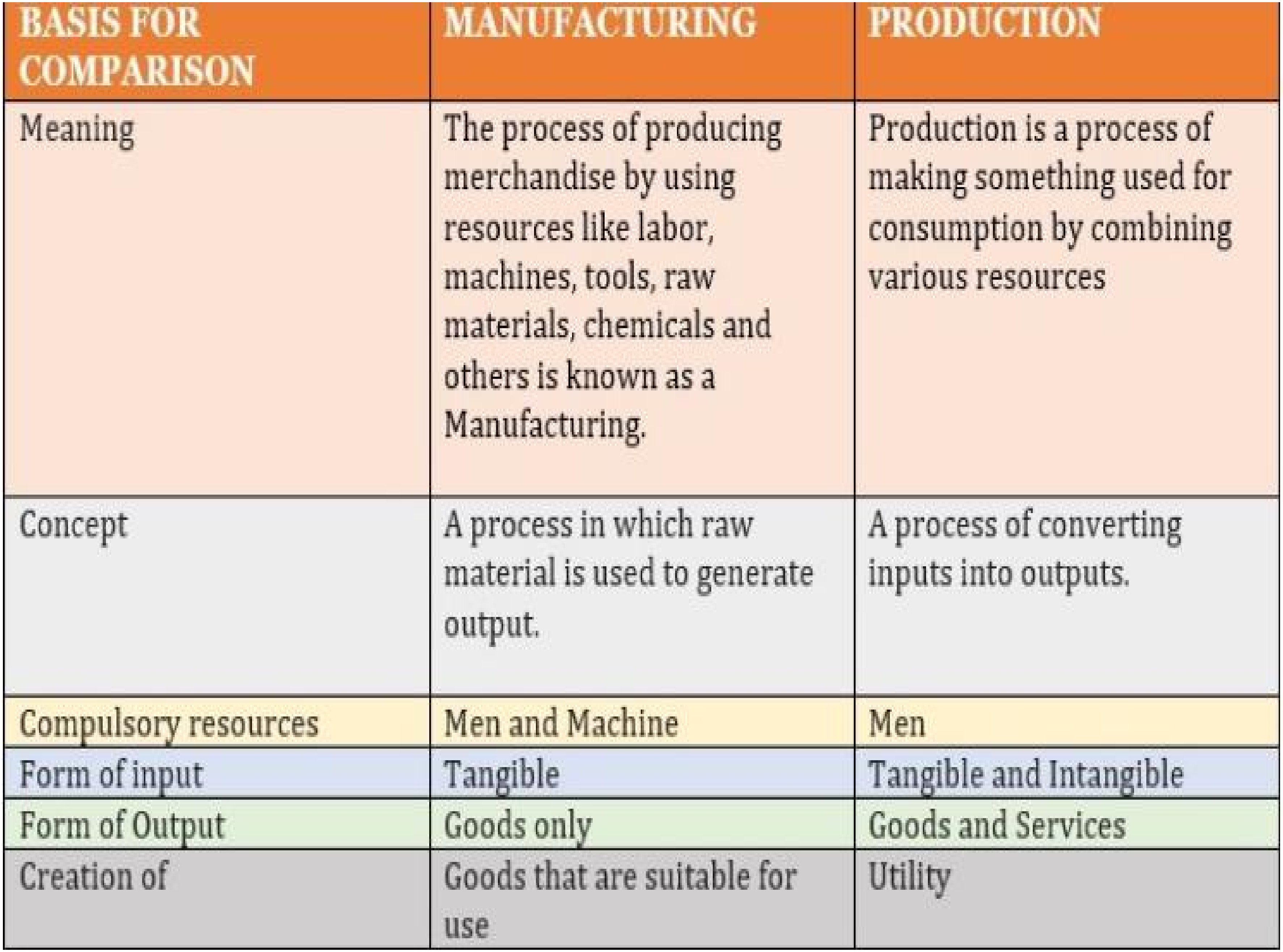
Manufacturing Technology



BASIS FOR COMPARISON	MANUFACTURING	PRODUCTION
Meaning	The process of producing merchandise by using resources like labor, machines, tools, raw materials, chemicals and others is known as a Manufacturing.	Production is a process of making something used for consumption by combining various resources
Concept	A process in which raw material is used to generate output.	A process of converting inputs into outputs.
Compulsory resources	Men and Machine	Men
Form of input	Tangible	Tangible and Intangible
Form of Output	Goods only	Goods and Services
Creation of	Goods that are suitable for use	Utility

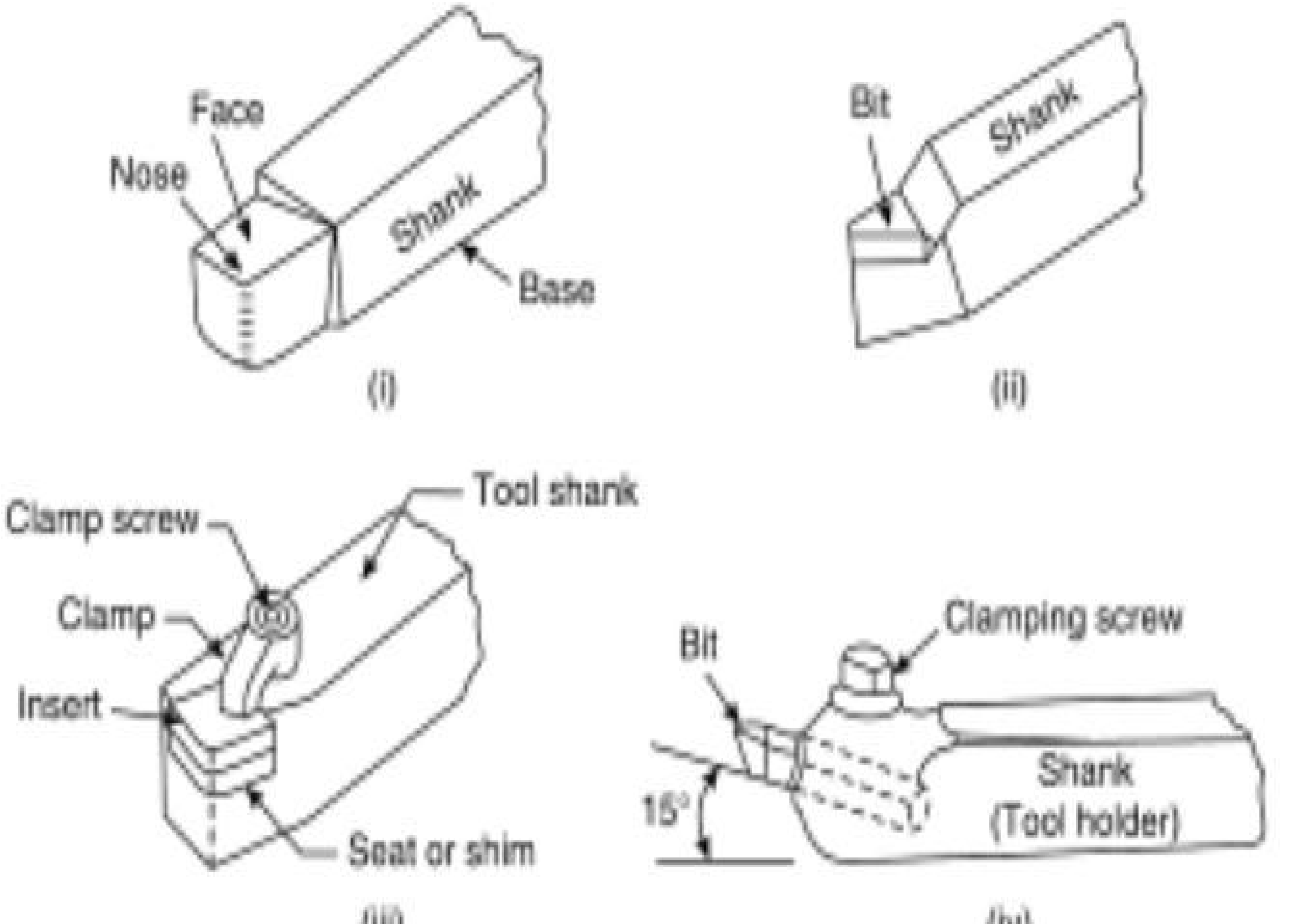
Cutting Tool Classification

1. ***Single-Point Tools***
   - One cutting edge
   - Point is usually rounded to form a *nose radius*
   - *Ex :* Turning, Shaping, and Planning uses single point tools.

2. ***Multiple Cutting Edge Tools***
   - More than one cutting edge
   - Motion relative to work usually achieved by rotating
   - *Ex :* Drilling, Reaming, Tapping, Milling, Broaching, and Sawing uses rotating multiple cutting edge tools.

Based on their motion during cutting

- **Linear motion tools**
  - Lathe, Shaper, Planner, Slotter.
- **Rotary motion tools**
  - Milling and Grinding machines.
- **Rotary and linear motion tools.**
  - Drilling, Reaming, Honing tools.



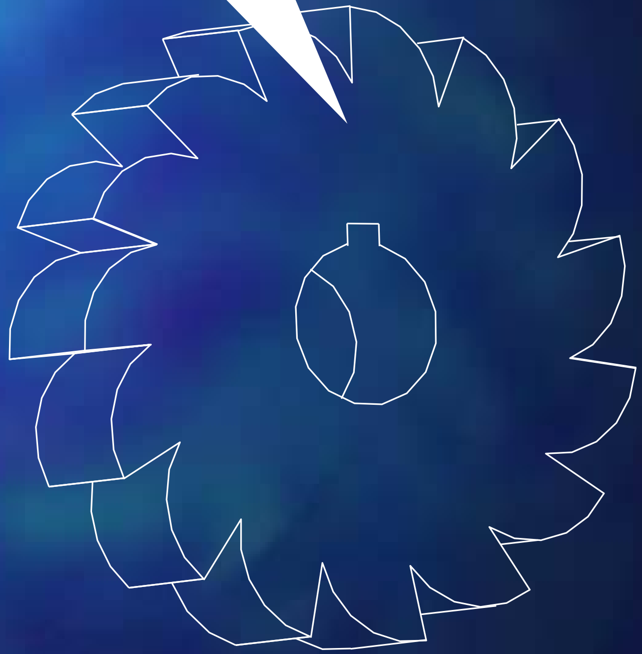
(i) (ii) (iii) (iv)

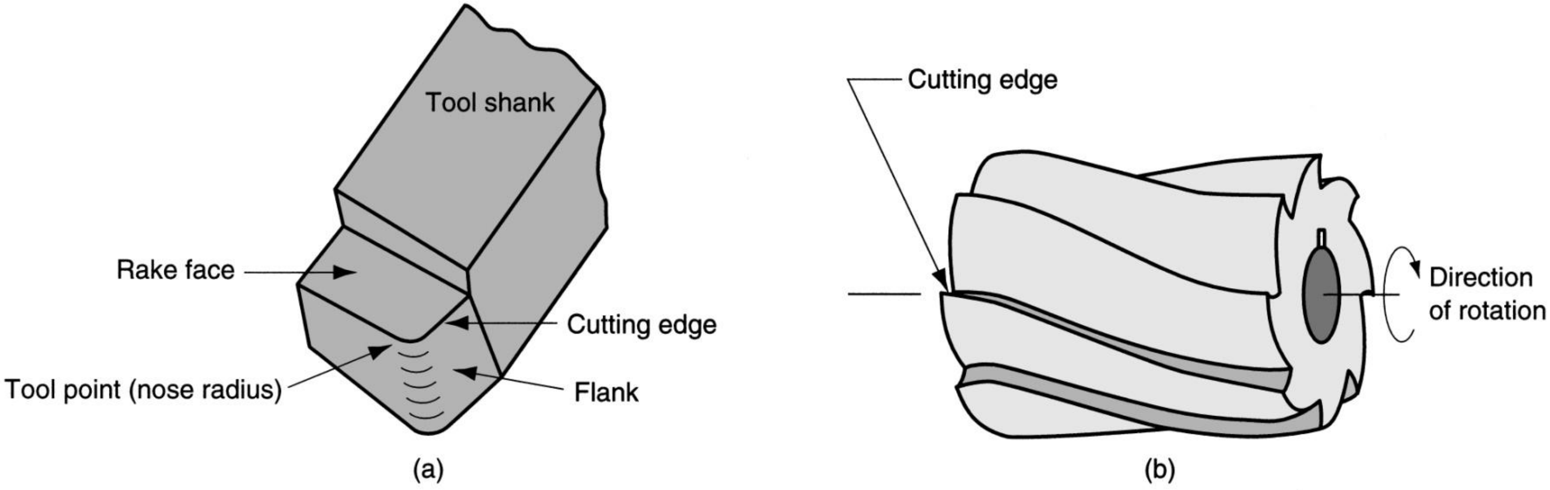
Different types of lathe tools: (i) Solid or forged tool, (ii) Brazed tipped tool, (iii) Mechanically held tool tip or insert and (iv) Tool bit held in a tool shank.

Types of Tools

Single Point

Multipoint





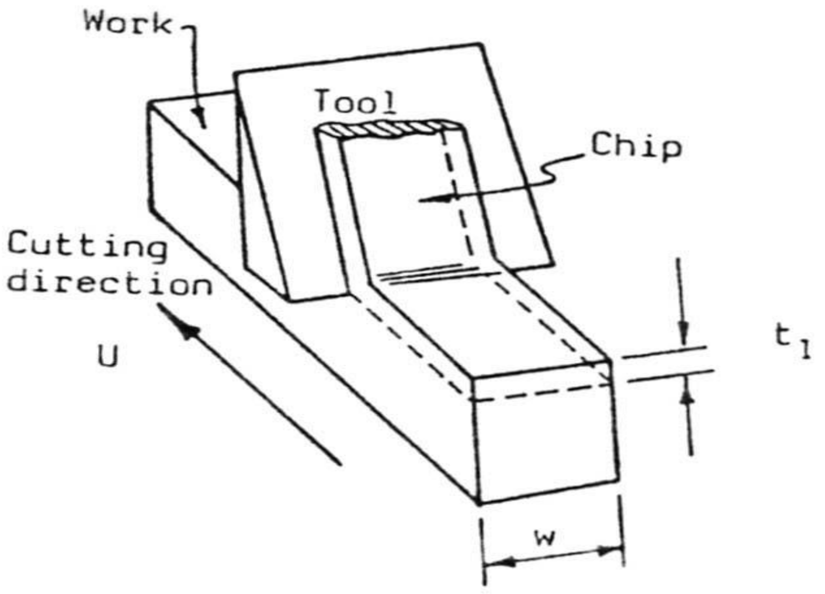
(a)

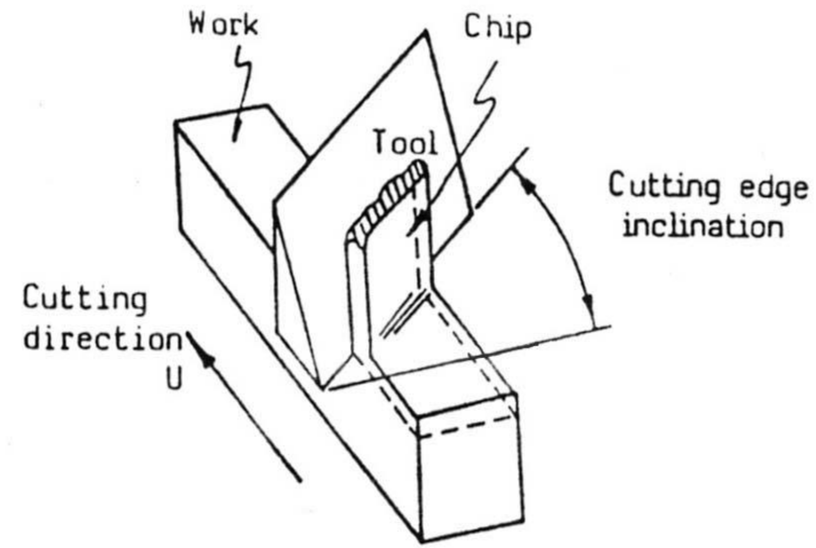
(b)

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

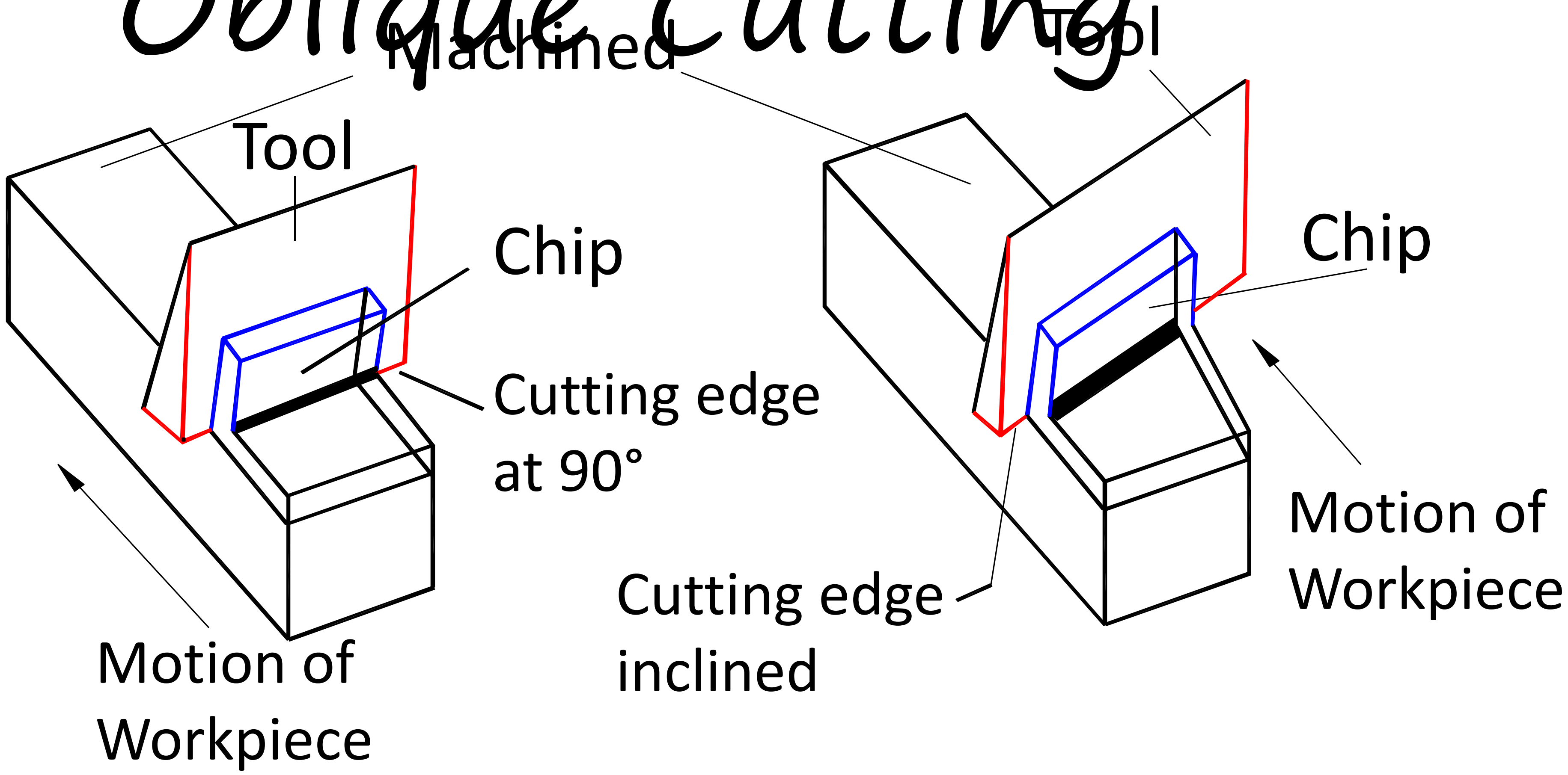
Orthogonal and Oblique Cutting

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





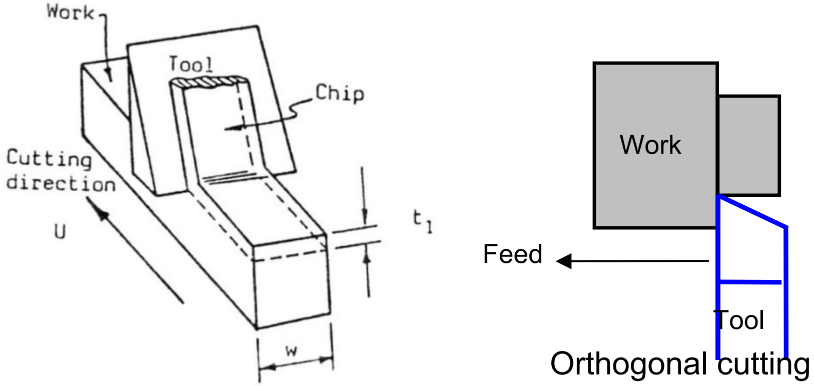
Orthogonal and Oblique Cutting



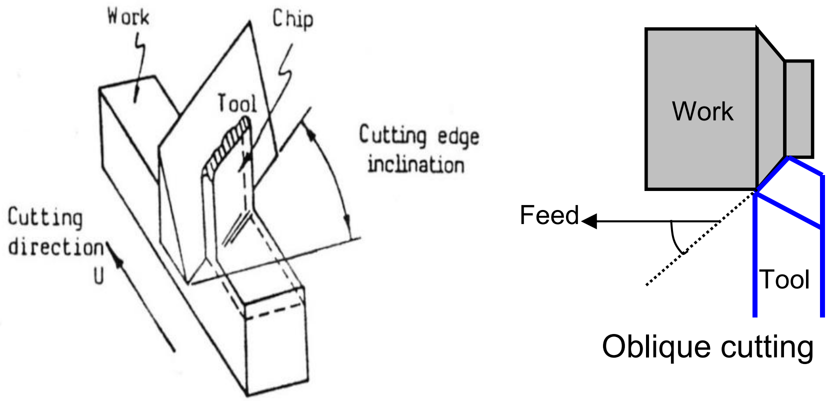
Orthogonal cutting

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:

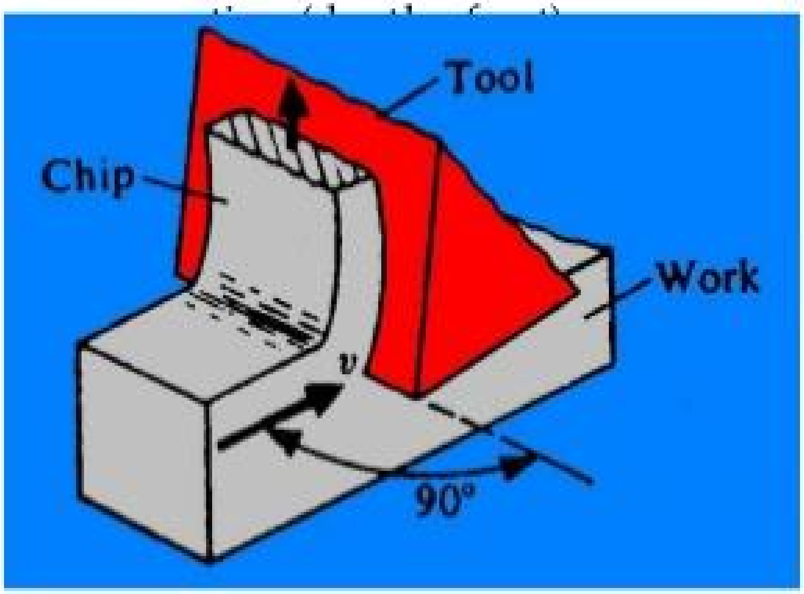
- The cutting edge of the tool remains inclined at an acute angle to the direction of tool feed or work feed.
- The direction of the chip flow velocity is at an angle with the normal to the cutting edge of the tool. The angle is known as chip flow angle.
- Here three components of forces are acting: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

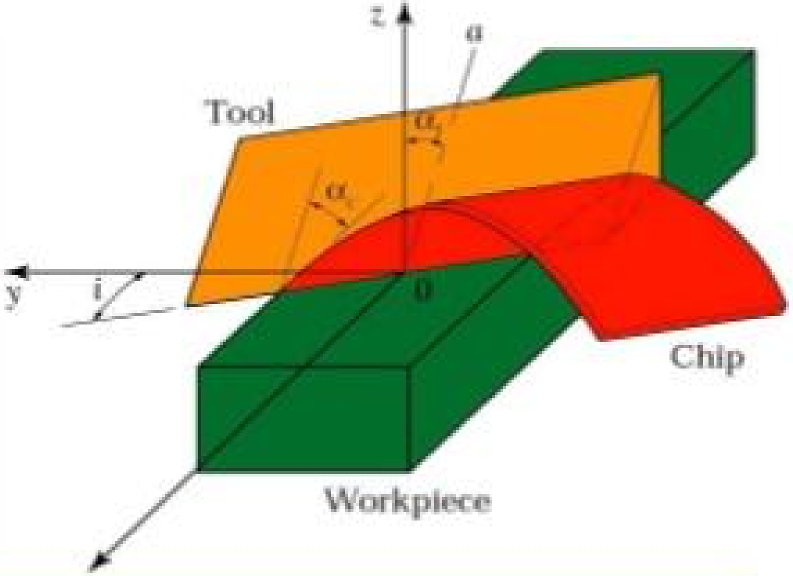
Orthogonal Cutting	**Oblique Cutting**
Cutting angle remains normal to the direction of work feed (or velocity)	Cutting edge remains inclined at an acute angle to the direction of work feed.
Direction of chip flow velocity is normal to the cutting edge.	Direction of chip flow velocity is at an angle (ηc)
Angle of inclination (i) is zero.	Cutting feed inclined at an angle (i) with normal to work feed (or velocity V)
Chip flow angle $(\eta c)\ \ is$ zero.	Three mutually perpendicular components of cutting forces act at the cutting edge of tool.
Cutting edge is larger than width of cut.	Cutting edge may or may not be longer than width of cut.

Manufacturing Technology

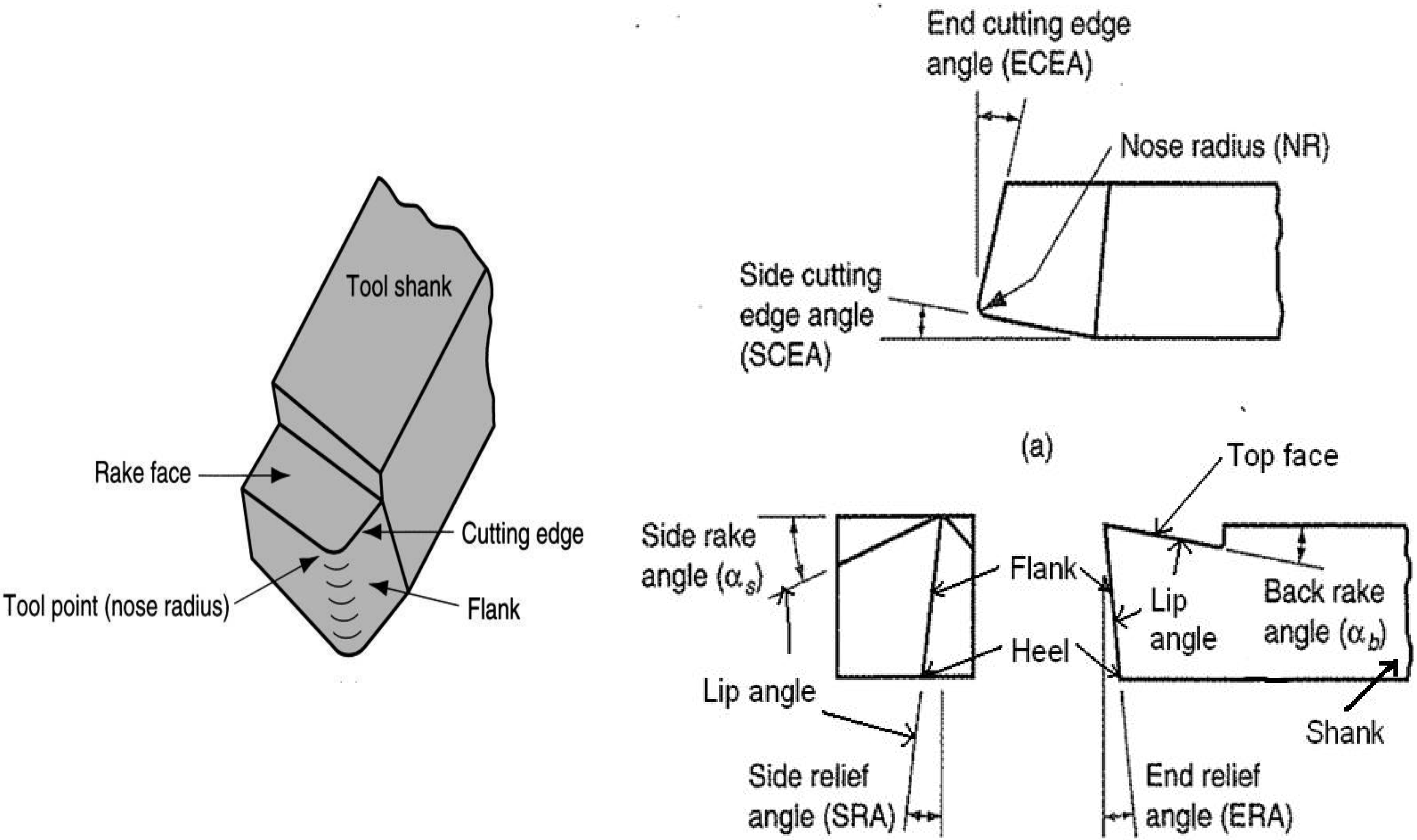
Orthogonal and oblique cutting

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

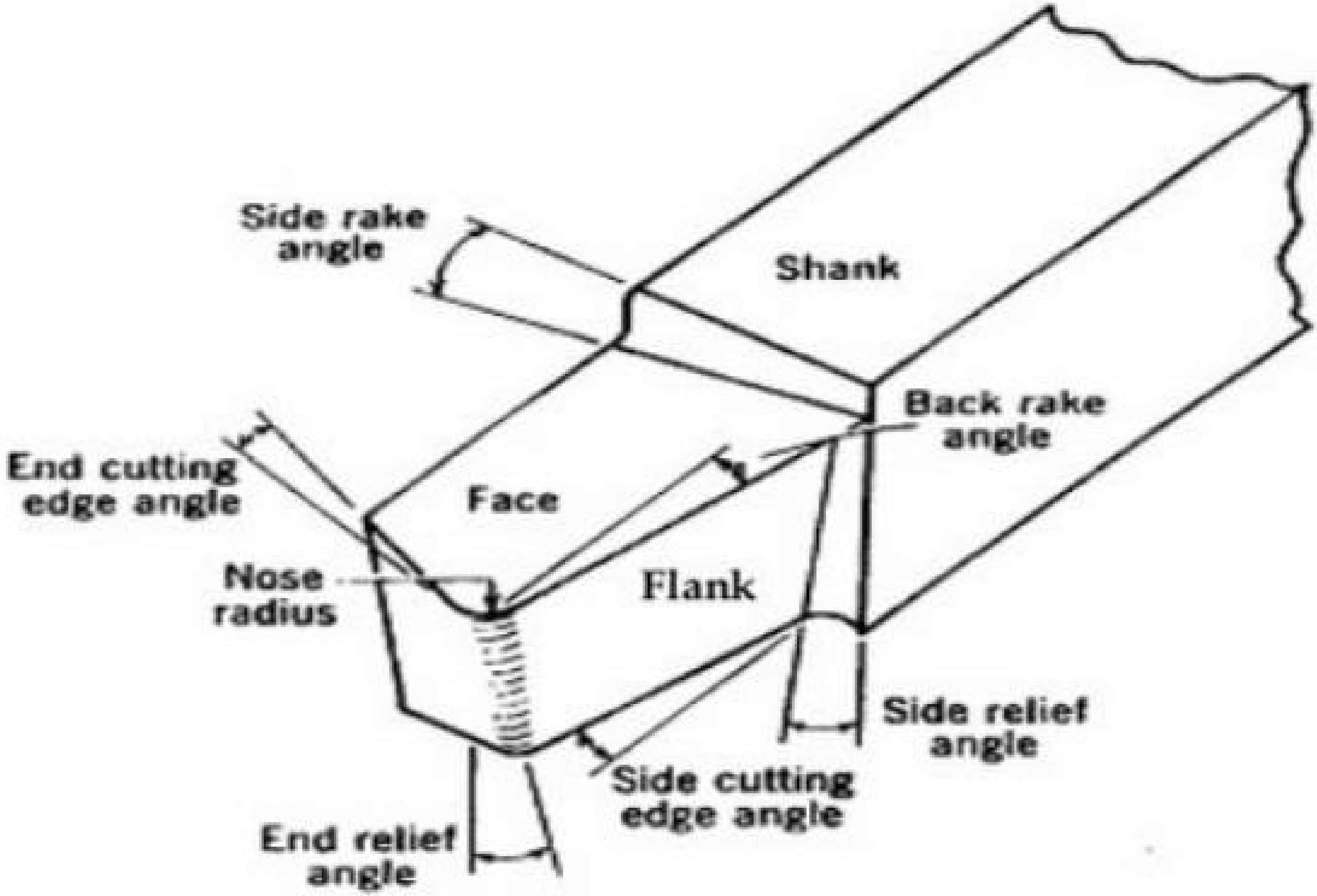




Cutting tool nomenclature



Single point cutting tool nomenclature



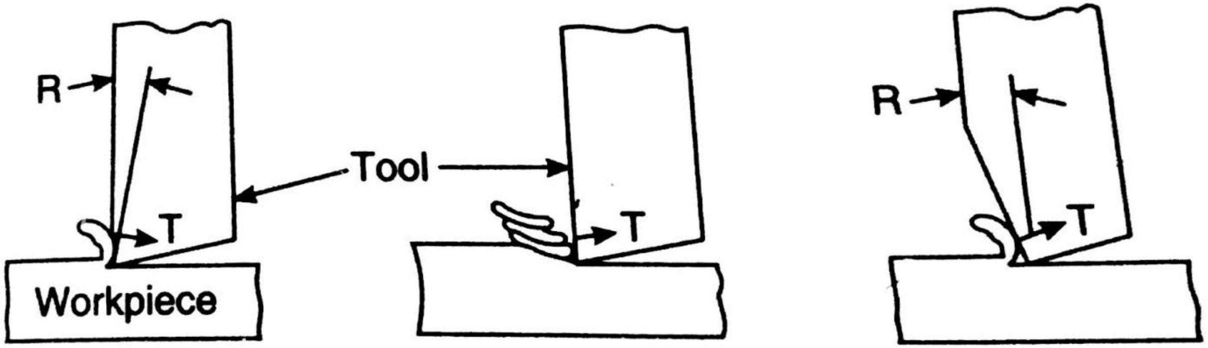
Cutting tool nomenclature

- Flank – surface which face the workpiece. It is the surface adjacent to and below the main cutting edge when tool lies in horizontal position.
- Heel – lowest portion of the side cutting and end cutting edges.
- Shank – portion of the tool bit which is not ground to form cutting edges
- Face – surface against which the chip slides upward
- Base – under-side of the shank
- Nose or point– conjunction of the side and end-cutting edges.
- Rake – refers to slope of tool top away from the cutting edge. Tool has side rake and back rake.

Angles of single point cutting tools

- Rake angle
- Clearance angle
- Side cutting edge angle
- End cutting edge angle
- Lip angle
- Nose radius

- **Rake angle**
  - Slope of tool face and is formed between tool face and a plane parallel to its base.
  - Back rake or top rake – slope is towards the shank
  - Side rake – when measured towards side of tool.
  - Positive rake – when face of tool slopes away from cutting edge and also slants towards side of tool.
  - Negative rake – when tool face slopes away from cutting edge and slants upwards towards side of tool.
  - Zero rake – tool face has no slope and is parallel to upper surface of tool shank.



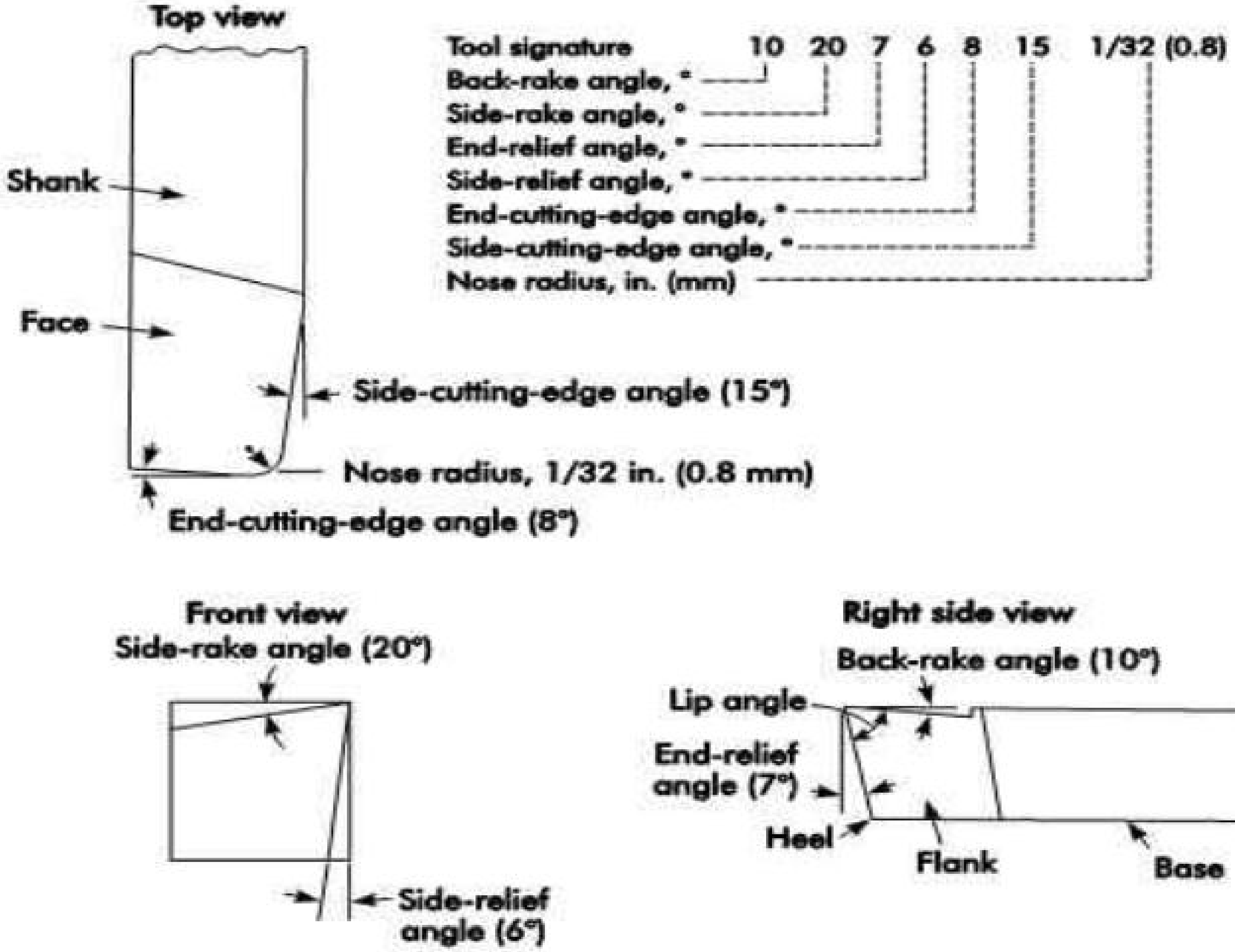
(a) Positive rake (b) Zero rake (c) Negative rake

- **Functions of rake**
  - Allows chip to flow in convenient direction away from cutting edge.
  - Reduces chip pressure on tool face and provides keenness to cutting edge and consequently improves surface finish on work piece.
  - Reduces cutting force required to shear the metal.
  - **Provision of rake angle depends on**
  - Work piece material
    - Harder- small rake angle(cast iron)
    - Soft- large rake angle(al, steel)
  - Tool material
  - Depth of cut

- **Clearance angle**
  - Angle between machined surface and flank faces of tool.
  - Helps in preventing flank of tool from rubbing against the surface of work piece, thus allowing cutting edge of tool only to contact with work piece.
  - Front clearance angle
  - Side clearance angle
  - Angles for these cutting tools vary between 5 and 15.

- **Side cutting edge angle**
  - Angle between side cutting edge and longitudinal axis of tool.
  - Helps providing a wider cutting edge and thus an increased tool life.
  - Controls direction of chip flow
  - Angle kept around 15
- **End cutting edge angle**
  - Prevents the trailing end of cutting edge of tool from rubbing against work piece.
  - Larger end cutting edge angle weakness the tool.
  - Angle – 8 to 15

- **Lip angle**
  - Depends on rake and clearance angle
  - Determines strength of cutting edge
  - Lip angle is maximum, when rake(positive) and clearance angle are minimum.
  - Larger lip angle – permits machining of harder metals, allows heavier depth of cut and increases tool life and better heat dissipation.
- **Nose radius**
  - Greater nose radius increases abrasion, it also helps in improving surface finish, tool strength and tool life.
  - For rough turning – 0.4mm
  - For finish turning – 0.8-1.6mm.


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

Material	Front rake, deg	Front clearance, deg	Side rake,deg	Side clearance ,deg
Mild steel	10-12	6-8	10-12	6-8
Stainless steel	5-7	6-8	8-10	7-9
Aluminium	30-35	8-10	14-16	12-14
Brass	0-6	8-10	1-5	10-12
Cast iron	3-5	6-8	10-12	6-9
copper	14-16	12-14	18-20	12-14

Types of chips

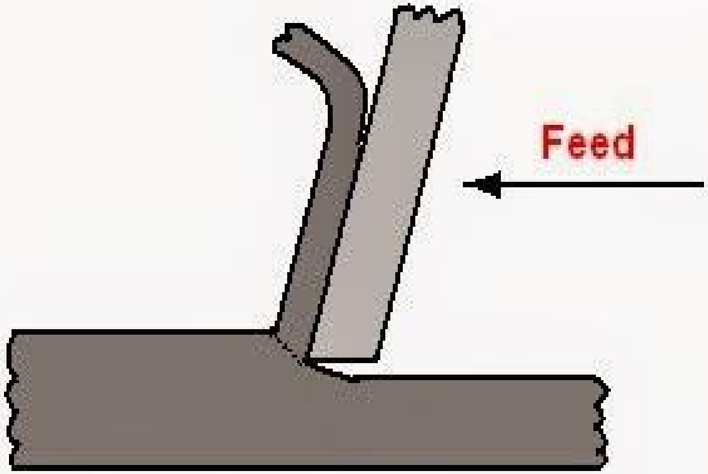
Chip because of its form and dimensions is the indication of nature and quality of particular machining process.

Type of chips formed is mainly based on the properties of workpiece material and cutting conditions.

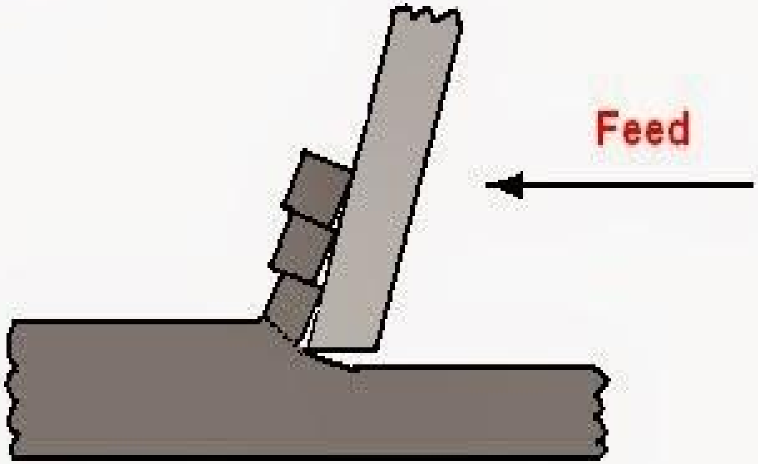
Three types of chips.

1. Continuous chip
2. Discontinuous chip or segmental chip
3. Continuous chip with Built-up Edge (BUE)

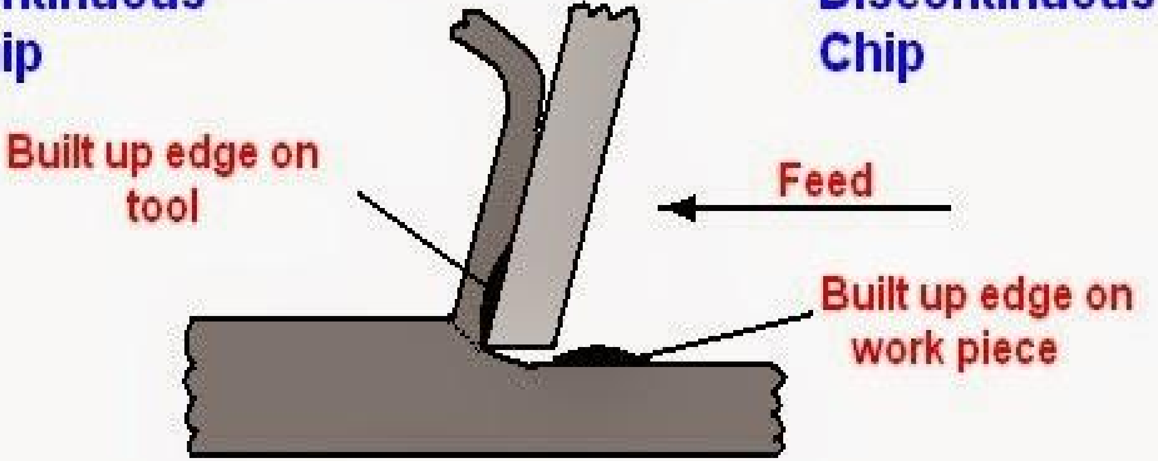
Types of Chips



Continuous Chip



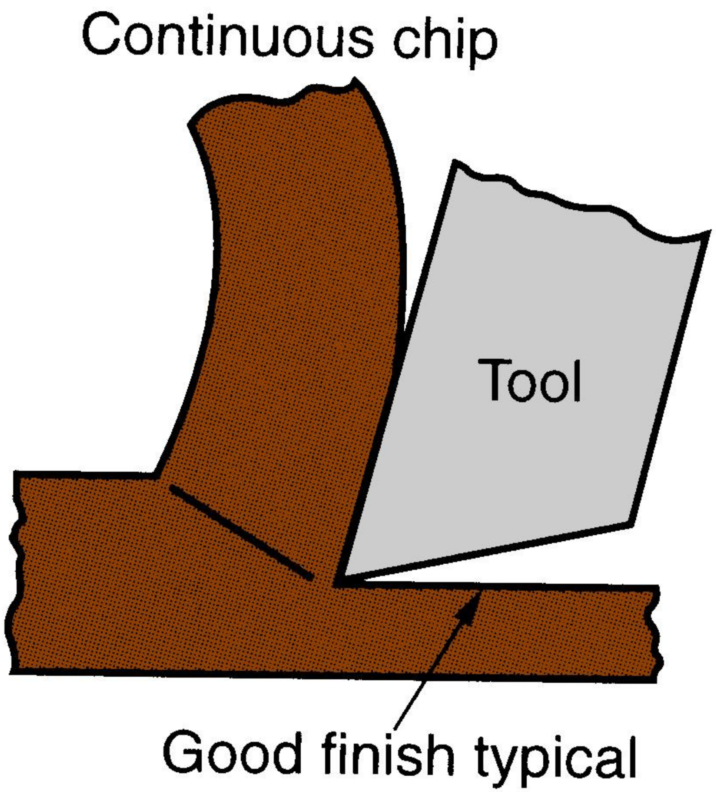
Discontinuous Chip



Built up Chip

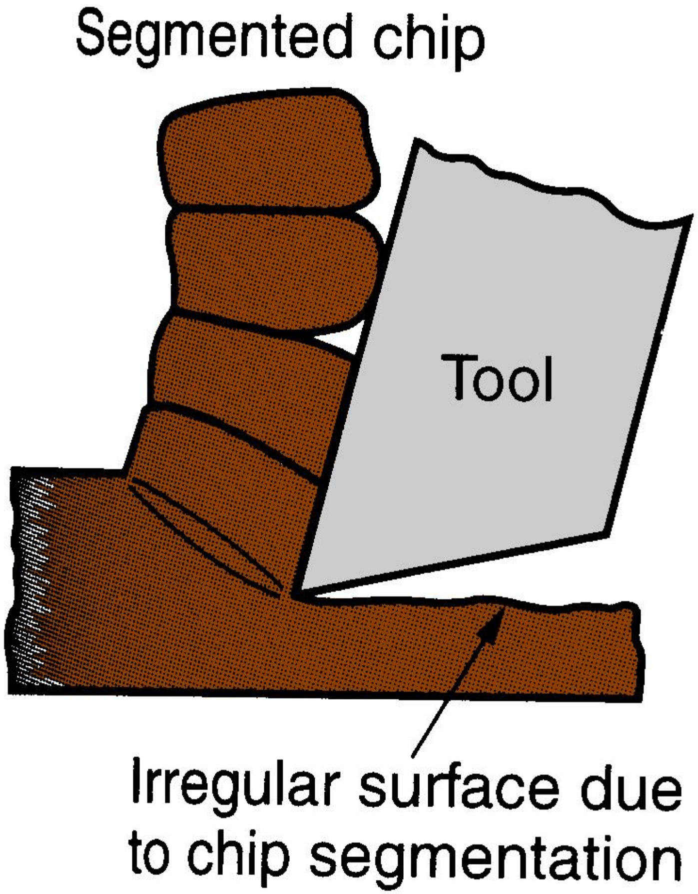
Continuous Chip

- Ductile work materials (e.g., low carbon steel, mild steel,copper)
- High cutting speeds
- Small feeds and depths
- Sharp cutting edge on the tool
- Low tool- chip friction



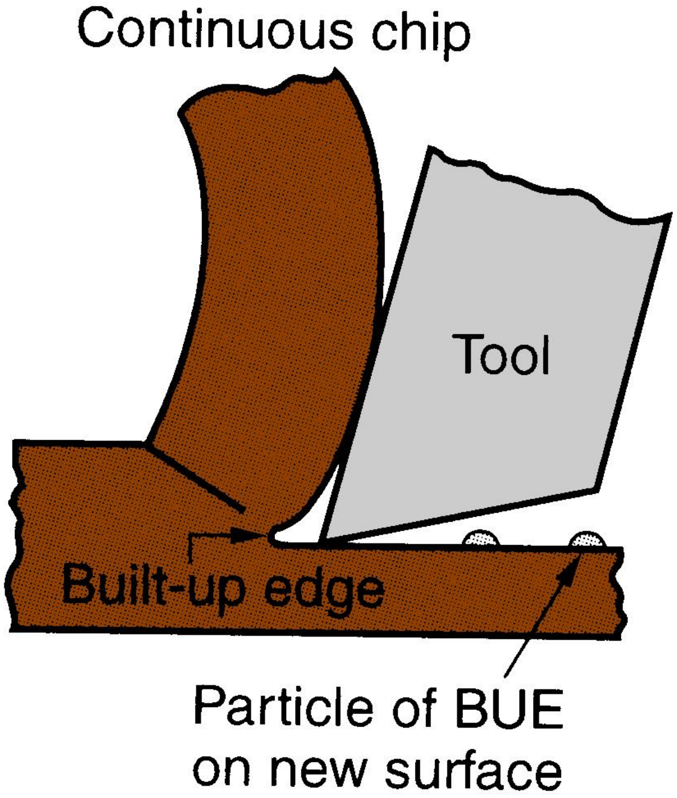
Segmented Chip (Discontinuous)

- **Brittle material**
- Hard and Brittle work materials. (e.g., cast irons, bronze.)
- Low cutting speeds
- Large feed and depth of cut
- High tool- chip friction
- Good surface finish.
- **Ductile material**
  - Poor surface finish
  - Smaller rake angle
  - Excessive tool wear



Continuous with BUE

- Ductile materials
- Tool-chip friction causes portions of chip to adhere to rake face
- BUE formation is cyclical; it forms, then breaks off.
- Factors responsible
  - Low cutting speed
  - Excessive feed
  - Smaller rake angle
  - Poor lubrication.
- Leads to formation of crater
- Rough surface



Cutting Fluids

Cutting fluids are materials which are applied to the tool and workpiece to facilitate the cutting operation by removing heat and reducing friction.

- Two main problems addressed by cutting fluids:
  1. Heat generation at shear and friction zones
  2. Friction at tool‑ chip and tool‑ work interfaces
- Other functions and benefits:
  - Wash away chips (e.g., grinding and milling)
  - Reduce temperature of workpart for easier handling
  - Improve dimensional stability of workpart

Functions of cutting fluid

- To cool the cutting tool and work piece
- Lubricates the cutting tool and reduces the co-efficient of friction between tool and work.
- Improves the surface finish.
- It causes the chips to break up into small parts.
- It protects the finished surface from corrosion
- Washes away the chips from the tool..
- It prevents corrosion of work and machine.

Properties of cutting fluid

- Good lubricant properties for producing low coefficient of friction.
- High heat absorbing capacity for quickly absorbing the heat.
- High specific heat, high heat conductivity and high film co-efficient.
- High flash point
- Odorless, harmless to skin of operator and bearings of machine.
- Non-corrosive to work and tool.
- Low viscosity to permit free flow of the liquid.
- Low priced to minimize production cost.

Classification of cutting fluids

- **Aqueous solutions**
  - Include water either plain or containing alkali like borax, sodium carbonate
  - Have high specific heat and heat conductivity.
  - Used where cooling and washing away chips is required.
- **Soluble oils or conventional emulsions**
  - 80% of water, fatty acids, mineral oils and soap acting as an emulsifying agent.
  - Water provides cooling effect and oil provides lubricating effect.
- **Mineral oils**
  - Hydrocarbons such as paraffin and naphthalene.
  - Highly oxidation resistant.
  - Do not applicable for boundary lubrication(deep drawing and extrusion)
- **Fatty oils and acids**
  - Boundary lubrication as friction reducing agents under extremely high pressures.
  - Lard oil and tallow.

- **Compound mineral oils**
  - Mineral oils compounded or mixed with substances such as fatty oils and acids.
- **Waxes**
  - Derived from petroleum and used as lubricants in rolling and drawing.
  - Paraffin wax, natural bees wax
- **Graphite suspensions**
  - Mixing graphite powder in oil or water
  - Used in forging, foundry works, extrusion, wire drawing.
- **Minerals**
  - **Salt(common quenching media) for heat treatment process.**
  - Salts: chlorides and hydroxides of brine and caustic soda.(Rapid cooling)
  - Metals: Lead and copper coating on steel wires, graphite, bentonite for drawing.

- **Chemical compounds**
  - Consists mainly of a rust inhibitor such as Sodium nitrate mixed with good amount of water.
  - Used in grinding, where corrosion has to be avoided.
- **Solid lubricants**
  - Powders, vitreous materials, pastes, greases, dry film.
  - Wax and bar soap is sometimes used to lubricate the tool.
- **Gaseous fluids**
  - Refrigerated compressed air, nitrogen and carbon dioxide, Oil mist, argon.
  - Carbon dioxide – used with carbide tools for reducing carter wear when machining titanium alloys.
  - To reduce chemical effects, liquid nitrogen is also used.

Tool failure

- **Tool failure criteria**
- ***Based on tool wear:*** Size of wear, depth/width of crater, fine crack or chipping developing at cutting edge, weight of material worn off tool or total destruction of tool.
- ***Based on resulting performance of worn-out tool***: limiting value of surface finish, limiting value of change in component size, fixed increase in cutitng force.
- **Reasons for tool failure**
  - Thermal cracking and softening
  - Excessive stress and mechanical chipping
  - Gradual wear(Flank wear and crater wear)

  Mechanism of tool wear
  - Abrasion wear
  - Adhesion wear
  - Diffusion wear
  - Chemical wear

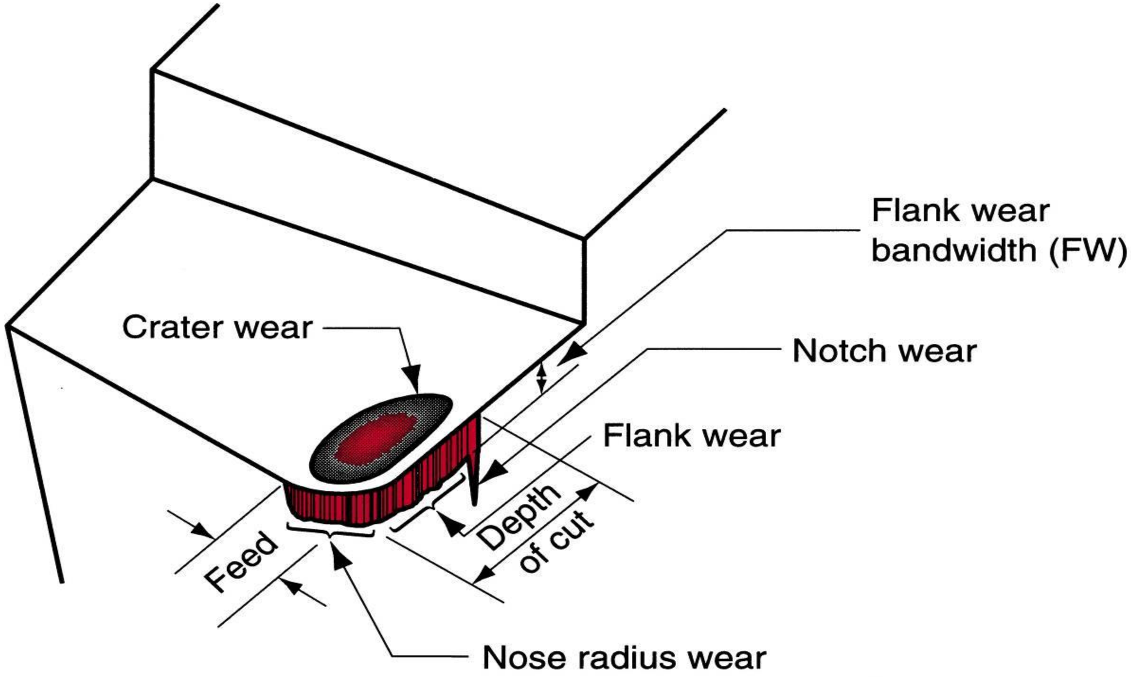
- **Thermal cracking and softening**
  - High heat in metal cutting produces high temperature in cutting region
  - Tool failure due to softening.
  - Thermal cracks.
  - Edge depression and localised bulging.
  - ❑ ***Factors responsible***
  - Higher cutting speed, High feed rate, Higher depth of cut, Smaller nose radius and wrong choice of tool material.
- **Excessive stress and mechanical chipping**
  - Takes place at nose or cutting edge of tool.
  - ❑ ***Factors responsible***
  - High cutting pressure, too high vibrations, mechanical impact, excessive wear.
- **Gradual wear**
  - Wear is judged by loss of weight or material from tool.
    - Crater wear
    - Flank wear

Tool Wear

Crater wear occurs because of tool chip flow on top rake face. High friction, temp and stresses at the face/chip interface, lack of cutting fluid are responsible. *Measured as area or depth of dip.It modifies the tool geometry and increases cutting forces and softens the tool tip.*

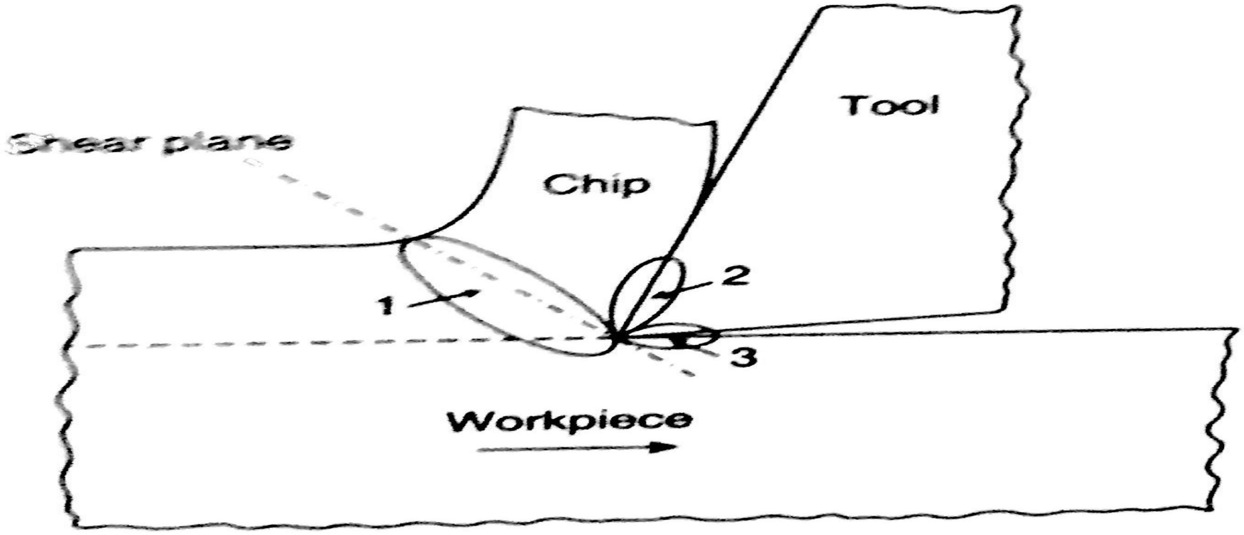
Notch wear occurs because of tool rubbing against original work surface, which is harder than machined one.

Flank wear results from rubbing of flank (& or relief) face to the newly generated surface. Measured by width of wear band called **wear land**. Feed more than 0.15mm/rev.



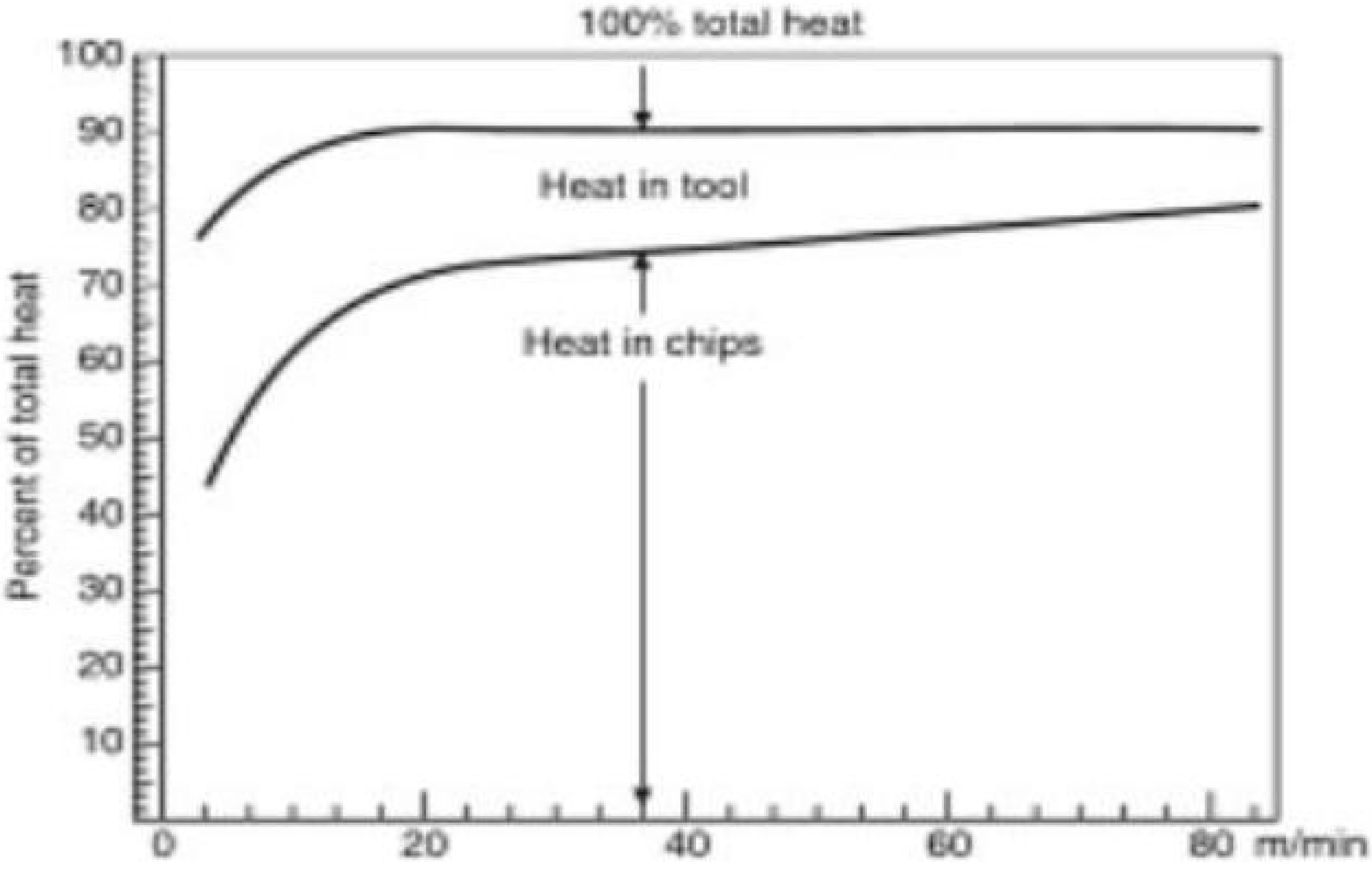
Heat/ thermal aspects in metal cutting

- The main sources of heat
  - **The shear zone or primary deformation zone**
  - **Chip tool interface zone or secondary deformation zone**
  - **Work tool interface zone.**



- **Shear zone or primary deformation zone**
  - Region in which primary deformation occurs during machining.
  - 80% of total heat generated in shear zone.
  - Amount of heat conducted(chip-tool-work piece)-
    - Temperature difference between these elements
    - Their masses
    - Time of contact with each other
- **Secondary deformation or chip tool interface zone**
  - Region where secondary deformation takes place due to friction between heated chip and tool causing a further rise in chip temperature.
  - 15-20% of total heat is generated.
- **Work-tool interface zone**
  - Portion of tool flank which rubs against work surface and generates heat due to friction.
  - 1-3% of heat generated.
- **Factors affecting temperature in metal cutting**
  - Materials of work piece and tool
  - Tool geometry
  - Cutting conditions.

Distribution of heat during metal cutting



Cutting tool materials

- Cutting tool materials are those materials which are used for making tools for cutting metals and other materials.
- **Characteristics**
  - **Hot hardness**
  - **Wear resistance**
  - **Toughness**
  - **Coefficient of friction**
  - **Thermal conductivity and specific heat**
  - **Cost and fabrication.**

- **Principal tool materials**
- High carbon steels
- High alloy tool steels(high speed steels)
  - 18-4-1 high speed steel
  - Cobalt high speed steel
  - Vanadium high speed steel
  - Molybdenum high speed steel
- Cutting alloys
  - Cast alloys
  - Cemented carbides
  - Coated tools
  - Ceramics or oxide tool materials
  - Diamond

- **High carbon steels**
  - Used for making cutting tools for lathe and other machines
  - Suitable for low cutting speeds.
  - Not able to cut harder and tougher materials.
- **High speed steels(HSS)**
  - Used for making cutters and tools for cutting and machining of metals.
  - Retain their strength, form, hardness at elevated temperature(620^0)
  - Operate at cutting speed two to three times higher than high carbon steel tools.

- **High speed steel(18-4-1 type) or tungsten high speed steel**
  - Tungsten-18%, chromium-4%, vanadium-1%
  - Carbon-0.7% and has combination of red hardness and shock and wear resistance.
  - Cutting tool- Lathe, Milling, Shaper, Slotter, Broaches, Drill bits.
- **Cobalt high speed steel**
  - Cobalt-2-15% (to increase hot hardness and wear resistance)
  - Cobalt-12%, Tungsten-20%, Cr-4%, Va-2% and C-0.8%.
- **Vanadium high speed steel**
  - Has higher abrasive resistance than 18-4-1 type and is used for tools for machining hard and difficult to machine metals.
- **Molybdenum high speed steel**
  - Mb-6%, Cr-4%, Tungsten-6%, Vanadium-2% and higher carbon contents.
  - Very tough and has improved cutting properties.

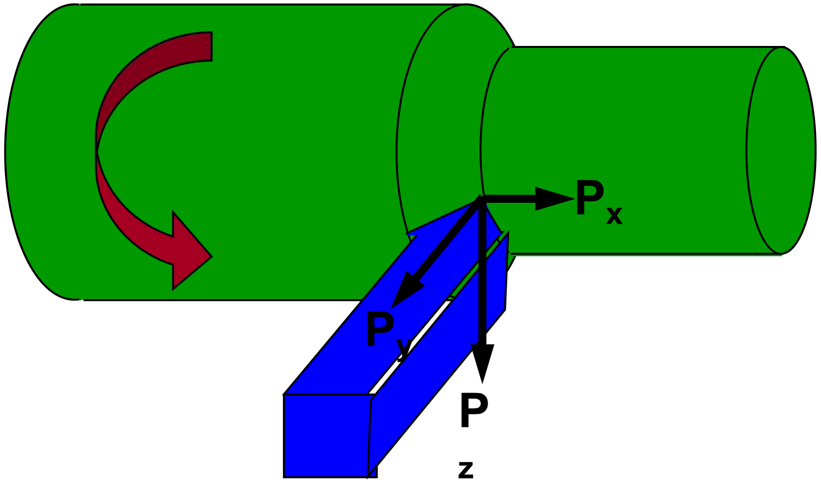
- **High carbon steels**
  - Carbon -0.8-1.6%
  - Making hand tools and general purpose machining tools for operating at low cutting speed (12m/min)
  - Cheaper, easy to forge and heat treat.
- **Cutting alloys**
  - Superior to high speed steel
  - Withstand high temperature(1100 Celsius)
  - More suitable for cutting metals at much higher cutting speeds removing larger volume of metal at faster rate.
- **Cast alloys (stellite, cobalt, black alloy)**
  - Comprise cobalt, chromium, tungsten and carbon
  - Superior to high speed steels because of higher red hardness (about 60 HRC upto 1000 Celsius)
  - Cobalt-38-53%, Tungsten-12-17%, carbon-2.25-2.75%

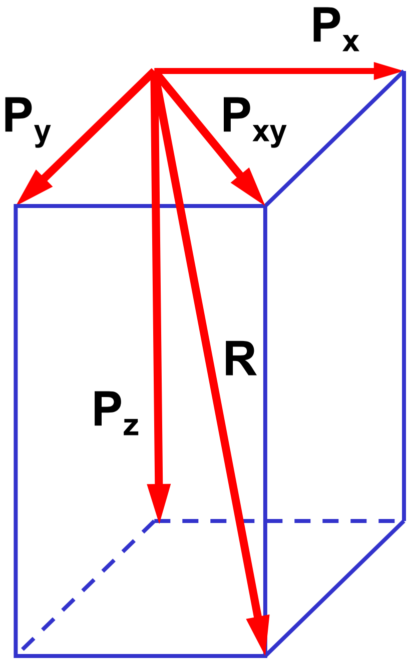
- **Cemented carbides**
  - Being costly are used in form of bits only (triangular, square, diamond)
  - High hot hardness and withstand high temperature(1200 Celsius)
  - Also used for making dies for wire drawing.
- Two types
  - Tungsten carbide
    - Hardness (1800-2400) used for cutting steels, cast iron and abrasive non ferrous materials.
  - Titanium carbide
    - High wear resistance(1800-3200)
    - Matrix of nickel molybdenum
    - Capable of machining hard steels and cast iron at higher speeds than that used with tungsten carbides.

- **Coated tools**
  - Coating materials- TiN, TiC, TiCN, Al2O3.
  - Coating thickness range 2-15 micrometre.
  - Method –CVD or PVD.
- **Ceramics tool materials**
  - Alumina- high hardness(2000-3000) and has moderate strength and toughness. Chemically more stable than high speed steels and carbide tools.
  - Zirconia- high strength and toughness, thermal expansion close to cast iron. They are used in heat engine components.
- **Diamond tools**
  - Hardest known material
  - Polycrystalline diamond – used for wire drawing dies, grinding wheels and abrasive coatings.
  - Run at cutting speeds 50 times higher than high speed tools.
  - Used for producing high surface finish on soft materials.
  - Single point tools – used in machining non ferrous alloys, ceramics, graphite, fibre glass and rubber,

CUTTING FORCES IN ORTHOGONAL CUTTING

- The force system in the general case of conventional turning process is shown in the following **Figure.**





P_x = **Axial feed force** or Thrust force acting in horizontal plane parallel to axis of work but in direction opposite to feed.

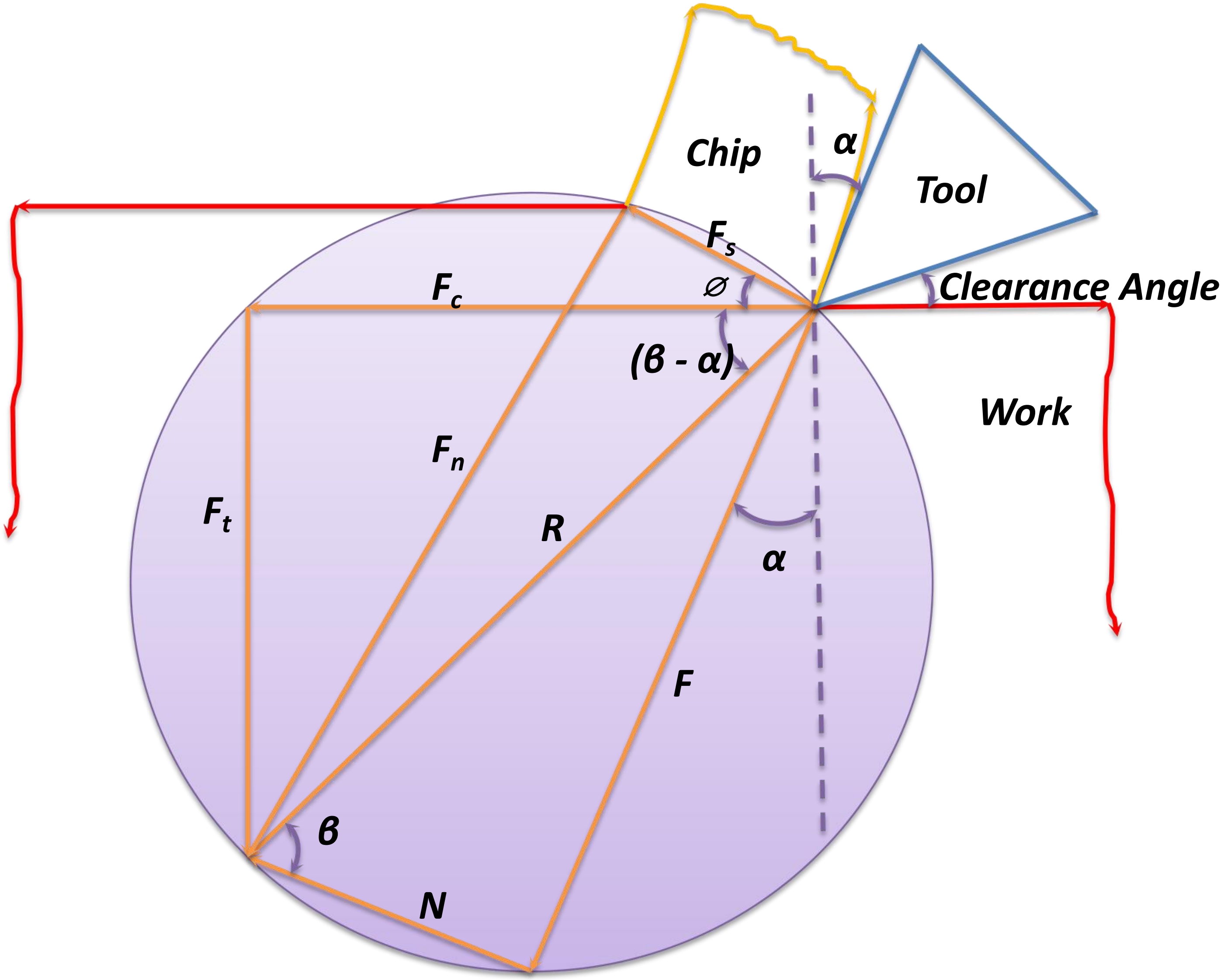
P_y = **Radial force** in the horizontal plane along radius of work ie)axis of tool.

P_z = **cutting force** or **tangential force** acting in vertical plane and tangential to work surface.

Merchants analysis

- **Merchant** established relationship between various forces acting on chip during orthogonal metal cutting but with following assumptions
  - Cutting velocity always remains constant.
  - Cutting edge of tool remains sharp always during cutting with no contact between work piece and tool flank.
  - Chip does not flow sideways.
  - Only continuous chip is produced.
  - There is no built-up edge.
  - No consideration is made of inertia force of chip.
  - Width of tool is greater than width of cut.
  - Behaviour of chip is like that a free body which is in the state of a stable equilibrium due to action of two resultant forces which are equal, opposite and collinear.

Merchant’s Circle Diagram



Machinability

- Machinability of material refers to ease with which it can be worked with a machine tool.
- **Criteria to evaluate machinability**
  - Tool life between grinds
  - Quality of surface finish
  - Power consumption
  - Form and size of chips
  - Cutting forces
  - Shear angle
  - Rate of metal removal under standard cutting conditions.

- **Factors responsible for increasing machinability**
  - Chemical composition(Pb, Mn, S, P)
  - Microstructure
  - Treatment given to metal(Hot working and cold working)
  - Less hardness, less ductility and less tensile strength
- **Machinability index**
- Machinability's of different metals are compared in terms of their machinability index.
- Machinability index%

$$= \frac{\text{cutting speed of metal investigated for 20min tool life}}{\text{cutting speed of a standard steel for20min tool life}} * 100$$

- SAE 1112 steel 100%(C:0.13, S:0.08-0.03%, Mn:0.06-1.10)
    - Low carbon steel-55 to 65%
    - Copper-70%
    - Stainless steel-25%
    - Brass-180%
    - Aluminium alloys-300 to 1500%
    - Magnesium alloys-500 to 2000%.
- **Excellent machinability-** Mg alloys, Al alloys, Zn alloys
- **Good machinability-** Red brass, Gun metal, Grey and malleable cast iron.
- **Poor machinability-** Low carbon steels, low alloy steels.
- **Fair machinability-** Stainless steel, sintered carbide, high speed steel.

Measurement of cutting forces

- **Need for measurement of cutting forces**
  - For analysing relationship among different forces acting during metal cutting, determining temperature at tool-chip interface, assessing tool wear.
  - Investigating machinability problems and tool life, wear, power requirement.
  - For helping in designing proper tool to meet process requirement.
  - Help in designing jigs and fixtures of adequate strength.
  - Analysing static and dynamic behaviour of machine tool an designing proper machine tool accordingly.

Measurement of cutting forces

- **Cutting forces**
- The forces which are normally required to be measured are Cutting force, Feed force, Shear force.
- The device used for measuring cutting forces are tool dynamometer or force dynamometer.
- The force in metal cutting is determined by measuring deflections or strains in elements supporting cutting tool.
- The design of tool dynamometer should be such as to give strains or displacements large enough to be measured accurately.
- **Types of tool dynamometer**
  - Mechanical dynamometer
  - Strain gauge type dynamometer
  - Pneumatic or hydraulic dynamometer
  - Electrical dynamometer
  - Piezoelectric dynamometer

Tool life

- Tool life is the time interval for which tool works satisfactorily between two successive grindings or resharpening of tool.
- Expressed in following ways:
  - Time period in minutes between two successive grindings of tool.
  - Number of components machined between two successive grindings
  - Volume of metal removed between two successive grindings.
- Volume of metal removed per minute(V_m):
  - $V_m = \pi D.t.f.N$, mm^3/min.
- Where
  - D=dia of work piece, mm
  - t= depth of cut, mm
  - f= feed, mm/rev
  - N= Number of revolution of job per minute.

- If T is the time for tool failure in minutes, then total volume of metal removed up to tool failure
  - = $V_m = \pi D.t.f.N.T$, m/min
- Wkt
  - Cutting speed $= V = \pi DN/1000$, m/min
  - $\pi DN = 1000V$
  - Tool life $(T_L) = 1000V.f.T.t$ (mm^3)

- **Factors affecting tool life**
  - Cutting speed
  - Feed and depth of cut
  - Tool geometry
  - Tool material
  - Work material
  - Nature of cutting
  - Rigidity of machine tool and work
  - Cutting fluids

Taylor’s tool life equation

Taylor’s tool life equation

- $Vt^n = C$

Where, V = cutting speed in m/min

t = tool life in minute

c = constant

n = index depends upon tool and work

Important definitions

- **Cutting speed** – speed at which the workpiece moves or rotates with respect to the tool.
- **Cutting speed** in lathe means the number of metres measured on circumference of rotating job that passes cutting edge of tool in one minute.
  - Cutting speed=V= $\pi DN/1000$, m/min
- **Depth of cut** – distance that tool bit moves in to work(usually measured in inches or mill meters). Volume of work piece material removed per unit time.
- **Depth of cut** is the advancement of tool in job in a direction perpendicular to surface being machined.
  - Depth of cut=$(d_1-d_2)/2$
    - d_1-dia of job before machining
    - d_2-dia of machined surface

- **Feed rate** – distance the tool travels one revolution of the part.
- **Feed rate** is amount of advancement of tool per revolution of job.
- It is usually given in millimetres per revolution of job.
  - Feed=L/(NT), mm/rev.
  - Where L=length of cut
    - N=rpm of job
  - T=machining time

Cutting speed and feed determines surface finish, power requirements and material removal rate.

- **Metal cutting -** It is a type of process in which a piece of raw material is cut into desired final shape and size by a controlled material-removal process.
- It is a type in which removal of material from work piece is effected by relative motion between cutting tool and work piece.
- **Metal removal rate(MRR)** – volume of material removed per unit time. Volume of metal removed is function of speed, feed and depth of cut as higher values of these, higher the metal removal rate.