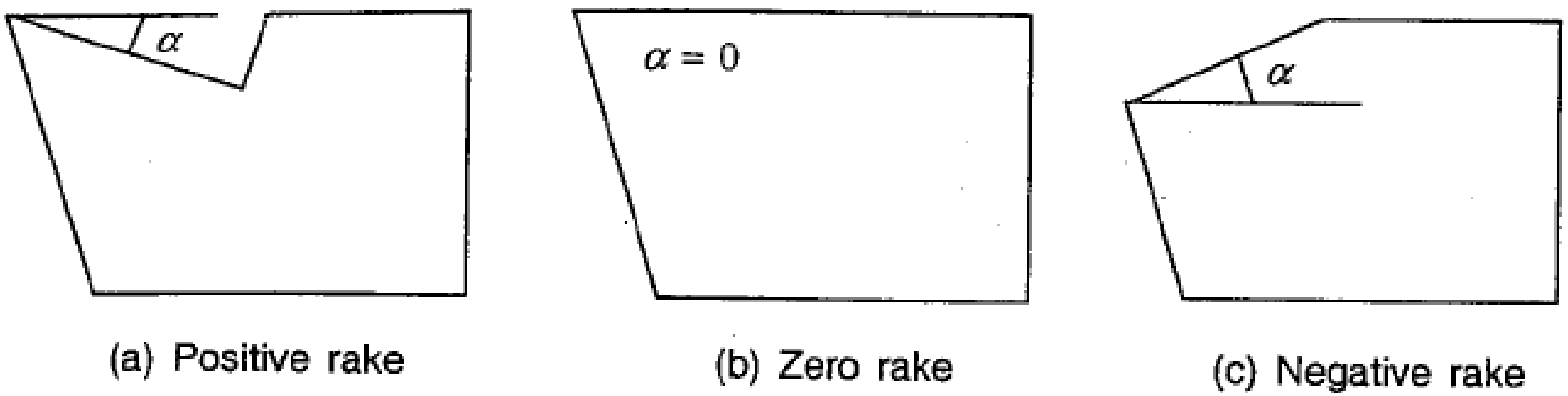
Nose: The nose is the element formed at the junction of the side and end cutting edges. This junction or the nose has a curve of small radius, known as nose radius.

Cutting Tool Angles

Back Rake Angle:

Commonly called as rake angle, is the angle between the face of the cutting tool and the normal to the machined surface at the cutting edge.

Rake angle may be +ve, zero or –ve.



Positive, zero and negative rake angles on a tool.

Cutting Tool Angles

- Side rake angle

it is the angle between the tool face and a line parallel to the base of the tool and is measured in a plane perpendicular to the base and the side cutting edge. This angle gives the slope of the face of the tool from the cutting edge.

Relief angle:

it is the angle between the flank of the cutting tool and the tangent to the machined surface of the cutting edge. The relief angle enables the flank of cutting tool to clear the work piece surface and prevent rubbing.

Cutting Tool Angles

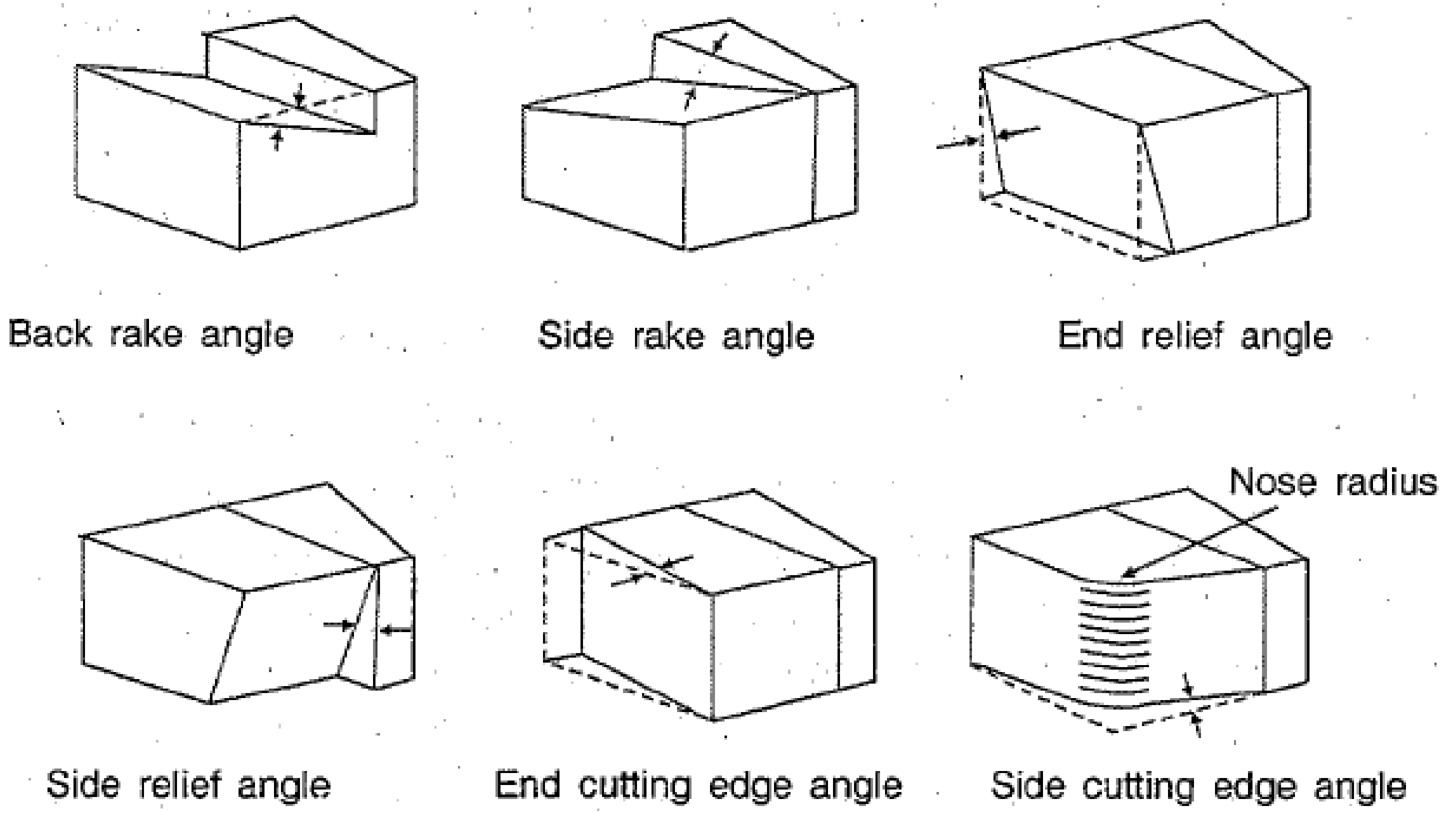


Figure 4.8 Different cutting angles of single-point tool.

Cutting Tool Angles

- Side cutting edge angle:

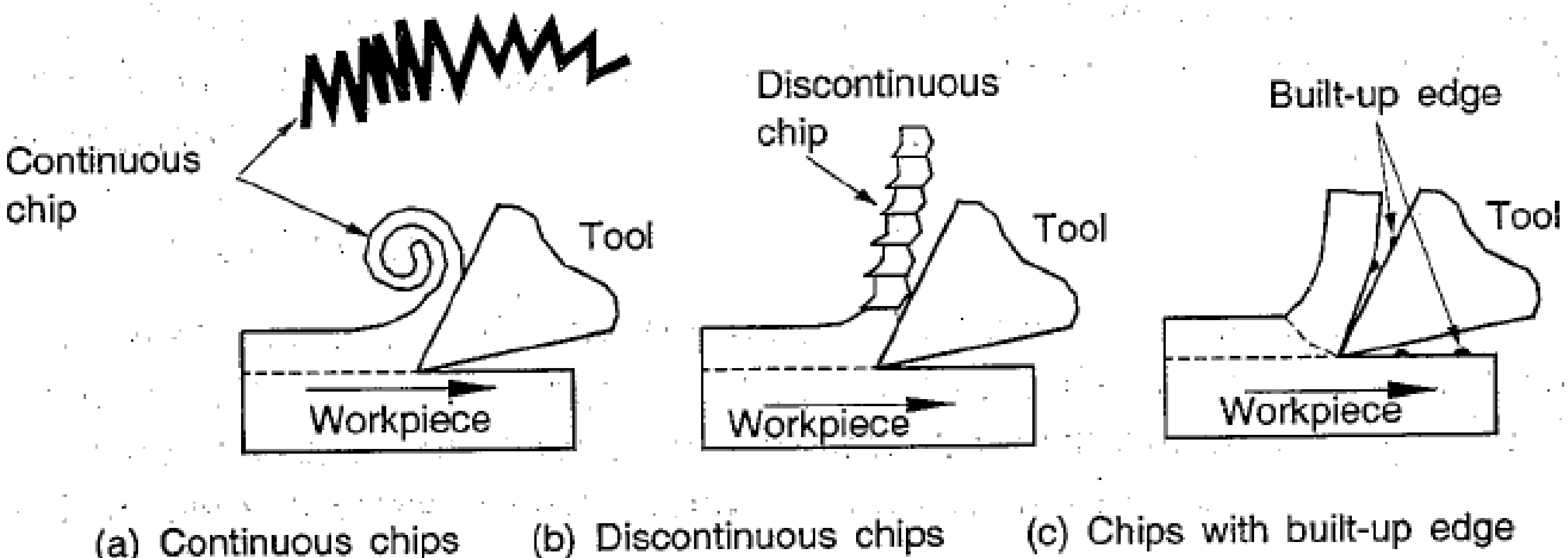
  angle formed by the side cutting edge with normal to machined surface. it is essential for enabling the cutting tool at the start of cut to first contact the work back from the tool tip.

End cutting edge angle:

the angle formed by the end cutting edge with the machined surface. It provides a clearance for that portion of the cutting edge, which is behind the nose radius.this reduces the length of cutting edge in contact with the work.

TYPES OF CHIPS

1. DISCONTINUOUS OR SEGMENTAL CHIPS
2. CONTINUOUS CHIPS
3. CONTINUOUS CHIPS WITH BUILTUP EDGE



Three common types of chips.

CONTINUOUS CHIPS

- continuous chips are formed while machining ductile material like mild steel.
- a continuous chip comes from the cutting edge of a cutting tool as single one piece, and it will remain as one piece unless purposefully broken.
- it will remain as one piece unless purposefully broken. it is done by using chip breakers.

CONTINUOUS CHIPS WITH BUILTUP EDGE

- during cutting operation, the temperature rises and as hot chip passes over the face of the tool, alloying and welding action take place due to high pressure, which results in builtup edge. it forms false cutting edge. it gives rough surface.
- the presence of builtup edge is undesirable.

DISCONTINUOUS OR SEGMENTAL CHIPS

- in discontinuous or segmental chips, the chip is produced in the form of small pieces. these type of chips are obtained while machining brittle material like cast iron.
- good surface finish and tool life

THERMAL ASPECTS IN MACHINING

- knowledge of temperature rise is essential because

1. the rise in temperature adversely affects the properties of the tool material
2. increased temperature causes dimentional changes in the workpiece and hence th accuracy of machining

THERMAL ASPECTS IN MACHINING

3. increased temperature can even distort the accuracy of the machine tool itself.

the heat generated depends on the rate of metal cutting, cutting speed, specific heat and thermal conductivity of the workpiece and tool materials.

THERMAL ASPECTS IN MACHINING

$Q = Q1+Q2+Q3+Q4$

AMOUNT OF HEAT TAKEN AWAY BY

Q1= THE CHIPS

Q2=AMOUNT OF HEAT CONDUCTED INTO THE TOOL

Q3=AMOUNT OF HEAT CONDUCTED INTO WORKPIECE

Q4=AMOUNT OF HEAT DISSIPATED TO THE SURROUNDINGS

THERMAL ASPECTS IN MACHINING

- th amount of heat dissipated on the surrounding is very small.
- the chip carries much of the heat generated.
- q1:q2:q3=80:10:10

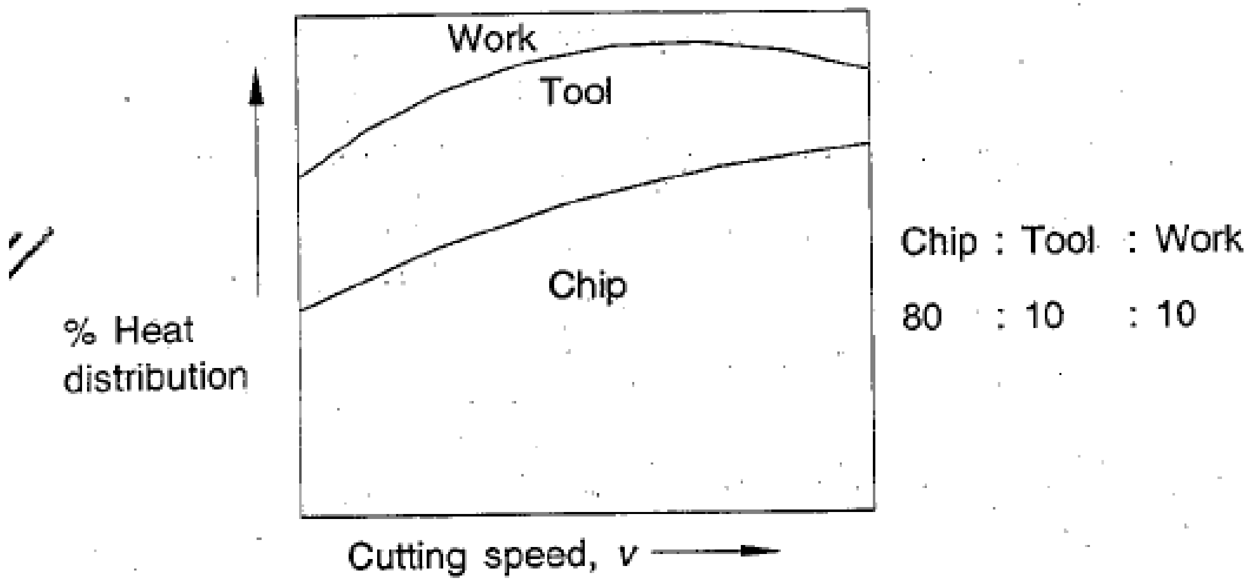


Figure 4.12 Heat distribution between tool, workpiece and chips.

FAILURE OF TOOL

1. **CATASTROPHIC FAILURE**

   it will occur when the cutting force acting on the tool exceeds the critical strength of the tool material, and tool fails without giving any indication.

2. **GRADUAL OR PROGRESSIVE WEAR**

   it may happen because of creater formation leading to creater wear or flank wear.

CRATER WEAR

- crater wear occurs on the rake face of the cutting tool and it occurs at a distance from cutting edge.
- crater wear is a result of rubbing between the chip and the rake face of the tool.
- as the crater wear progresses, the cutting edge becomes weaker and it may lead to chipping of cutting edge .
- crater wear can be reduced by using chip breakers

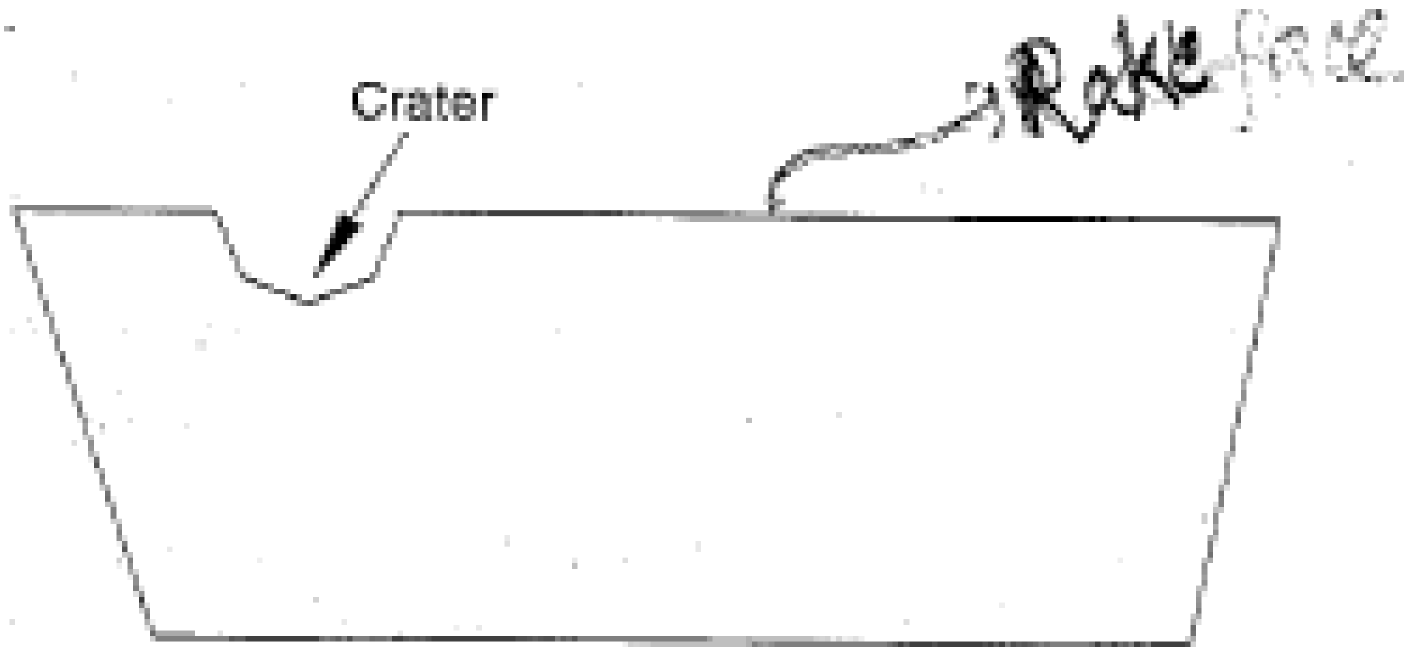


Figure 4.13 Crater formation and wear.

FLANK WEAR

- flank wear occurs on the face of the tool. flank wear is due to *continuous contact between the newly machined surface* and *flank face of the tool.*

Figure 4.14 Flank wear.

Cutting Fluids

The functions that a cutting fluid is expected to fulfill are:

1. Absorb and carry away the generated heat, thereby lowering the cutting zone temperature.
2. Cool the work piece and tool,
3. Reduce friction between tool and work piece by acting as a lubricant(this reduces the heat generation),
4. Wash away the chips,

Cutting Fluids

5. Carry away the built-up edges formed,
6. Give very fine surface finish to the workpiece, and
7. Prevent corrosion of the machined surface, tool and machine.

Operating conditions in Metal Cutting

- The term operating conditions include the parameters such as

a) Cutting speed

b) Feed and

c) Depth of cut

Cutting speed,v

- Cutting speed is the distance traveled by the work surface in a unit time with reference to the cutting edge of the tool.
- Usually expressed in m/min

Table 4.3 Cutting Speeds for Machining Different Materials Using a High Speed Steel Tool

Workpiece material	Average cutting speed (m/min)
Aluminium	300
Brass	45-90
Bronze	15-20
Cast iron	18-25
High carbon steel	12-18
Mild steel	20-30

Feed, f

- The feed is the distance advanced by the tool (assuming job remains stationary) for each revolution of the work.
- Expressed in mm/rev

Depth of Cut, d

- It is the measured perpendicular distance between the machined surface and the unmachined (uncut) surface or the previously machined surface of the workpiece.
- Expressed in mm.

Material Removal Rate and Machining Time

- The total material to be removed, cutting speed, feed and depth of cut determine the material removal rate and the time required to machine a work piece , the machining time.

Machining Time

- The time required to make one cut or pass on the work piece
- Total machining time = machining time X no. of cuts

Tool Life

- Tool Life is defined as the time for which a tool can cut effectively or it is the time between two successive re-sharpenings of a cutting tool.
- The tool life is a function of cutting speed as shown in figure:

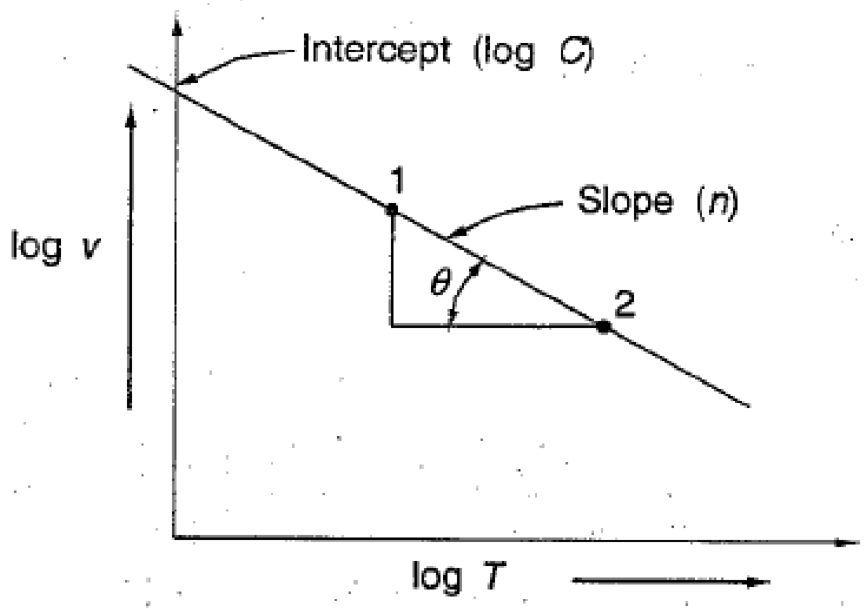


Figure 4.15 Tool life graph.

Taylor's expression or Tool life equation

$$vT^n = C$$

v = cutting speed in m/min

T = Tool life in minutes

C = a constant which depends on the tool and work material

n = slope of the curve which depends on tool and work material

Tool Life (Contd.)

$$n = \tan\theta = \frac{\log v_1 - \log v_2}{\log T_2 - \log T_1}$$

where T_1 and T_2 are the tool life at cutting speeds v_1 and v_2, respectively.

Table 4.5 Constants n and C for Different Work Material and Tool Material

Work material	Tool material	n	C
Steel	HSS	0.1–0.16	160–190
	Carbide	0.18–0.2	220–290
Cast Iron	HSS	0.08–0.1	100–180
	Carbide	0.2–0.28	250–325

Taking consideration the values of depth of cut and feed rate

are

$$vT^n f^{n_1} d^{n_2} = C$$

Where n1 and n2 constants

Machinability

- The term machinability refers to the evaluation of the work materials with reference to machining.
- Machinability may be defined as the ease or difficulty with which a material can be machined under a given set of conditions.
- If v_s is the specific cutting speed to produce a tool life T for a standard material, v_t is the cutting speed to produce a tool life T for a test material,

Machinability or Machinability index

$$= v_t/v_s \times 100\%$$

Theory of metal cutting

Problems

Problem 1

While machining cast iron using a high speed steel tool, tool life of 50 minutes was observed when machined with a cutting speed of 100 m/min. determine

a) General Taylor's tool life equation, and
b) Tool life for a cutting speed of 80 m/min.

Assume n=0.09 in Taylor's tool life expression.

Solution: Given $v = 100$ m/min, $T = 50$ min, $n = 0.09$.

(a) *Tool life equation*:

$$vT^n = C$$

or

$$\boxed{\log v + n \log T = \log C}$$

Substituting the values, we get

$$\log 100 + 0.09 \log 50 = \log C$$

or

$$C = 142.20$$

Therefore, the tool life equation becomes:

$$vT^{0.09} = 142.20 \quad \textbf{Ans.}$$

Note: Using the above expression it is possible to find the tool life for any cutting speed.

(b) For calculating T, at $v = 80$ m/min in the tool life equation,

$$80 \times T^{0.09} = 142.20$$

or

$$T = 596.57 \text{ min} \quad \textbf{Ans.}$$

Problem 2

- Using Taylor's equation for tool life and taking n=0.5 and c=300, calculate the change in tool life when the cutting speed is reduced by 25%.

Solution: Since, $n = 0.5$, we can write the Taylor's equation as

$$v\sqrt{T} = 300$$

Let v_1 be the initial speed and v_2, the reduced speed. Given that

$$v_2 = 0.75v_1$$

Since C is constant, we have the relationship:

$$0.75v_1\sqrt{T_2} = v_1\sqrt{T_1}$$

Simplifying this expression, we find that

$$\frac{T_2}{T_1} = \left(\frac{1}{0.75}\right)^2 = 1.78$$

This indicates that the tool life change is

$T_2 - T_1 / T_1 = T_2 / T_1 - 1 = 1.78 - 1 = 0.78$

i.e., tool life increases by 78% when cutting speed is reduced by 25%

Problem 4.3

- A carbide- cutting tool when used for machining mild steel work piece material at a cutting speed of 50m/min, lasted for 100 minutes. Determine a) life of the tool when the cutting speed is increased by 25% and b) cutting speed of the tool to get a tool life of 180 minutes. Assume n=0.26 in the Taylor's expression.

Problem 4.4

- In assessing machinability of different work piece materials, the data obtained during machining is given below. Determine the cutting speed for 'A' and 'B' to get a tool life of 50 min. Estimate the relative machinability, considering material 'A' as standard material.

Work material	Tool life in Min	Cutting speed m/min
A	25 10	100 150
B	40 20	200 250

Problem 27

- During the machining of low carbon steel with HSS cutting tool, it was found that for cutting speeds of 40 and 50m/s tool life was 40 and 10 minutes respectively. Derive v-T relationship.

Ans: $vT^{0.16} = 72.44$

Problem 28

- The tool life for a high speed steel tool is expressed by the relation $vT^{1/7}=C_1$, and for tungsten carbide is expressed as $vT^{1/5}=C_2$. if at a speed of 24m/min the tool life is 128 minutes, compare the tool life of the two tools at a speed of 30m/min.

- Ans: $T_1/T_2=0.64$

Problem 29

- A tool life of 80 minutes is obtained at a speed of 30m/min and 8 minutes at 60m/min. Determine the following a) Tool life equation b) Cutting speed for 4 minutes tool life

Ans: a) $vT^{0.3}=C$ b) 73.69 m/min

Problem 30

- A carbide tool while machining a mild steel work piece was found to have a life of 1 hour and 40 min when cutting at 50m/min. Find the tool life if the tool is to operate at a speed 30% higher than previous one. Also, calculate the cutting speed if the tool is required to have a life of 2hours and 45 minutes. Assume n=0.28

- Ans: T=39 min V=43.4 m/min