LECTURE NOTES

ON

TOOL DESIGN

(B.Tech – V SEMESTER)

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UNIT-I

TOOL MATERIAL

Needs and Chronological Development of Cutting Tool Materials:

With the progress of the industrial world it has been needed to continuously develop and improve the cutting tool materials and geometry;

- To meet the growing demands for high productivity, quality and economy of machining
- To enable effective and efficient machining of the exotic materials that are coming up with the rapid and vast progress of science and technology
- For precision and ultra-precision machining
- For micro and even nano machining demanded by the day and future.

It is already stated that the capability and overall performance of the cutting tools depend upon,

- The cutting tool materials
- The cutting tool geometry
- Proper selection and use of those tools
- The machining conditions and the environments

Out of which the tool material plays the most vital role.

The relative contribution of the cutting tool materials on productivity, for instance, can be roughly assessed from Fig. 1.1

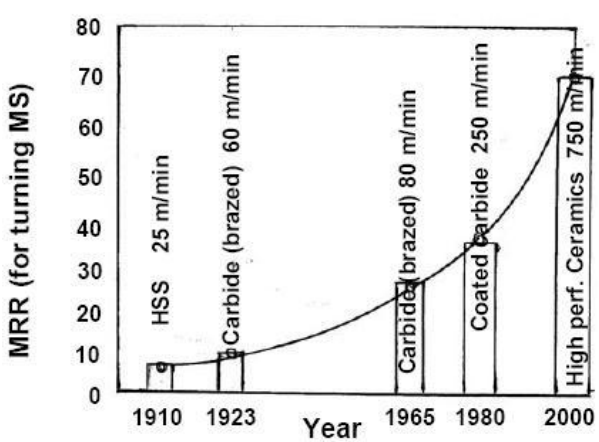

Fig. 1.1 Productivity raised by cutting tool materials.

The chronological development of cutting tool materials is briefly indicated in Fig. 1.2

Characteristics and Applications of the Primary Cutting Tool Materials:

(a) High Speed Steel (HSS)

Advent of HSS in around 1905 made a break through at that time in the history of cutting tool materials though got later superseded by many other novel tool materials like cemented carbides and ceramics which could machine much faster than the HSS tools.

The basic composition of HSS is 18% W, 4% Cr, 1% V, 0.7% C and rest Fe. Such HSS tool could machine (turn) mild steel jobs at speed only upto 20 ~ 30 m/min (which was quite substantial those days)

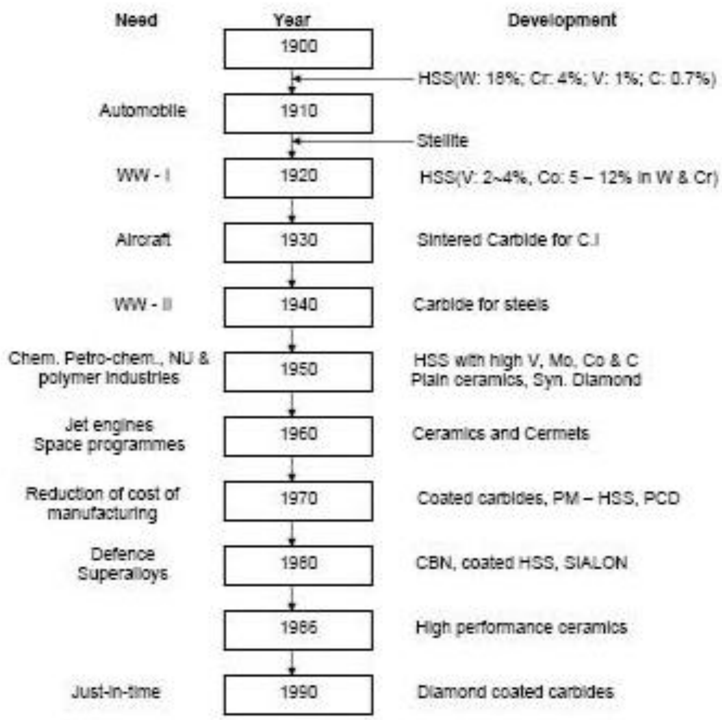

Fig. 1.2 *Chronological Development of cutting tool materials*

However, HSS is still used as cutting tool material where;

- The tool geometry and mechanics of chip formation are complex, such as helical twist drills, reamers, gear shaping cutters, hobs, form tools, broaches etc.
- Brittle tools like carbides, ceramics etc. are not suitable under shock loading
- The small scale industries cannot afford costlier tools
- The old or low powered small machine tools cannot accept high speed and feed.
- The tool is to be used number of times by re-sharpening.

With time the effectiveness and efficiency of HSS (tools) and their application range were gradually enhanced by improving its properties and surface condition through -

- Refinement of microstructure
- Addition of large amount of cobalt and Vanadium to increase hot hardness and wear resistance respectively
- Manufacture by powder metallurgical process
- Surface coating with heat and wear resistive materials like TiC, TiN, etc by Chemical Vapor Deposition (CVD) or Physical Vapor Deposition (PVD)

The commonly used grades of HSS are given in Table 1.1.

Table 1.1 Compositions and types of popular high speed steels

Type	C	W	Mo	Cr	V	Co	R_C
T – 1	0.70	18		4	1		
T – 4	0.75	18		4	1	5	
T – 6	0.80	20		4	2	12	
M – 2	0.80	6	5	4	2		64.7
M – 4	1.30	6	5	4	4		
M – 15	1.55	6	3	5	5	5	
M – 42	1.08	1.5	9.5	4	1.1	8	62.4

Addition of large amount of Co and V, refinement of microstructure and coating increased strength and wear resistance and thus enhanced productivity and life of the HSS tools remarkably.

(b) Stellite

This is a cast alloy of Co (40 to 50%), Cr (27 to 32%), W (14 to 19%) and C (2%). Stellite is quite tough and more heat and wear resistive than the basic HSS (18 – 4 – 1) But such stellite as cutting tool material became obsolete for its poor grindability and especially after the arrival of cemented carbides.

(c) Sintered Tungsten carbides

The advent of sintered carbides made another breakthrough in the history of cutting tool materials.

Straight or single carbide:

First the straight or single carbide tools or inserts were powder metallurgically produced by mixing, compacting and sintering 90 to 95% WC powder with cobalt. The hot, hard and wear resistant WC grains are held by the binder Co which provides the necessary strength and toughness. Such tools are suitable for machining grey cast iron, brass, bronze etc. which produce short discontinuous chips and at cutting velocities two to three times of that possible for HSS tools.

Disadvantages: The single carbide is not suitable for machining steels because of rapid growth of wear, particularly crater wear, by diffusion of Co and carbon from the tool to the chip under the high stress and temperature bulk (plastic) contact between the continuous chip and the tool surfaces.

Composite carbides:

For machining steels successfully, another type called composite carbide have been developed by adding (8 to 20%) a gamma phase to WC and Co mix. The gamma phase is a mix of TiC, TiN, TaC, NiC etc. which are more diffusion resistant than WC due to their more stability and less wettability by steel.

Mixed carbides:

Titanium carbide (TiC) is not only more stable but also much harder than WC. So for machining ferritic steels causing intensive diffusion and adhesion wear a large quantity (5 to 25%) of TiC is added with WC and Co to produce another grade called Mixed carbide. But increase in TiC content reduces the toughness of the tools. Therefore, for finishing with light cut but high speed, the harder grades containing upto 25% TiC are used and for heavy roughing work at lower speeds lesser amount (5 to 10%) of TiC is suitable.

Gradation of cemented carbides and their applications:

The standards developed by ISO for grouping of carbide tools and their application ranges are given in Table 1.2.

Table 1.2 Broad classifications of carbide tools.

ISO Code	Colour Code	Application
P		For machining long chip forming common materials like plain carbon and low alloy steels
M		For machining long or short chip forming ferrous materials like Stainless steel
K		For machining short chipping, ferrous and non-ferrous material and non-metals like Cast Iron, Brass etc.

- **K-group** is suitable for machining short chip producing ferrous and non-ferrous metals and also some non metals.
- **P-group** is suitably used for machining long chipping ferrous metals i.e. plain carbon and low alloy steels
- **M-group** is generally recommended for machining more difficult-to-machine materials like strain hardening austenitic steel and manganese steel etc

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Table 2.3 Detail grouping of cemented carbide tools

ISO Application group	Material	Process
P01	Steel, Steel castings	Precision and finish machining, high speed
P10	Steel, steel castings	Turning, threading and milling high speed, small chips
P20	Steel, steel castings, malleable cast iron	Turning, milling, medium speed with small chip section
P30	Steel, steel castings, malleable cast iron forming long chips	Turning, milling, low cutting speed, large chip section
P40	Steel and steel casting with sand inclusions	Turning, planning, low cutting speed, large chip section
P50	Steel and steel castings of medium or low tensile strength	Operations requiring high toughness turning, planning, shaping at low cutting speeds
K01	Hard grey C.I., chilled casting, Al. alloys with high silicon	Turning, precision turning and boring, milling, scraping
K10	Grey C.I. hardness > 220 HB. Malleable C.I., Al. alloys containing Si	Turning, milling, boring, reaming, broaching, scraping
K20	Grey C.I. hardness up to 220 HB	Turning, milling, broaching, requiring high toughness
K30	Soft grey C.I. Low tensile strength steel	Turning, reaming under favourable conditions
K40	Soft non-ferrous metals	Turning milling etc.
M10	Steel, steel castings, manganese steel, grey C.I.	Turning at medium or high cutting speed, medium chip section
M20	Steel casting, austentic steel, manganese steel, spherodized C.I., Malleable C.I.	Turning, milling, medium cutting speed and medium chip section
M30	Steel, austenitic steel, spherodized C.I. heat resisting alloys	Turning, milling, planning, medium cutting speed, medium or large chip section
M40	Free cutting steel, low tensile strength steel, brass and light alloy	Turning, profile turning, specially in automatic machines.

The smaller number refers to the operations which need more wear resistance and the larger numbers to those requiring higher toughness for the tool.

(d) Plain ceramics

Inherently high compressive strength, chemical stability and hot hardness of the ceramics led to powder metallurgical production of indexable ceramic tool inserts since 1950. Table 2.4 shows the advantages and limitations of alumina ceramics in contrast to sintered carbide. Alumina (Al_2O_3) is preferred to silicon nitride (Si_3N_4) for higher hardness and chemical stability. Si_3N_4 is tougher but again more difficult to process. The plain ceramic tools are brittle in nature and hence had limited applications.

Table 1.4 Cutting tool properties of alumina ceramics.

Advantages	Shortcoming
very high hardness	poor toughness
very high hot hardness	poor tensile strength
chemical stability	poor TRS
antiwelding	low thermal conductivity
less diffusivity	less density
high abrasion resistance	
high melting point	
very low thermal conductivity*	
very low thermal expansion coefficient	

*Cutting tool should resist penetration of heat but should disperse the heat throughout the core.

Basically three types of ceramic tool bits are available in the market;

- Plain alumina with traces of additives – these white or pink sintered inserts are cold pressed and are used mainly for machining cast iron and similar materials at speeds 200 to 250 m/min
- Alumina; with or without additives – hot pressed, black colour, hard and strong – used for machining steels and cast iron at Vc = 150 to 250 m/min
- Carbide ceramic (Al2 O3 + 30% TiC) cold or hot pressed, black colour, quite strong and enough tough – used for machining hard cast irons and plain and alloy steels at 150 to 200 m/min.

The plain ceramic outperformed the then existing tool materials in some application areas like high speed machining of softer steels mainly for higher hot hardness as indicated in Fig. 1.3

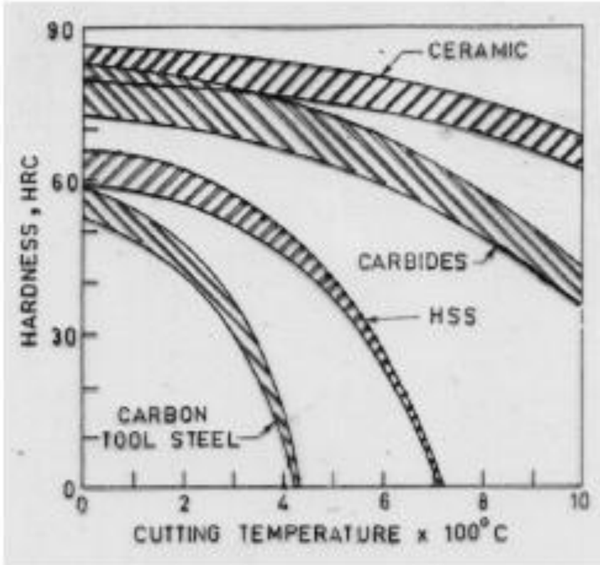


Fig. 1.3 Hot hardness of the different commonly used tool materials.(Ref. Book by A.Bhattacharya)

However, the use of those brittle plain ceramic tools, until their strength and toughness could be substantially improved since 1970, gradually decreased for being restricted to

- Uninterrupted machining of soft cast irons and steels only
- Relatively high cutting velocity but only in a narrow range (200 ~ 300 m/min)
- Requiring very rigid machine tools

Advent of coated carbide capable of machining cast iron and steels at high velocity made the then ceramics almost obsolete.

Coated carbides:

The properties and performance of carbide tools could be substantially improved by

- Refining microstructure
- Manufacturing by casting – expensive and uncommon
- Surface coating – made remarkable contribution.

Thin but hard coating of single or multilayers of more stable and heat and wear resistive materials like TiC, TiCN, TiOCN, TiN, Al2 O3 etc on the tough carbide inserts (substrate) (Fig. 2.4) by processes like chemical Vapour Deposition (CVD), Physical Vapour Deposition (PVD) etc at controlled pressure and temperature enhanced MRR and overall machining economy remarkably enabling,

- Reduction of cutting forces and power consumption
- Increase in tool life (by 200 to 500%) for same V or increase in V (by 50 to 150%) for same tool life
- Improvement in product quality
- Effective and efficient machining of wide range of work materials
- Pollution control by less or no use of cutting fluid through

- Reduction of abrasion, adhesion and diffusion wear
- Reduction of friction and BUE (Built up edge) formation
- Heat resistance and reduction of thermal cracking and plastic deformation

The contributions of the coating continue even after rupture of the coating as indicated in Fig. 1.5.

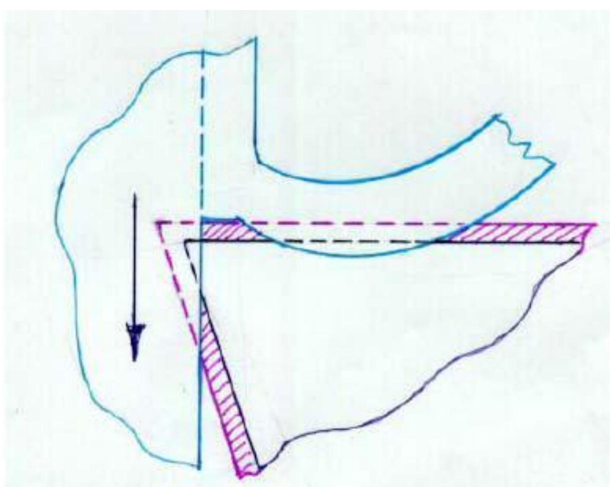


Fig. 1.5 Role of coating even after its wear and rupture

The cutting velocity range in machining mild steel could be enhanced from 120 ~ 150 m/min to 300 ~ 350 m/min by properly coating the suitable carbide inserts.

About 50% of the carbide tools being used at present are coated carbides which are obviously to some extent costlier than the uncoated tools.

Different varieties of coated tools are available. The appropriate one is selected depending upon the type of the cutting tool, work material and the desired productivity and product quality.

The properties and performances of coated inserts and tools are getting further improved by;

- Refining the microstructure of the coating
- Multilayering (already upto 13 layers within 12 ~ 16 μm)
- Direct coating by TiN instead of TiC, if feasible
- Using better coating materials.

Cutting Fluid:

The basic purposes of cutting fluid application are :

- Cooling of the job and the tool to reduce the detrimental effects of cutting temperature on the job and the tool
- Lubrication at the chip–tool interface and the tool flanks to reduce cutting forces and friction and thus the amount of heat generation.
- Cleaning the machining zone by washing away the chip – particles and debris which, if present, spoils the finished surface and accelerates damage of the cutting edges
- Protection of the nascent finished surface – a thin layer of the cutting fluid sticks to the machined surface and thus prevents its harmful contamination by the gases like SO , O , H S, N O present in the atmosphere.

However, the main aim of application of cutting fluid is to improve machinability through reduction of cutting forces and temperature, improvement by surface integrity and enhancement of tool life.

Essential properties of cutting fluids:

To enable the cutting fluid fulfill its functional requirements without harming the Machine – Fixture – Tool – Work (M-F-T-W) system and the operators, the cutting fluid should possess the following properties:

For cooling:

- High specific heat, thermal conductivity and film coefficient for heat transfer
- Spreading and wetting ability

For lubrication:

High lubricity without gumming and foaming

Wetting and spreading

High film boiling point

Friction reduction at extreme pressure (EP) and temperature

Chemical stability, non-corrosive to the materials of the M-F-T-W system

Less volatile and high flash point

High resistance to bacterial growth

Odorless and also preferably colorless

Non toxic in both liquid and gaseous stage

Easily available and low cost.

Types of cutting fluids and their application:

Generally, cutting fluids are employed in liquid form but occasionally also employed in gaseous form. Only for lubricating purpose, often solid lubricants are also employed in machining and grinding.

The cutting fluids, which are commonly used, are:

- **Air blast or compressed air only:** Machining of some materials like grey cast iron become inconvenient or difficult if any cutting fluid is employed in liquid form. In such case only air blast is recommended for cooling and cleaning

- **Water:** For its good wetting and spreading properties and very high specific heat, water is considered as the best coolant and hence employed where cooling is most urgent.

- **Soluble oil:** Water acts as the best coolant but does not lubricate. Besides, use of only water may impair the machine-fixture-tool-work system by rusting So oil containing some emulsifying agent and additive like EPA, together called cutting compound, is mixed with water in a suitable ratio (1 ~ 2 in 20 ~ 50). This milk like white emulsion, called soluble oil, is very common and widely used in machining and grinding.

- **Cutting oils:** Cutting oils are generally compounds of mineral oil to which are added desired type and amount of vegetable, animal or marine oils for improving spreading, wetting and lubricating properties. As and when required some EP additive is also mixed to reduce friction, adhesion and BUE formation in heavy cuts.

- **Chemical fluids:** These are occasionally used fluids which are water based where some organic and or inorganic materials are dissolved in water to enable desired cutting fluid action.

There are two types of such cutting fluid;

- Chemically inactive type – high cooling, anti-rusting and wetting but less lubricating
- Active (surface) type – moderate cooling and lubricating.
- **Solid or semi-solid lubricant:** Paste, waxes, soaps, graphite, Moly-disulphide (MoS_2) may also often be used, either applied directly to the workpiece or as an impregnant in the tool to reduce friction and thus cutting forces, temperature and tool wear.

- **Cryogenic cutting fluid:** Extremely cold (cryogenic) fluids (often in the form of gases) like liquid CO_2 or N_2 are used in some special cases for effective cooling without creating much environmental pollution and health hazards.

Selection of Cutting Fluid:

The benefit of application of cutting fluid largely depends upon proper selection of the type of the cutting fluid depending upon the work material, tool material and the machining condition. As for example, for high speed machining of not-difficult-to-machine materials greater cooling type fluids are preferred and for low speed machining of both conventional and difficult-to-machine materials greater lubricating type fluid is preferred. Selection of cutting fluids for machining some common engineering materials and operations are presented as follows:

Grey cast iron:

Generally dry for its self lubricating property

Air blast for cooling and flushing chips

Soluble oil for cooling and flushing chips in high speed machining and grinding

Steels:

If machined by HSS tools, sol. Oil (1: 20 ~30) for low carbon and alloy steels and neat oil with EPA for heavy cuts.

If machined by carbide tools thinner sol. Oil for low strength steel, thicker sol. Oil (1:10 ~ for stronger steels and straight sulphurised oil for heavy and low speed cuts and EP cutting oil for high alloy steel.

Often steels are machined dry by carbide tools for preventing thermal shocks.

- Aluminium and its alloys:
  - Preferably machined dry
  - Light but only soluble oil
  - Straight neat oil or kerosene oil for stringent cuts.
- Copper and its alloys :
  - Water based fluids are generally used
  - Oil with or without inactive EPA for tougher grades of Cu-alloy.
- Stainless steels and Heat resistant alloys:
  - High performance soluble oil or neat oil with high concentration with chlorinated EP additive.

The brittle ceramics and cermets should be used either under dry condition or light neat oil in case of fine finishing.

Grinding at high speed needs cooling (1: 50 ~ 100) soluble oil. For finish grinding of metals and alloys low viscosity neat oil is also used.

Sources and causes of heat generation and development of temperature in machining:

During machining heat is generated at the cutting point from three sources, as indicated in Fig. 1.6. Those sources and causes of development of cutting temperature are:

- Primary shear zone (1) where the major part of the energy is converted into heat
- Secondary deformation zone (2) at the chip – tool interface where further heat is generated due to rubbing and / or shear
- At the worn out flanks (3) due to rubbing between the tool and the finished surfaces.

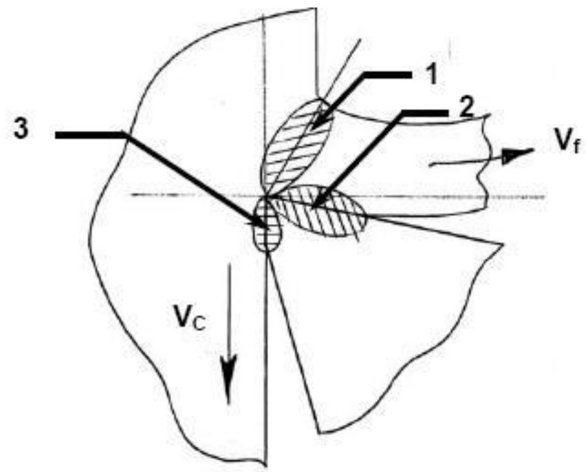


Figure 1.6 Sources of Heat Generation in Machining

The heat generated is shared by the chip, cutting tool and the blank. The apportionment of sharing that heat depends upon the configuration, size and thermal conductivity of the tool – work material and the cutting condition. Fig. 1.7 visualises that maximum amount of heat is carried away by the flowing chip. From 10 to 20% of the total heat goes into the tool and some heat is absorbed in the blank. With the increase in cutting velocity, the chip shares heat increasingly.

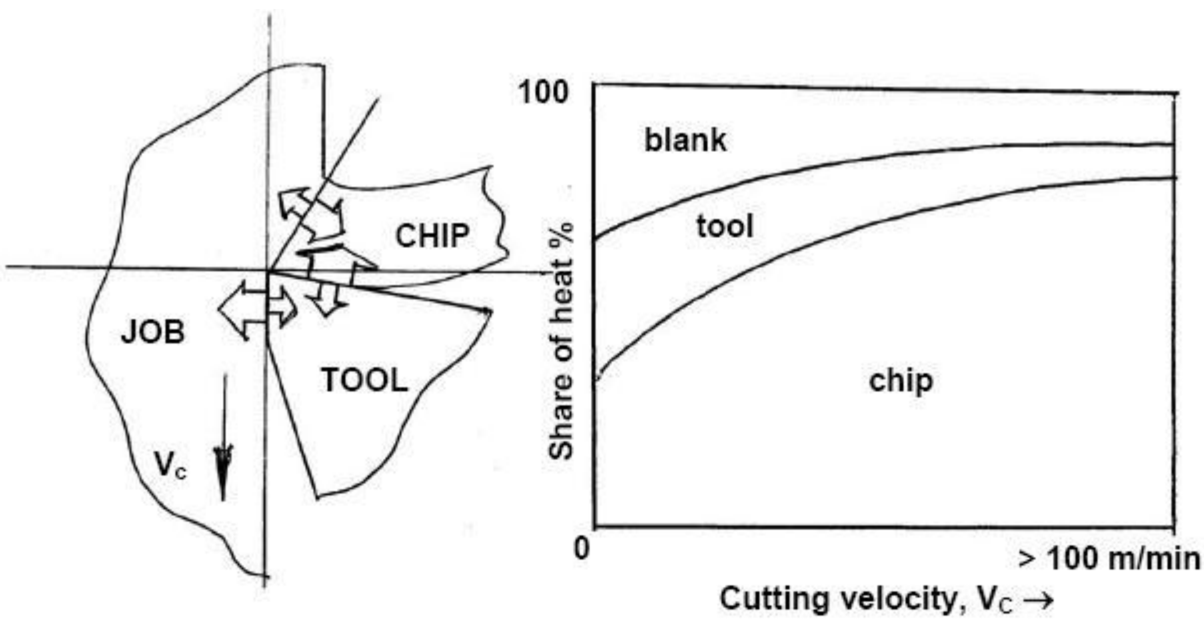


Figure 1.7 Apportionment of heat among chip, tool and blank

Determination of cutting temperature:

The magnitude of the cutting temperature need to be known or evaluated to facilitate

- Assessment of machinability which is judged mainly by cutting forces and temperature and tool life
- Design and selection of cutting tools
- Evaluate the role of variation of the different machining parameters on cutting temperature
- Proper selection and application of cutting fluid
- Analysis of temperature distribution in the chip, tool and job.

The temperatures which are of major interests are:

θ_s : Average shear zone temperature

θ_i : Average (and maximum) temperature at the chip-tool interface

θ_f : Temperature at the work-tool interface (tool flanks)

θ_{avg} : Average cutting temperature

Cutting temperature can be determined by two ways:

- Analytically – using mathematical models (equations) if available or can be developed. This method is simple, quick and inexpensive but less accurate and precise.
- Experimentally – this method is more accurate, precise and reliable.

Experimental methods of determination of cutting temperature:

Amongst θ_S, θ_i, and θ_f, θ_i is obviously the highest one and its value is maximum almost at the middle of the chip – tool contact length. Experimental methods generally provide the average or maximum value of θ_i. Some techniques also enable get even distribution of temperature in the chip, tool and job at the cutting zone.

The feasible experimental methods are:

- Calorimetric method – quite simple and low cost but inaccurate and gives only grand average value
- Decolourising agent – some paint or tape, which change in colour with variation of temperature, is pasted on the tool or job near the cutting point; the as such colour of the chip (steels) may also often indicate cutting temperature
- Tool-work thermocouple – simple and inexpensive but gives only average or maximum value

- Moving thermocouple technique
- Embedded thermocouple technique
- Using compound tool
- Indirectly from Hardness and structural transformation
- Photo-cell technique
- Infra ray detection method

The aforesaid methods are all feasible but vary w.r.t. accuracy, preciseness and reliability as well as complexity or difficulties and expensiveness.

Some of the methods commonly used are briefly presented here.

Tool work thermocouple technique:

Fig. 1.8 shows the principle of this method.

In a thermocouple two dissimilar but electrically conductive metals are connected at two junctions. Whenever, one of the junctions is heated, the difference in temperature at the hot and cold junctions produce a proportional current. This is detected and measured by a milli-voltmeter. In machining like turning, the tool and the job constitute the two dissimilar metals and the cutting zone functions as the hot junction. Then the average cutting temperature is evaluated from the mV after thorough calibration for establishing the exact relation between mV and the cutting temperature.

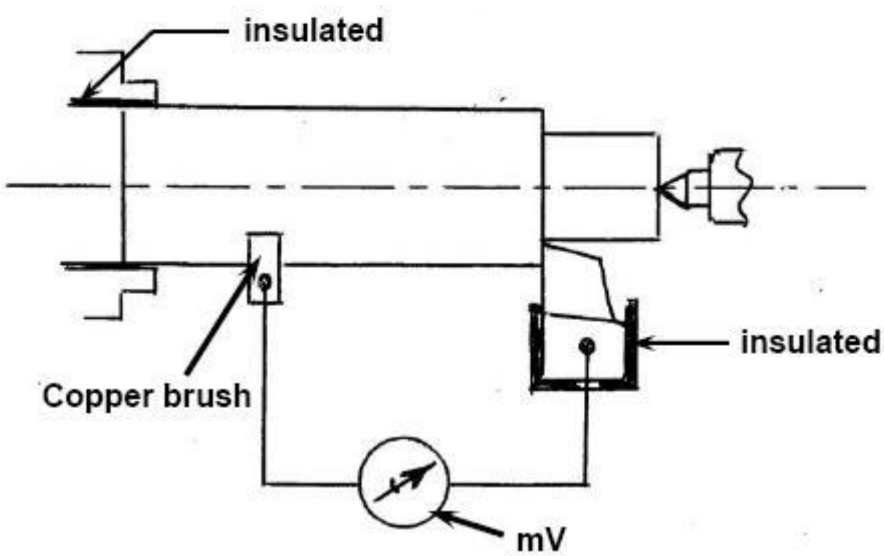


Fig. 1.8 Tool-work thermocouple technique of measuring cutting temperature.

UNIT-II

DESIGN OF CUTTING TOOLS

Geometry of single point turning tools:

Both material and geometry of the cutting tools play very important roles on their performances in achieving

- Effectiveness,
- Efficiency and
- Overall economy of machining.

Cutting tools may be classified according to the number of major cutting edges (points) involved as follows:

1. Single point: e.g., turning tools, shaping, planning and slotting tools and boring tools
2. Double (two) point: e.g., drills
3. Multipoint (more than two): e.g., milling cutters, broaching tools, hobs, gear shaping cutters etc.

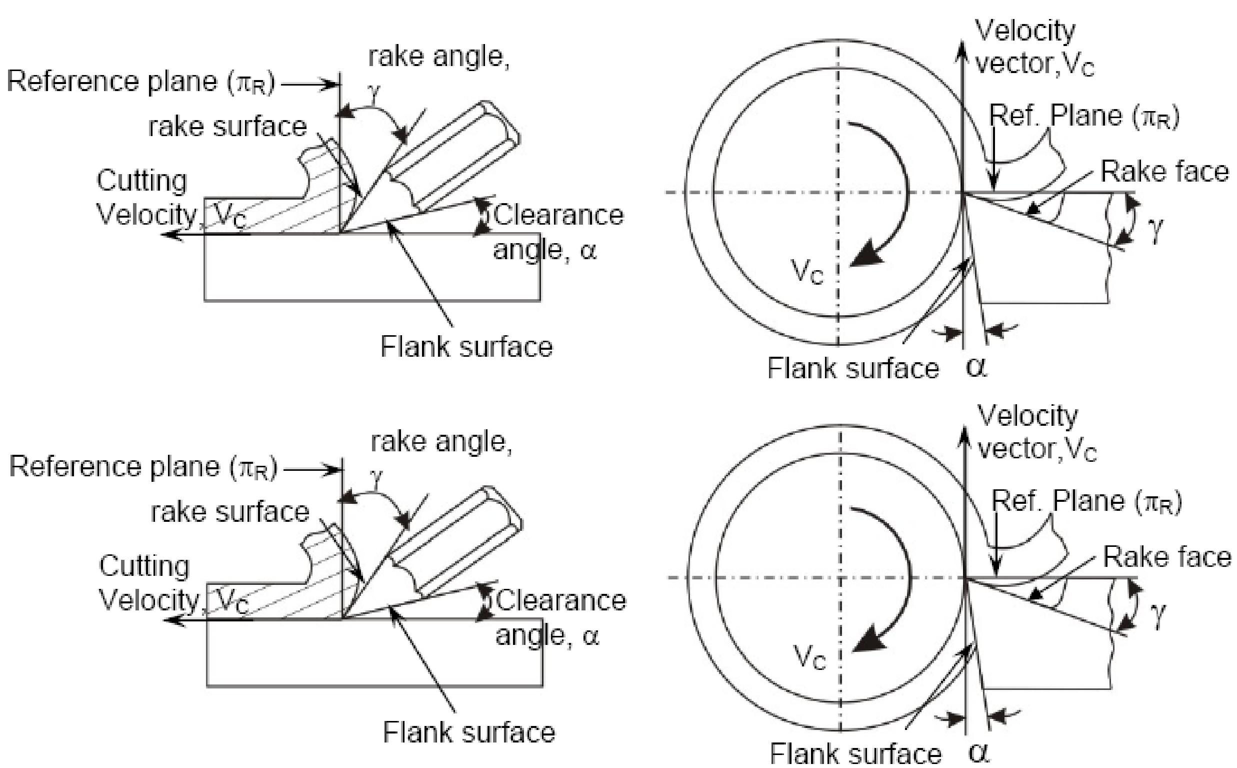
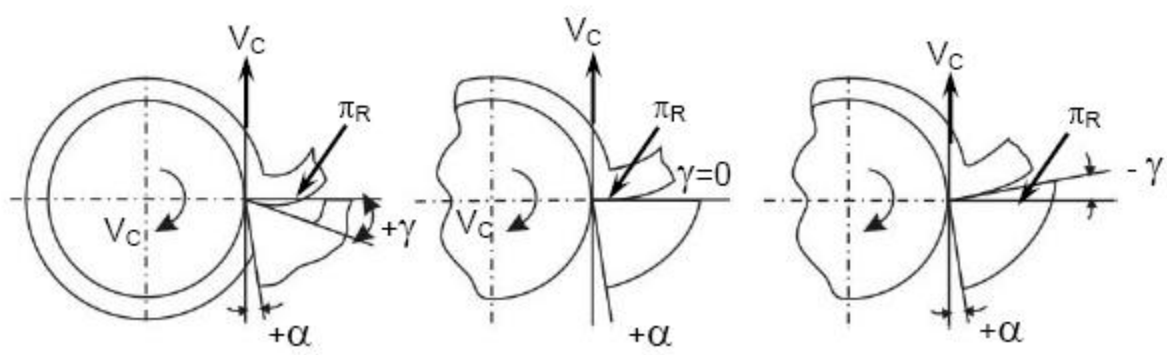


Fig: Rake and clearance angles of cutting tools

Definition:

- Rake angle (γ): Angle of inclination of rake surface from reference plane.
- Clearance angle (α): Angle of inclination of clearance or flank surface from the finished surface

Rake angle: is provided for ease of chip flow and overall machining. Rake angle may be positive, or negative or even zero as shown in Fig below.



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

Fig: Three possible types of rake angles

Relative advantages of such rake angles are:

- Positive rake – helps reduce cutting force and thus cutting power requirement.
- Negative rake – to increase edge-strength and life of the tool
- Zero rake – to simplify design and manufacture of the form tools.

Clearance angle: is essentially provided to avoid rubbing of the tool (flank) with the machined surface which causes loss of energy and damages of both the tool and the job surface. Hence, clearance angle is a must and must be positive (3^o ~ 15^o depending upon tool-work materials and type of the machining operations like turning, drilling, boring etc.)

(ii) Systems of description of tool geometry

• Tool-in-Hand System – where only the salient features of the cutting tool point are identified or visualized as shown in Fig. 1.3. There is no quantitative information, i.e., value of the angles.

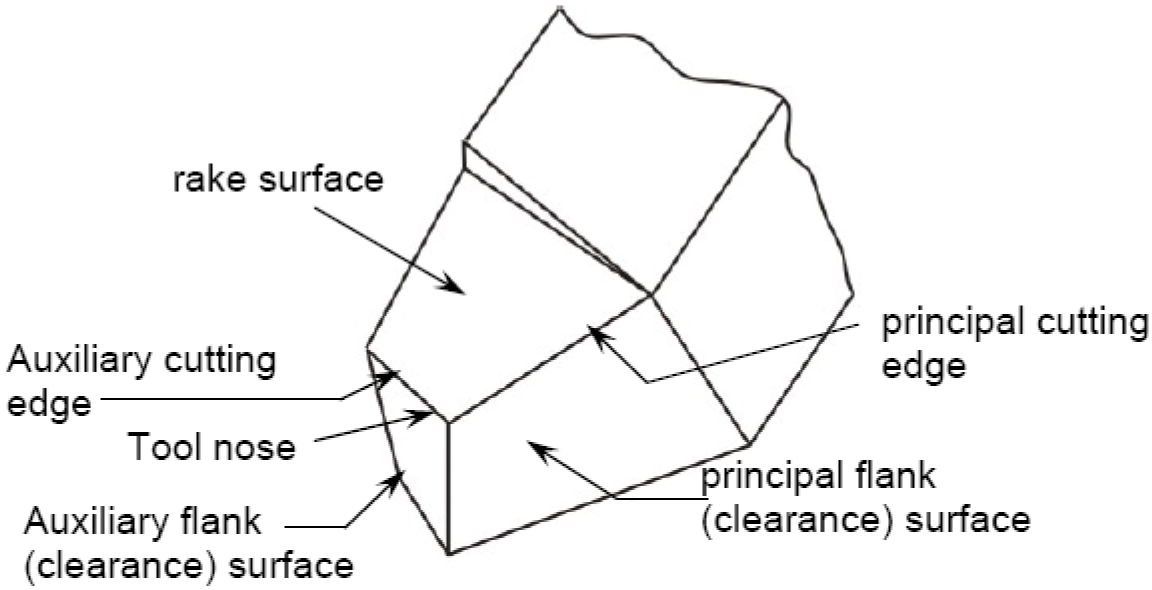


Fig: Basic features of single point tool (turning) in Tool-in-hand system

Machine Reference System – ASA system

Tool Reference Systems

- Orthogonal Rake System – ORS
- Normal Rake System – NRS

Work Reference System – WRS

(iii) Demonstration (expression) of tool geometry in:

Machine Reference System:

This system is also called ASA system; ASA stands for American Standards Association. Geometry of a cutting tool refers mainly to its several angles or slope of its salient working surfaces and cutting edges. Those angles are expressed w.r.t. some planes of reference. In Machine Reference System (ASA), the three planes of reference and the coordinates are chosen based on the configuration and axes of the machine tool concerned. The planes and axes used for expressing tool geometry in ASA system for turning operation are shown in Fig. below.

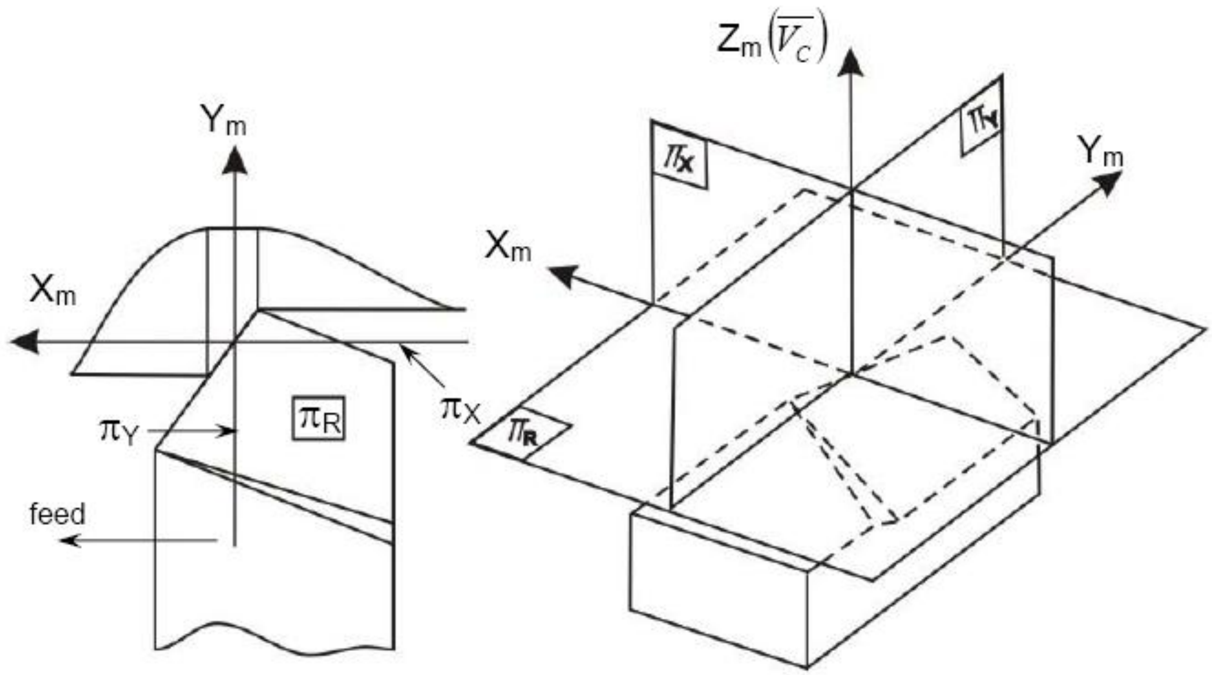


Fig: Planes and axes of reference in ASA system **feed**

The planes of reference and the coordinates used in ASA system for tool geometry are:

π_R - π_X - π_Y and X_m – Y_m - Z_m

Where,

π_R = Reference plane; plane perpendicular to the velocity vector (shown in Fig. 1.4)

π_X = Machine longitudinal plane; plane perpendicular to π_R and taken in the direction of assumed longitudinal feed

π_Y = Machine Transverse plane; plane perpendicular to both π_R and π_X [This plane is taken in the direction of assumed cross feed]

The axes X_m, Y_m and Z_m are in the direction of longitudinal feed, cross feed and cutting velocity (vector) respectively. The main geometrical features and angles of single point tools in ASA systems and their definitions will be clear from Fig below.

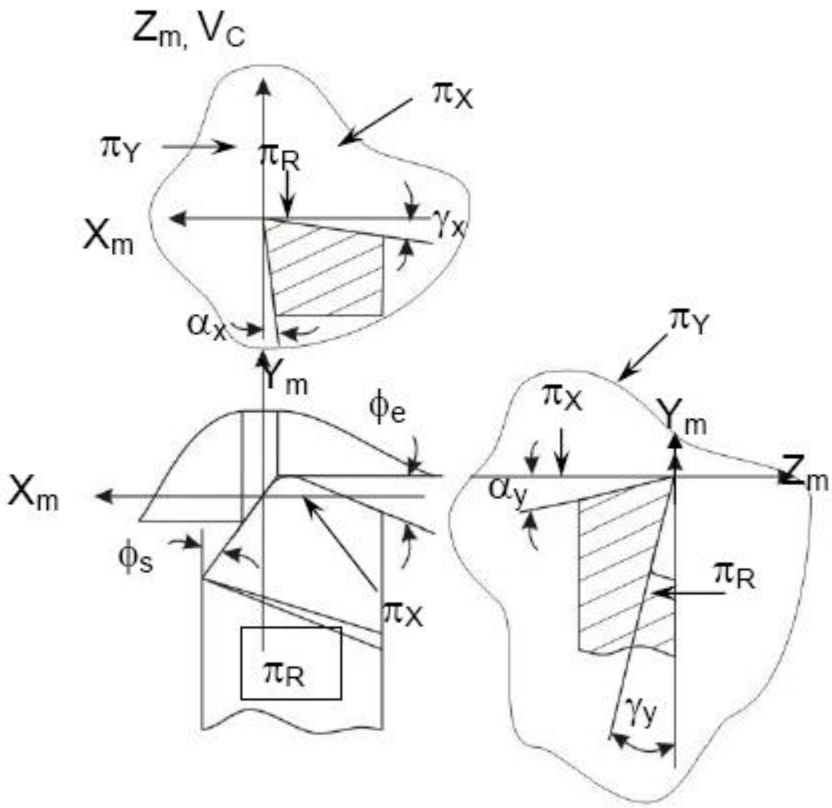


Fig: Tool angles in ASA system

Rake angles: in ASA system:

γ_x = side (axial rake: angle of inclination of the rake surface from the reference plane (π_R) and easured on Machine Ref. Plane, π_X.

γ_y = back rake: angle of inclination of the rake surface from the reference plane and measured on Machine Transverse plane, π_Y.

Clearance angles:

α_x = side clearance: angle of inclination of the principal flank from the machined surface (or CV) and measured on π_X plane.

α_y = back clearance: same as α_x but measured on π_Y plane.

Cutting angles:

φ_s = approach angle: angle between the principal cutting edge (its projection on π_R) and π_Y and measured on π_R

φ_e = end cutting edge angle: angle between the end cutting edge (its projection on π_R) from π_X and measured on π_R

Nose radius, r (in inch):

r = nose radius : curvature of the tool tip. It provides strengthening of the tool nose and better surface finish.

Tool Reference Systems

Orthogonal Rake System – ORS:

This system is also known as ISO – old.

The planes of reference and the co-ordinate axes used for expressing the tool angles in ORS are:

π_R - π_C - π_O and X_o - Y_o - Z_o

which are taken in respect of the tool configuration as indicated in Fig below.

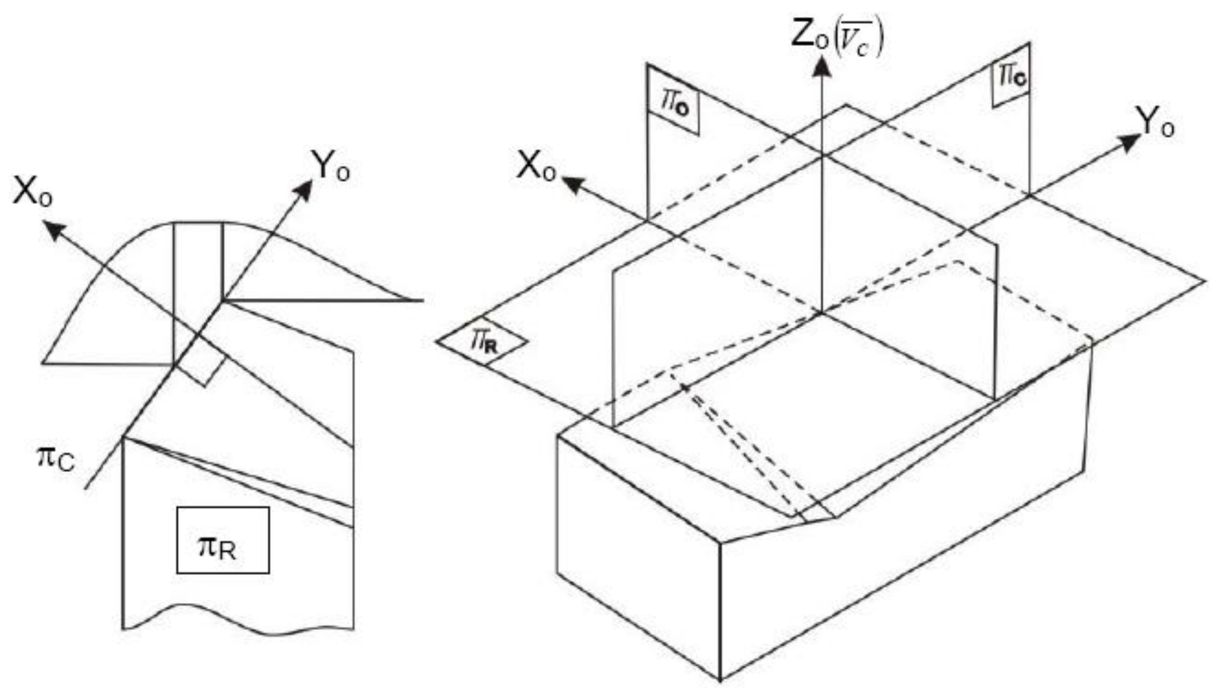


Fig: Planes and axes of reference in OR

Where,

π_R = Reference plane perpendicular to the cutting velocity vector, CV

π_C = cutting plane; plane perpendicular to π_R and taken along the principal cutting edge

π_O = Orthogonal plane; plane perpendicular to both π_R and π_C

and the axes;

X_o = along the line of intersection of π_R and π_O

Y_o = along the line of intersection of π_R and π_C

Z_o = along the velocity vector, i.e., normal to both X_o and Y_o axes.

The main geometrical angles used to express tool geometry in Orthogonal Rake System (ORS) and their definitions will be clear from Fig. below.

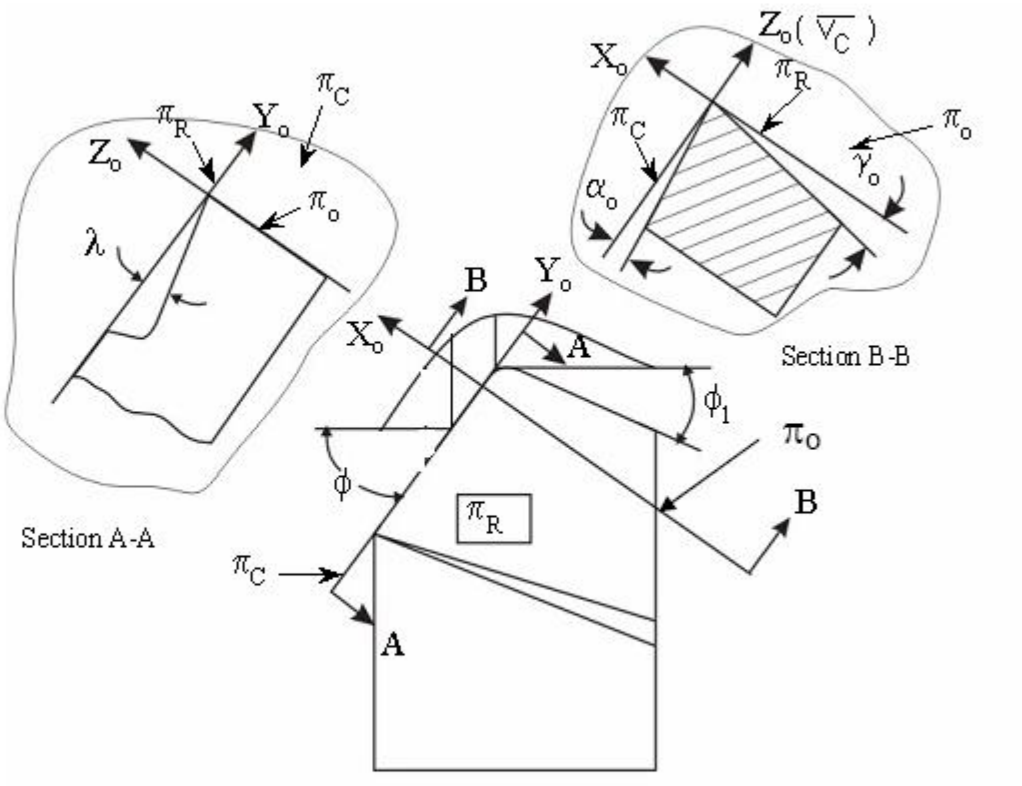


Fig: Tool angles in ORS system

Definition of **Rake angles in ORS:**

$\gamma_{\mathbf{o}}$ = orthogonal rake: angle of inclination of the rake surface from Reference plane, $\pi_{\mathbf{R}}$ and measured on the orthogonal plane, $\pi_{\mathbf{o}}$

λ = inclination angle; angle between $\pi_{\mathbf{C}}$ from the direction of assumed longitudinal feed [π_X] and measured on $\pi_{\mathbf{C}}$

Clearance angles:

$\alpha_{\mathbf{o}}$ = orthogonal clearance of the principal flank: angle of inclination of the principal flank from π_C and measured on $\pi_{\mathbf{o}}$

α_o' = auxiliary orthogonal clearance: angle of inclination of the auxiliary flank from auxiliary cutting plane, π_C' and measured on auxiliary orthogonal plane, π_o' as indicated in Fig below.

Cutting angles:

φ = principal cutting edge angle: angle between π_C and the direction of assumed longitudinal feed or π_X and measured on π_R

φ_1 = auxiliary cutting angle: angle between π_C' and π_X and measured on π_R

Nose radius, r (mm):

r = radius of curvature of tool tip

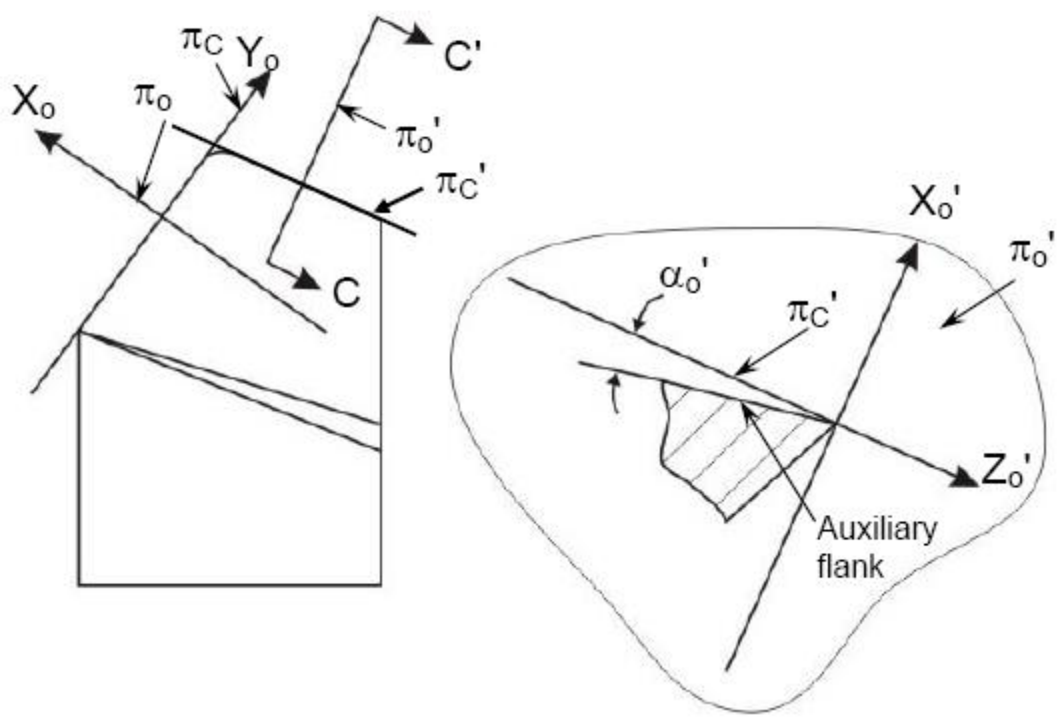


Fig: Auxiliary orthogonal clearance angle

Normal Rake System – NRS:

This system is also known as ISO – new.
ASA system has limited advantage and use like convenience of inspection. But ORS is advantageously used for analysis and research in machining and tool performance. But ORS does not reveal the true picture of the tool geometry when the cutting edges are inclined from the reference plane, i.e., $\lambda \neq 0$. Besides, sharpening or re-sharpening, if necessary, of the tool by grinding in ORS requires some additional calculations for correction of angles.

These two limitations of ORS are overcome by using NRS for description and use of tool geometry.

The basic difference between ORS and NRS is the fact that in ORS, rake and clearance angles are visualized in the orthogonal plane, π_o, whereas in NRS those angles are visualized in another plane called Normal plane, π_N. The orthogonal plane, π_o is simply normal to π_R and π_C irrespective of the inclination of the cutting edges, i.e., λ, but π_N (and π_N' for auxiliary cutting edge) is always normal to the cutting edge. The differences between ORS and NRS have been depicted in Fig. 1.9.

The planes of reference and the coordinates used in NRS are:

π_{RN} - π_C - π_N and $X_n – Y_n – Z_n$

where,

π_{RN} = normal reference plane

π_N = Normal plane: plane normal to the cutting edge

and

$X_n = X_o$

Y_n = cutting edge

Z_n = normal to X_n and Y_n

It is to be noted that when $\lambda = 0$, NRS and ORS become same, i.e. $\pi_o \cong \pi_N$, $Y_N \cong Y_o$ and $Z_n \cong Z_o$.

Definition (in NRS) of **Rake angles:**

γ_n = normal rake: angle of inclination angle of the rake surface from π_R and measured on normal plane, π_N

α_n = normal clearance: angle of inclination of the principal flank from π_C and measured on π_N

α_n'= auxiliary clearance angle: normal clearance of the auxiliary flank (measured on π_N' – plane normal to the auxiliary cutting edge.

The cutting angles, φ and φ_1 and nose radius, r (mm) are same in ORS and NRS.

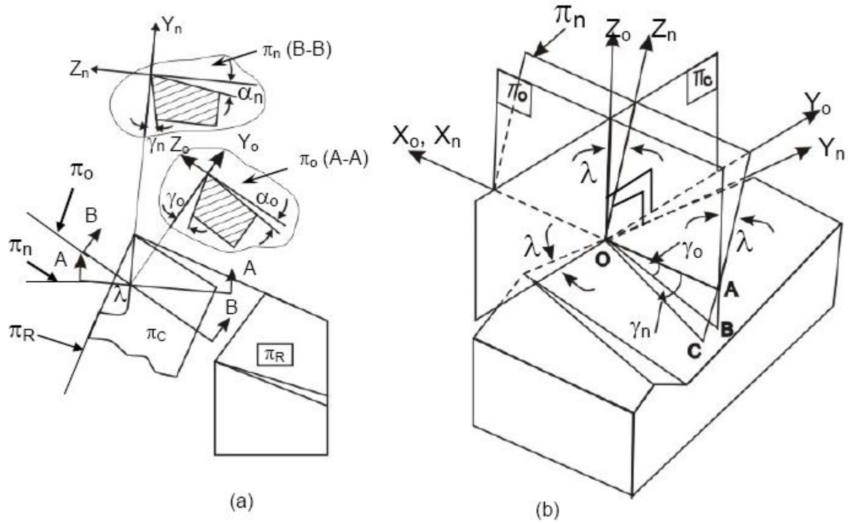


Fig: Differences of NRS from ORS w.r.t. cutting tool geometry.

(b) Designation of tool geometry

The geometry of a single point tool is designated or specified by a series of values of the salient angles and nose radius arranged in a definite sequence as follows:

Designation (signature) of tool geometry in

- ASA System – γ_y, γ_x, α_y, α_x, φ_e, φ_s, r (inch)
- ORS System – λ, γ_o, α_o, α_o’, φ_1, φ, r (mm)
- NRS System – λ, γ_n, α_n, α_n’, φ_1, φ, r (mm)

Failure of cutting tools and tool life:

(i) Failure of cutting tools:

Smooth, safe and economic machining necessitate

- Prevention of premature and catastrophic failure of the cutting tools
- Reduction of rate of wear of tool to prolong its life

To accomplish the aforesaid objectives one should first know why and how the cutting tools fail.

Cutting tools generally fail by:

i) Mechanical breakage due to excessive forces and shocks. Such kind of tool failure is random and catastrophic in nature and hence are extremely detrimental.

ii) Quick dulling by plastic deformation due to intensive stresses and temperature. This type of failure also occurs rapidly and are quite detrimental and unwanted.

iii) Gradual wear of the cutting tool at its flanks and rake surface.

The first two modes of tool failure are very harmful not only for the tool but also for the job and the machine tool. Hence these kinds of tool failure need to be prevented by using suitable tool materials and geometry depending upon the work material and cutting condition.

But failure by gradual wear, which is inevitable, cannot be prevented but can be slowed down only to enhance the service life of the tool.

The cutting tool is withdrawn immediately after it fails or, if possible, just before it totally fails. For that one must understand that the tool has failed or is going to fail shortly.

It is understood or considered that the tool has failed or about to fail by one or more of the following conditions:

(a) In R&D laboratories

- Total breakage of the tool or tool tip(s)
- Massive fracture at the cutting edge(s)
- Excessive increase in cutting forces and/or vibration
- Average wear (flank or crater) reaches its specified limit(s)

(b) In machining industries

- Excessive (beyond limit) current or power consumption
- Excessive vibration and/or abnormal sound (chatter)
- Total breakage of the tool
- Dimensional deviation beyond tolerance
- Rapid worsening of surface finish
- Adverse chip formation.

(ii) Mechanisms and pattern (geometry) of cutting tool wear:

For the purpose of controlling tool wear one must understand the various mechanisms of wear, that the cutting tool undergoes under different conditions.

The common mechanisms of cutting tool wear are :

i) Mechanical wear

- Thermally insensitive type; like abrasion, chipping and delamination
- Thermally sensitive type; like adhesion, fracturing, flaking etc.

ii) Thermochemical wear

- Macro-diffusion by mass dissolution

- Micro-diffusion by atomic migration

iii) Chemical wear

iv) Galvanic wear

In diffusion wear the material from the tool at its rubbing surfaces, particularly at the rake surface gradually diffuses into the flowing chips either in bulk or atom by atom when the tool material has chemical affinity or solid solubility towards the work material. The rate of such tool wear increases with the increase in temperature at the cutting zone.

Diffusion wear becomes predominant when the cutting temperature becomes very high due to high cutting velocity and high strength of the work material.

Chemical wear, leading to damages like grooving wear may occur if the tool material is not enough chemically stable against the work material and/or the atmospheric gases.

Galvanic wear, based on electrochemical dissolution, seldom occurs when both the work tool materials are electrically conductive, cutting zone temperature is high and the cutting fluid acts as an electrolyte.

The usual pattern or geometry of wear of turning and face milling inserts are typically shown in Figures respectively.

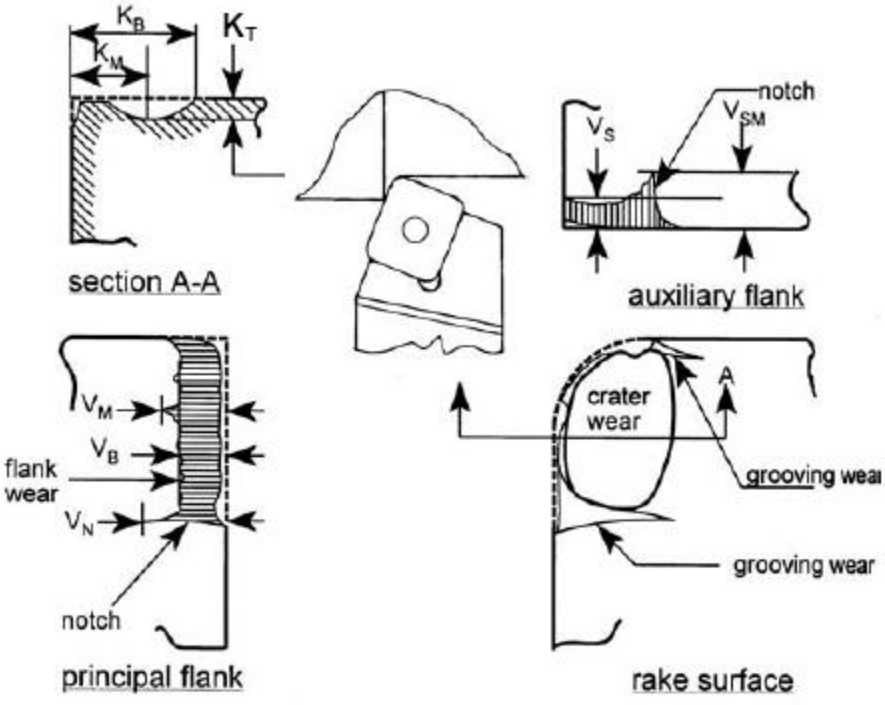


Fig: Geometry and major features of wear of turning tools

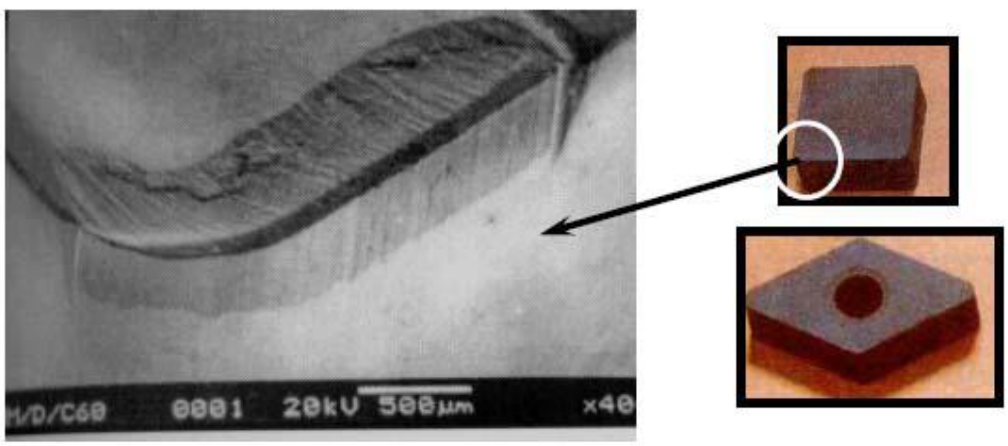


Fig: Photographic view of the wear pattern of a turning tool insert

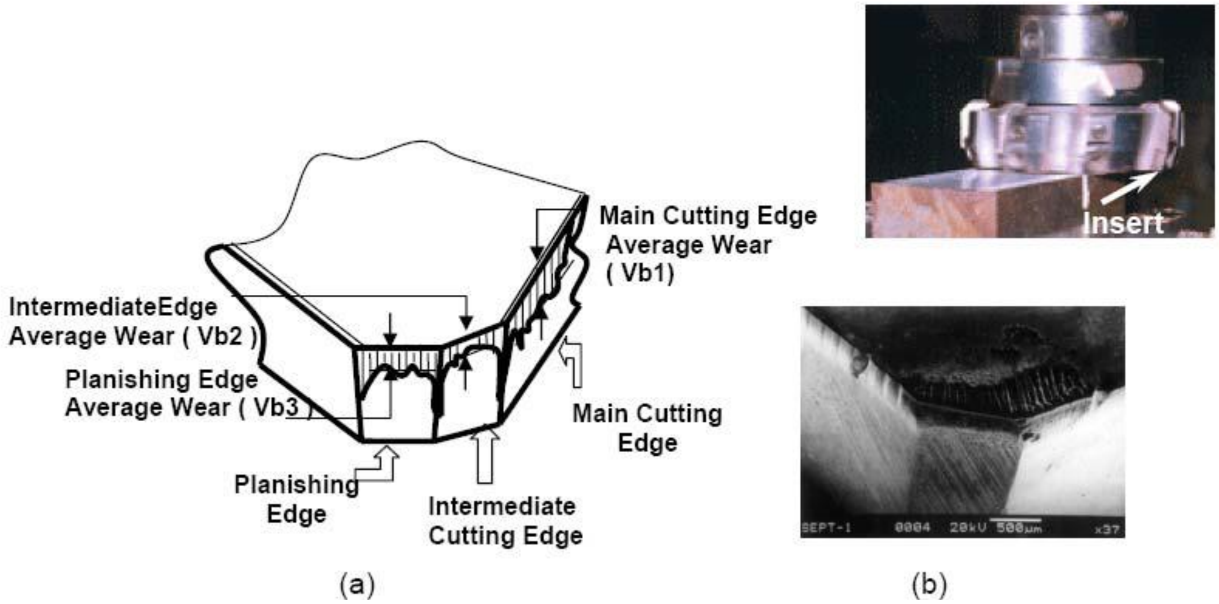


Fig: Schematic (a) and actual view (b) of wear pattern of face milling insert

In addition to ultimate failure of the tool, the following effects are also caused by the growing tool-wear:

- Increase in cutting forces and power consumption mainly due to the principal flank wear
- Increase in dimensional deviation and surface roughness mainly due to wear of the tool-tips and auxiliary flank wear (V_s)
- Odd sound and vibration
- Worsening surface integrity
- Mechanically weakening of the tool tip.

(iii) Essential properties for cutting tool materials:

The cutting tools need to be capable to meet the growing demands for higher productivity and economy as well as to machine the exotic materials which are coming up with the rapid progress in science and technology.

The cutting tool material of the day and future essentially require the following properties to resist or retard the phenomena leading to random or early tool failure:

1. High mechanical strength; compressive, tensile, and TRA
2. Fracture toughness – high or at least adequate

3. High hardness for abrasion resistance
4. High hot hardness to resist plastic deformation and reduce wear rate at elevated temperature
5. Chemical stability or inertness against work material, atmospheric gases and cutting fluids
6. Resistance to adhesion and diffusion
7. Thermal conductivity – low at the surface to resist incoming of heat and high at the core to quickly dissipate the heat entered
8. High heat resistance and stiffness
9. Manufacturability, availability and low cost.

Tool Life:

Definition – Tool life generally indicates the amount of satisfactory performance or service rendered by a fresh tool or a cutting point till it is declared failed.

Tool life is defined in two ways:

(a) **In R & D:**

- Actual machining time (period) by which a fresh cutting tool (or point) satisfactorily works after which it needs replacement or reconditioning.
- The modern tools hardly fail prematurely or abruptly by mechanical breakage or rapid plastic deformation.
- Those fail mostly by wearing process which systematically grows slowly with machining time.
- In that case, **t**ool life means the span of actual machining time by which a fresh tool can work before attaining the specified limit of tool wear.
- Mostly tool life is decided by the machining time till flank wear, V_B reaches 0.3 mm or crater wear, K_T reaches 0.15 mm.

(b) **In industries or shop floor**

- The length of time of satisfactory service or amount of acceptable output provided by a fresh tool prior to it is required to replace or recondition.

Assessment of tool life

- For R & D purposes, tool life is always assessed or expressed by span of machining time in minutes,

Whereas, in industries besides machining time in minutes some other means are also used to assess tool life, depending upon the situation, such as

- No. of pieces of work machined
- Total volume of material removed
- Total length of cut.

Measurement of tool wear

The various methods are :

1. By loss of tool material in volume or weight, in one life time – this method is crude and is generally applicable for critical tools like grinding wheels.
2. By grooving and indentation method – in this approximate method wear depth is measured indirectly by the difference in length of the groove or the indentation outside and inside the worn area
3. Using optical microscope fitted with micrometer – very common and effective method
4. Using scanning electron microscope (SEM) – used generally, for detailed study; both qualitative and quantitative
5. Talysurf, especially for shallow crater wear.

Taylor's tool life equation:

- Wear and hence tool life of any tool for any work material is governed mainly by the level of the machining parameters i.e., cutting velocity, (V_C), feed, (s_o) and depth of cut (t).
- Cutting velocity affects maximum and depth of cut minimum.

The usual pattern of growth of cutting tool wear (mainly V_B), principle of assessing tool life and its dependence on cutting velocity are schematically shown in Fig below.

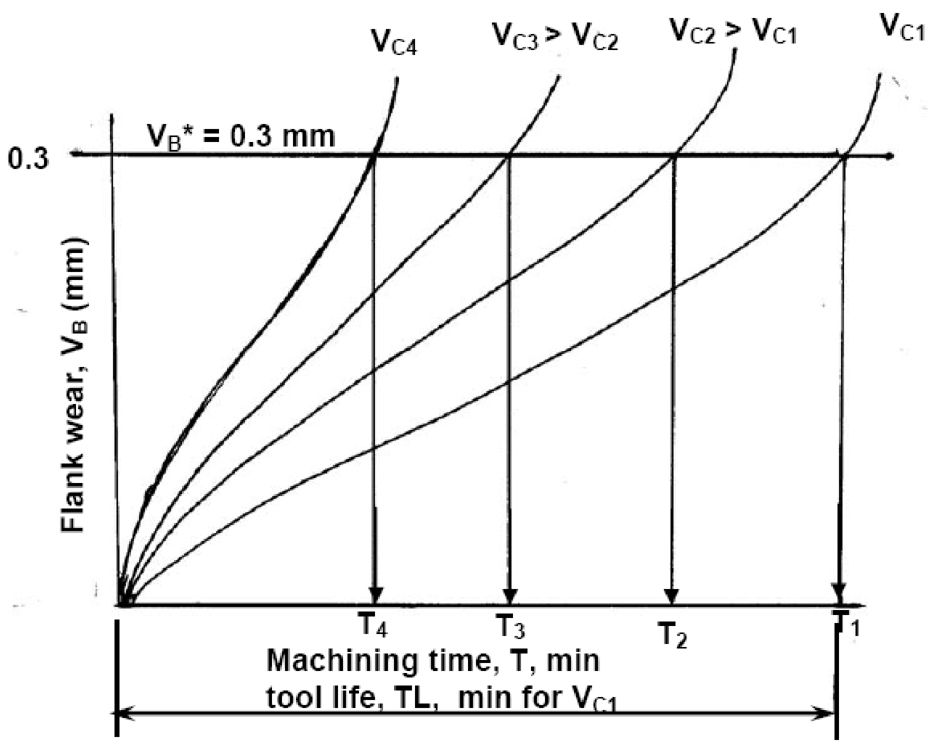


Fig: Growth of flank wear and assessment of tool life

The tool life obviously decreases with the increase in cutting velocity keeping other conditions unaltered as indicated in the above figure.

If the tool lives, T_1, T_2, T_3, T_4 etc are plotted against the corresponding cutting velocities, V_1, V_2, V_3, V_4 etc as shown in Fig. 1.13, a smooth curve like a rectangular hyperbola is found to appear. When F. W. Taylor plotted the same figure taking both V and T in log-scale, a more distinct linear relationship appeared as schematically shown in the below figure.

With the slope, n and intercept, c, Taylor derived the simple equation as

$$VT^n = C$$

where, n is called, Taylor's tool life exponent. The values of both 'n' and 'c' depend mainly upon the tool-work materials and the cutting environment (cutting fluid application). The value of C depends also on the limiting value of V_B undertaken (i.e., 0.3 mm, 0.4 mm, 0.6 mm etc.)

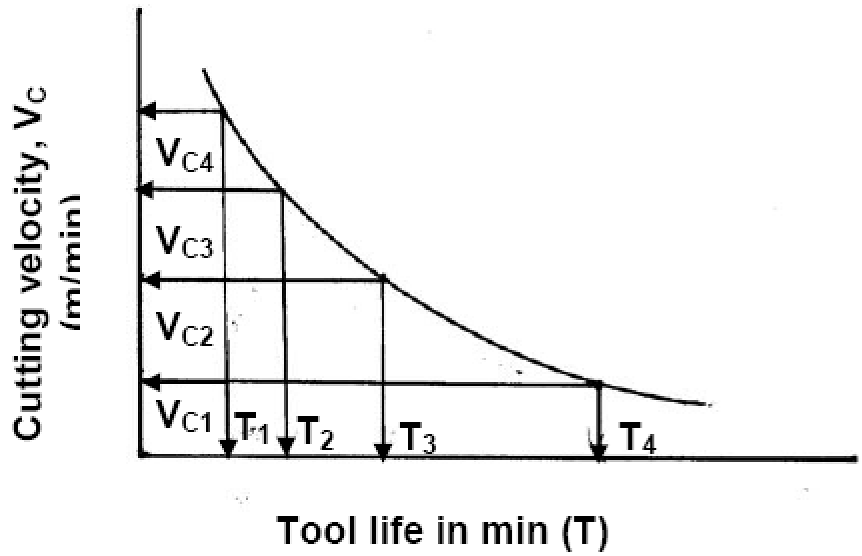


Fig: Cutting velocity – tool life relationship

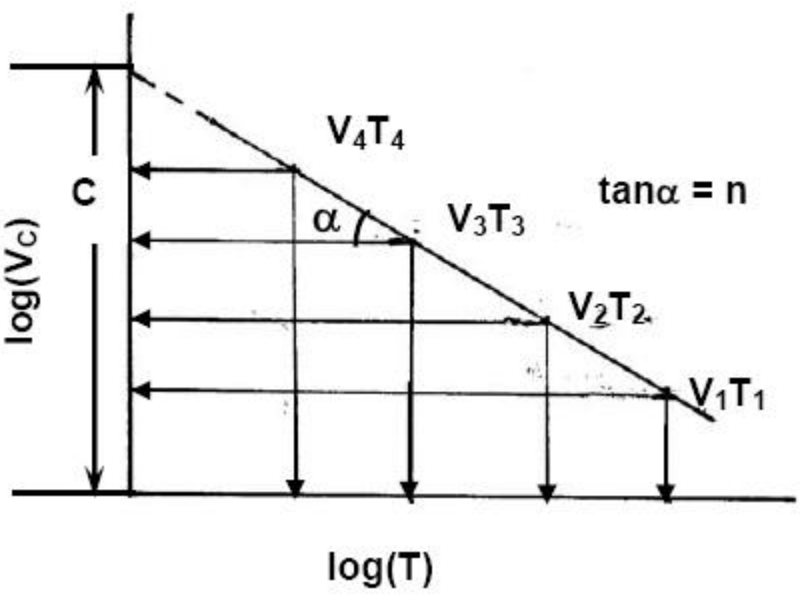


Fig: Cutting velocity vs tool life on a log-log scale

Modified Taylor's Tool Life equation

In Taylor's tool life equation, only the effect of variation of cutting velocity, V_C on tool life has been considered. But practically, the variation in feed (s_o) and depth of cut (t) also play role on tool life to some extent.

Taking into account the effects of all those parameters, the Taylor's tool life equation has been modified as,

0=TxyzcCTLVSt

where, TL = tool life in min

C_T = A constant depending mainly upon the tool – work materials and the limiting value of $V_{B\text{ undertaken.}}$

x, y and z - exponents so called tool life exponents depending upon the tool – work materials and the machining environment.

Generally, x > y > z as V_C affects tool life maximum and t minimum.

The values of the constants, C_T, x, y and z are available in Machining Data Handbooks or can be evaluated by machining tests.

UNIT-III

DESIGN OF JIGS AND FIXTURES

Introduction

The successful running of any mass production depends upon the interchangeability to facilitate easy assembly and reduction of unit cost. Mass production methods demand a fast and easy method of positioning work for accurate operations on it.

Jigs and fixtures are production tools used to accurately manufacture duplicate and interchangeable parts. Jigs and fixtures are specially designed so that large numbers of components can be machined or assembled identically, and to ensure interchangeability of components.

Jigs

It is a work holding device that holds, supports and locates the workpiece and guides the cutting tool for a specific operation. Jigs are usually fitted with hardened steel bushings for guiding or other cutting tools. a jig is a type of tool used to control the location and/or motion of another tool. A jig's primary purpose is to provide repeatability, accuracy, and interchangeability in the manufacturing of products. A device that does both functions (holding the work and guiding a tool) is called a jig.

An example of a jig is when a key is duplicated; the original is used as a jig so the new key can have the same path as the old one.

Fixtures

It is a work holding device that holds, supports and locates the workpiece for a specific operation but does not guide the cutting tool. It provides only a reference surface or a device. What makes a fixture unique is that each one is built to fit a particular part or shape. The main purpose of a fixture is to locate and in some cases hold a workpiece during either a machining operation or some other industrial process. A jig differs from a fixture in that it guides the tool to its correct position in addition to locating and supporting the workpiece.

Examples: Vises, chucks

Advantages of Jigs and Fixtures

Productivity:

Jigs and fixtures increase the productivity by eliminating the individual marking, positioning and frequent checking. The operation time is also reduced due to increase in speed, feed and depth of cut because of high clamping rigidity.

Interchangeability and Quality:

Jigs and fixtures facilitate the production of articles in large quantities with high degree of accuracy, uniform quality and interchangeability at a competitive cost.

Skill Reduction:

There is no need for skillful setting of work on tool. Jigs and fixtures makes possible to employ unskilled or semi skilled machine operator to make savings in labor cost.

Cost Reduction:

Higher production, reduction in scrap, easy assembly and savings in labor cost results in ultimate reduction in unit cost.

Fundamental principles of Jigs and Fixtures design

Locating Points: Good facilities should be provided for locating the work. The article to be machined must be easily inserted and quickly taken out from the jig so that no time is wasted in placing the workpiece in position to perform operations. The position of workpiece should be accurate with respect to tool guiding in the jig or setting elements in fixture.

Fool Proof: The design of jigs and fixtures should be such that it would not permit the workpiece or the tool to insert in any position other than the correct one.

Reduction of Idle Time: Design of Jigs and Fixtures should be such that the process, loading, clamping and unloading time of the workpiece takes minimum as far as possible.

Weight of Jigs and Fixtures: It should be easy to handle, smaller in size and low cost in regard to amount of material used without sacrificing rigidity and stiffness.

Jigs Provided With Feet: Jigs sometimes are provided with feet so that it can be placed on the table of the machine.

Materials for Jigs and Fixtures*:* Usually made of hardened materials to avoid frequent damage and to resist wear. Example-MS, Cast iron, Die-steel, CS, HSS.

Clamping Device:

It should be as simple as possible without sacrificing effectiveness. The strength of clamp should be such that not only to hold the workpiece firmly in place but also to take the strain of the cutting tool without springing when designing the jigs and fixtures.

Essential features of Jigs and Fixtures

- Reduction of idle time – Should enable easy clamping and unloading such that idle time is minimum
- Cleanliness of machining process – Design must be such that not much time is wasted in cleaning of scarf's, burrs, chips etc.
- Replaceable part or standardization – The locating and supporting surfaces as far as possible should be replaceable, should be standardized so that their interchangeable manufacture is possible
- Provision for coolant – Provision should be there so that the tool is cooled and the scarfs and chips are washed away.
- Hardened surfaces – All locating and supporting surfaces should be hardened materials as far as conditions permit so that they are not quickly worn out and accuracy is retained for a long time
- Inserts and pads – Should always be riveted to those faces of the clamps which will come in contact with finished surfaces of the workpiece so that they are not spoilt
- Fool-proofing – Pins and other devices of simple nature incorporated in such a position that they will always spoil the placement of the component or hinder the fitting of the cutting tool until the latter are in correct pos Economic soundness – Equipment should be economically sound, cost of design and manufacture should be in proportion to the quantity and price of producer
- Easy manipulation – It should be as light in weight as possible and easy to handle so that workman is not subjected to fatigue, should be provided with adequate lift aids
- Initial location – Should be ensured that workpiece is not located on more than 3 points in anyone plane test to avoid rocking, spring loading should be done
- Position of clamps – Clamping should occur directly above the points supporting the workpiece to avoid distortion and springing Clearance – Sufficient amount of clearance

should be provided around the work so that operator's hands can easily enter the body for placing the workpiece and any variations of work can be accommodated

- Ejecting devices – Proper ejecting devices should be incorporated in the body to push the workpiece out after operation
- Rigidity and stability – It should remain perfectly rigid and stable during operation. Provision should be made for proper positioning and rigidly holding the jigs and fixtures
- Safety – The design should assure perfect safety of the operator

General rules for designing

- Compare the cost of production of work with present tools with the expected cost of production, using the tool to be made and see that the cost of buildings is not in excess of expected gain.
- Decide upon locating points and outline clamping arrangement
- Make all clamping and binding devices as quick acting as possible
- Make the jig fool proof
- Make some locating points adjustable Avoid complicated clamping arrangements
- Round all corners
- Provide handles wherever these will make handling easy
- Provide abundant clearance
- Provide holes on escapes for chips
- Locate clamps so that they will be in best position to resist the pressure of the cutting tool when at work
- Place all clamps as nearly as possible opposite some bearing point of the work to avoid springing action
- Before using in the shop, test all jigs as soon as made

Materials Used

- Jigs and Fixtures are made of variety of materials, some of which can be hardened to resist.
- Materials generally used:
- High speed Steel: Cutting tools like drills, reamers and milling cutters.

- Die steels: Used for press tools, contain 1% carbon, 0.5 to 1% tungsten and less quantity of silicon and manganese.
- Carbon steels: Used for standard cutting tools.
- Collet steels: Spring steels containing 1% carbon, 0.5% manganese and less of silicon

Non shrinking tool steels:

- High carbon or high chromium
- Very little distortion during heat treatment.
- Used widely for fine, intricate press tools.
- Nickel chrome steels: Used for gears.
- High tensile steels: Used for fasteners like high tensile screws

Mild steel:

- Cheapest material
- Contains less than 0.3% carbon

Cast Iron:

- Used for odd shapes to some machining and laborious fabrication
- CI usage requires a pattern for casting
- Contains more than 2% carbon
- Has self lubricating properties
- Can withstand vibrations and suitable for base
- Nylon and Fiber: Used for soft lining for clamps to
- Damage to workpiece due to clamping pressure

  Phospher bronze:
- used for nuts as have high tensile strength Used for nuts of the lead screw

Factors to be considered for design of Jigs and Fixtures

- Component -Design to be studied carefully
- Ensure work is performed in a proper sequence
- Maximum operations should be performed on a machine in single setting
- Capacity of the machine- Careful consideration to be performed on type and capacity of machine.

- Production requirements- Design to be made on basis of actual production requirements.
- Decision on manual and automatic tooling arrangements.

Location:

- Location should ensure equal distribution of forces throughout all sequence of operation.
- Location should be hard resistant, wear resistant and high degree of accuracy.
- Movement of workpiece should be restricted.
- Should be fool proofed to avoid improper locations of the workpiece.
- Should facilitate easy and quick loading of workpiece.
- Redundant locators should be avoided.
- Sharp corners must be avoided.
- At least one datum surface should be established.

Loading and Unloading arrangements:

- There should be adequate clearance for loading and unloading. Hence process becomes quick and easy.
- Size variation must be accepted.
- It should be hardened material and non sticky.
- Clamping arrangements-
- Quick acting clamps must be used as far as possible.
- The clamping should not cause any deformation to the workpiece
- It should always be arranged directly above points supporting the work.
- Power driven clamps are favored as they are quick acting, controllable, reliable and operated without causing any fatigue to the operators.

Features of clamps:

- Clamping pressure should be low
- Should not cause distortion
- Simple and fool proof
- Movement of clamp should be minimum
- Case hardened to prevent wear
- Sufficiently robust to avoid bending

- Clearance between Jig and Component-to accommodate various sizes if work
- Chips to pass out of the opening between them
- Ejectors-to remove work from close fitting locators.
- Speeds up unloading of the part from the tool and hence production rate.

Base and Body construction-

- Methods used: Machining, Forging and machining, Casting, Fabricating, Welding.
- Tool guiding and cutter setting-
- By adjusting the machine or using cutter setting block, the cutter is set relative to the work in a fixture. The drill bushes fitted on jig plates guides the tools.
- Rigidity and vibration-
- Must possess enough rigidity and robustness.
- Should not vibrate as it may lead to unwanted movement of workpiece and tools.
- Safety-Operation should be assured full safety.