Module 3

1. Tool Wear/Tool Life
2. Machine Time

Tool Wear

Introduction to Tool Wear: *Tool Wear* is a term that describes the gradual failure of a cutting tool due to its operation.

- A cutting tool is ground with various angles to perform cutting operation efficiently & effectively on different materials & in different situations of varying speed, depth & feed of cut
- Under regular operation, the tool wears out gradually leading to changes in the angles ground on the cutting tool, which in turn ceases to tool to function satisfactorily
- A very short tool life is not economical, as tool grinding & tool replacement increases the cot of machining and in-turn increases the cost of the product
- Tool wear cannot be avoided, but under suitable operating conditions it can be minimized

Objectives of Tool Wear

- To study the wear mechanism and types of wear
- Understand about the factors affecting tool life and Taylor’s tool life equation
- To study the machinability and machinability index
- To know about the Economics of machining process and the factors affecting it

Conditions of Cutting Tool

a) high localized stresses at the tip of the tool

b) high temperatures, especially along the rake face

c) sliding of the chip along the rake face

d) sliding of the tool along the newly cut workpiece surface

These condition leads to *Tool Wear*:

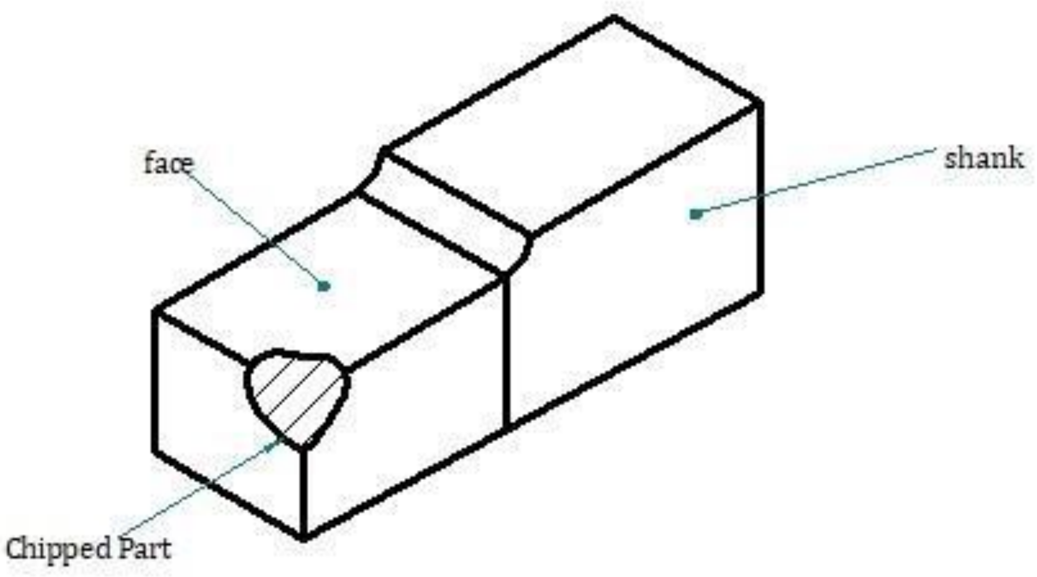
These conditions induce tool wear, which is a major consideration in all machining operations. Tool wear adversely affects tool life, the quality of the machined surface and its dimensional accuracy, and, consequently, the economics of cutting operations. Wear is a gradual process. The rate of tool wear depends on tool and workpiece materials, tool geometry, process parameters such as speed, feed and depth of cut, cutting fluids, and the characteristics of the machine tool.

Modes of Tool Wear

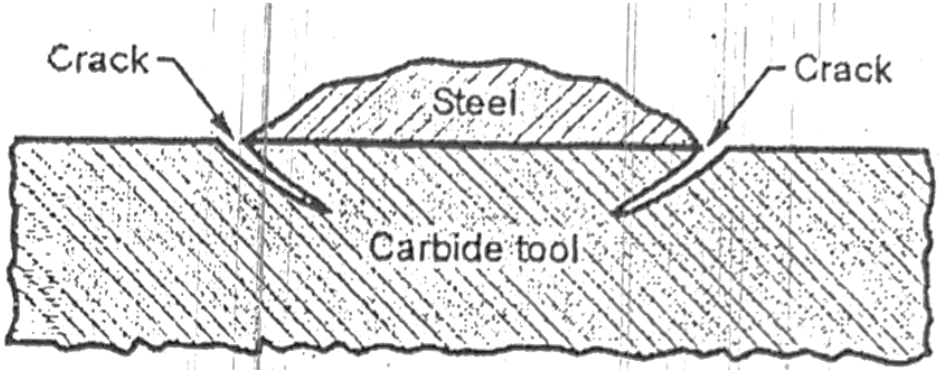
There are 3 possible ways a cutting tool can fail in machining:

- **Fracture Failure**: This mode of failure occurs when the cutting force at the tool point becomes excessive, causing it to fail suddenly by brittle fracture (Mechanical Chipping)
- **Temperature Failure**: This failure occurs when the cutting temperature is too high for the tool material, causing the material at the tool point to soften, which leads to plastic deformation and loss of the sharp edge
- **Gradual Wear**: Gradual wearing of the cutting edge causes loss of tool shape, reduction in cutting efficiency, an acceleration of wearing as the tool becomes heavily worn, and finally tool failure in a manner similar to a temperature failure

Modes of Tool Wear



Fracture Wear



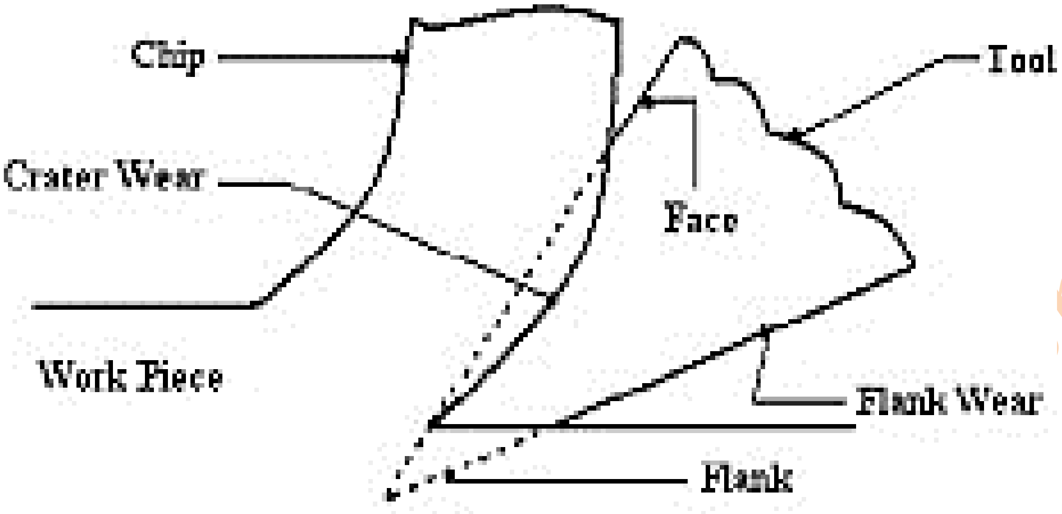
Temperature Wear

Tool Wear/Gradual Wear

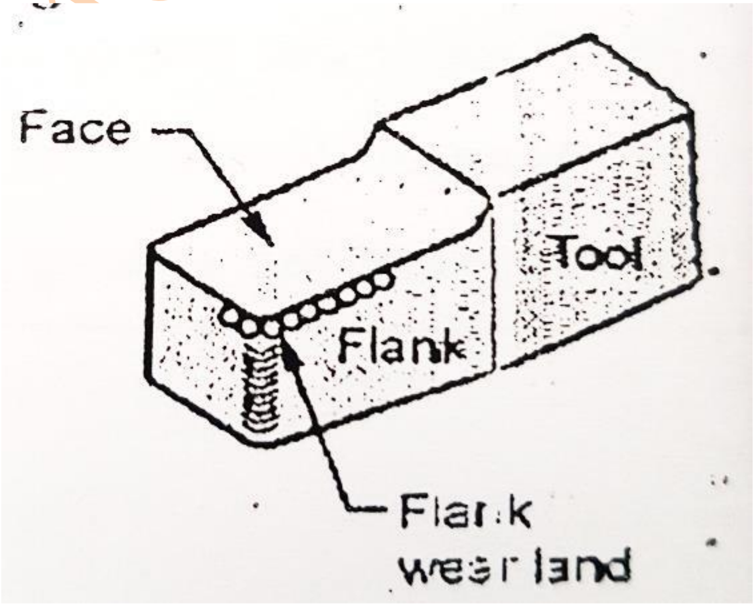
Gradual Wear/Tool Wear can be classified into:

- **Crater Wear**: It consists of a cavity in the rake face of the tool that forms and grows from the action of the chip sliding against the surface. High stresses and temperatures characterize the tool–chip contact interface, contributing to the wearing action. The crater can be measured either by its depth or its area
- **Flank Wear**: Flank wear occurs on the relief (flank) face of the tool. It generally is attributed to rubbing of the tool along the machined surface, thereby causing adhesive or abrasive wear and high temperatures, which adversely affect tool-material properties

Tool Wear/Gradual Wear



Crater Wear



Flank Wear

Tool Wear Mechanism

- **Abrasion.** This is a mechanical wearing action caused by hard particles in the work material gouging and removing small portions of the tool. This abrasive action occurs in both flank wear and crater wear; it is a significant cause of flank wear.
- **Adhesion.** When two metals are forced into contact under high pressure and temperature, adhesion or welding occur between them. These conditions are present between the chip and the rake face of the tool. As the chip flows across the tool, small particles of the tool are broken away from the surface, resulting in attrition of the surface.
- **Diffusion:** This is a process in which an exchange of atoms takes place across a close contact boundary between two materials. In the case of tool wear, diffusion occurs at the tool–chip boundary, causing the tool surface to become depleted of the atoms responsible for its hardness. As this process continues, the tool surface becomes more susceptible to abrasion and adhesion. Diffusion is believed to be a principal mechanism of crater wear.
- **Oxidation/Corrosion**: Oxidation is the result of a chemical reaction b/w the tool surface & surrounding oxygen at high temperatures. During metal cutting, the high temperatures generated at the tool-work interface causes oxidation of carbide in the cutting tool, forming a layer on tool surface. This layer is removed during ,machining process by abrasion, another layer is formed and it repeats

Tool Life

Tool life is the ***time duration*** a tool can be reliably used for cutting before it must be discarded or re-ground. The life of the cutting tool is one of the most important economic considerations in metal cutting. Hence the tool must be utilized efficiently to the maximum possible extent before it can be ground or discarded, because tool grinding or replacement costs are very high. The life of the tool is affected by various parameters.

Parameters affecting Tool Wear

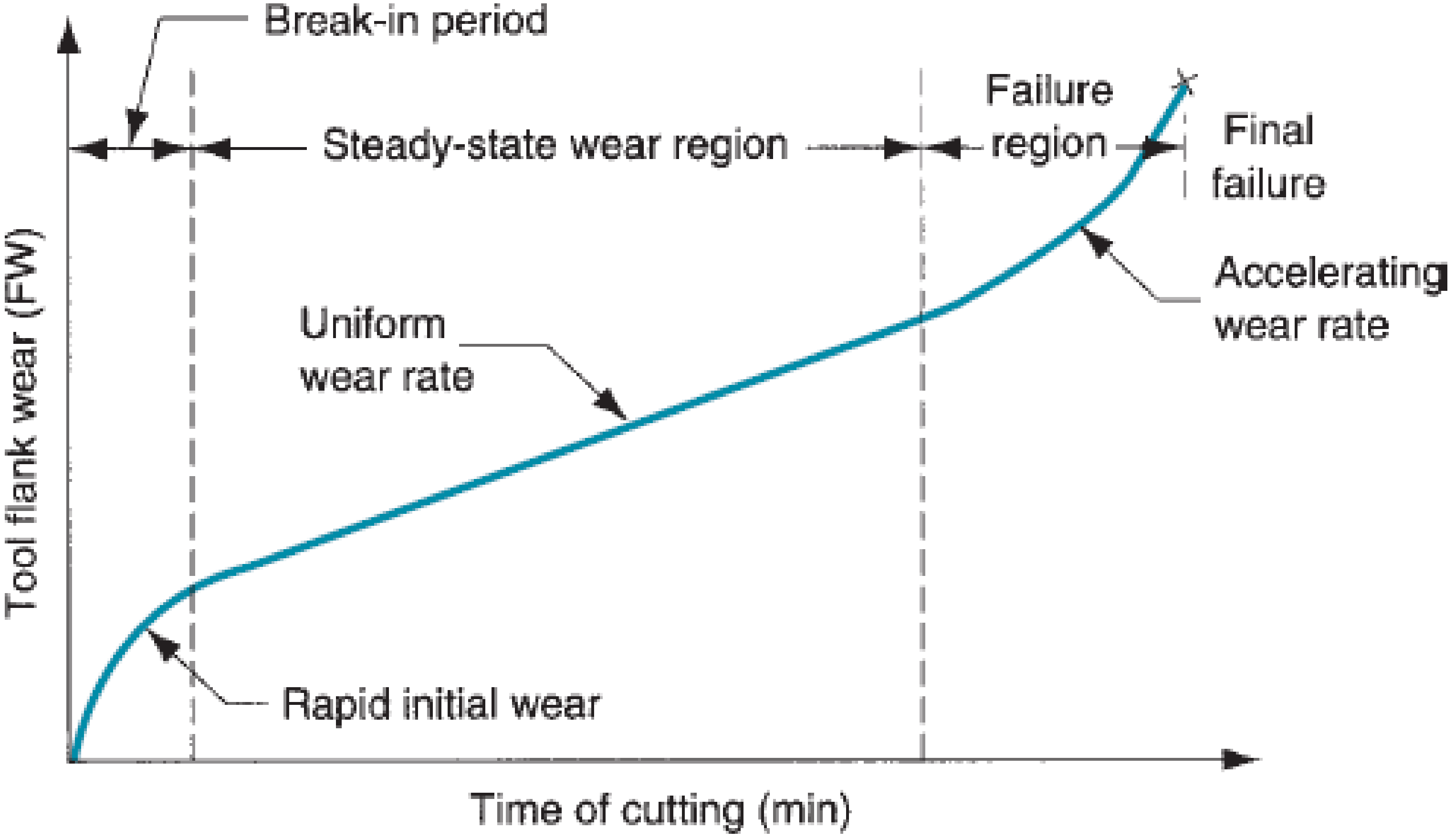
- **Cutting speed:** Cutting speed has the greatest influence on tool life. As the cutting speed increases the temperature also rises. The heat is more concentrated on the tool than on the work and the hardness of the cutting tool changes so the relative increase in the hardness of the work accelerates the abrasive action. The criterion of the wear is dependent on the cutting speed because the predominant wear may be wear for flank or crater if cutting speed is increased.
- **Feed and depth of cut:** The tool life is influenced by the feed rate also. With a fine feed the area of chip passing over the tool face is greater than that of coarse feed for a given volume of metal removal.
- **Tool Geometry:** The tool life is also affected by tool geometry. A tool with large rake angle becomes weak as a large rake reduces the tool cross-section and the amount of metal to absorb the heat.

- **Tool material:** Physical and chemical properties of work material influence tool life by affecting form stability and rate of wear of tool.
- **Cutting fluid:** It reduces the coefficient of friction at the chip tool interface and increases tool life.
- **Type of workpiece material**: work pieces with greater hardness require greater cutting forces leading to greater power consumption, tool wear increases with greater forces thereby reducing the life of cutting tool. Ductile materials deform easily, and low cutting forces are needed, thus tool wear reduces
- **Nature of cutting**: Tool life is more in case of continuous cutting when compared to intermitted type of cutting where the cutting edge of the tool will not be in continuous contact with the work surface, intermittent cutting causes regular impacts on the tool resulting in failure of tool in short span. It must be ensured through all means to have continuous type of cutting in order to enhance tool life

Tool Wear v/s Cutting Time

As cutting proceeds, the various wear mechanisms result in increasing levels of wear on the cutting tool. The general relationship of tool wear versus cutting time is shown in Figure Although the relationship shown is for flank wear, a similar relationship occurs for crater wear. Three regions can usually be identified in the typical wear growth curve. The first is the breaking period, in which the sharp cutting edge wears rapidly at the beginning of its use. This first region occurs within the first few minutes of cutting. The break-in period is followed by wear that occurs at a fairly uniform rate. This is called the steady-state wear region. In our figure, this region is pictured as a linear function of time, although there are deviations from the straight line in actual machining. Finally, wear reaches a level at which the wear rate begins to accelerate. This marks the beginning of the failure region, in which cutting temperatures are higher, and the general efficiency of the machining process is reduced. If allowed to continue, the tool finally fails by temperature failure

Tool Wear v/s Cutting Time



Tool Wear v/s Cutting Time

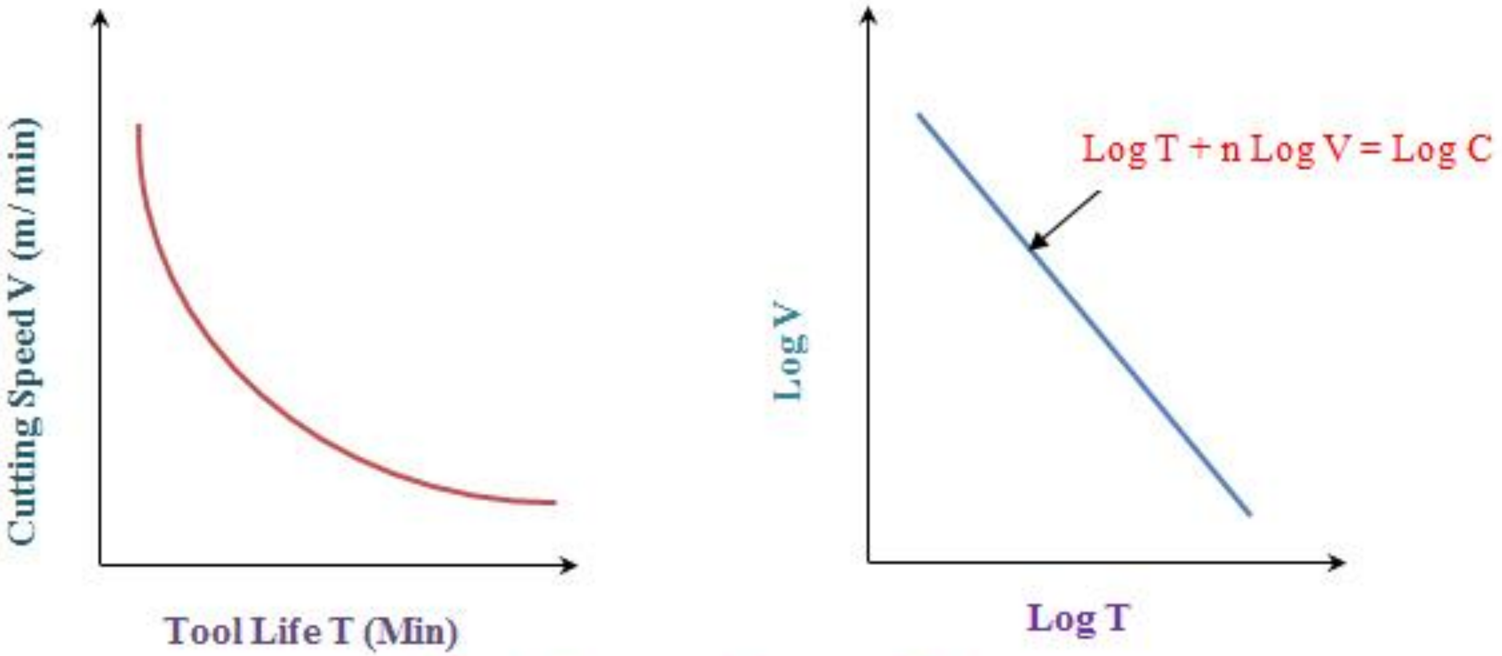
Tayler’s Tool Life Equation

- ***Cutting speed*** forms the most important parameter of all the variables (feed, depth of cut, type of work material, coolant, etc.,), that affects the tool life
- F. W. Taylor, an American engineer developed a standard test to determine the relationship b/w cutting speed & time the tool remains useful
- Test has been carried out for different combination of tool workpiece material; and the flank wear of the tool under test has been measured
- It has been found that a practical amount of wear to measure before breakage was 0.75 mm (V_B) for solid & brazed tips, and 1.25 mm (V_B) for ceramic tools
- Tests have been carried out to determine the time taken to reach this amount of wear at different cutting speeds
- The results have been plotted on a graph showing that a logarithmic relationship existed b/w the cutting speed & the tool life (cutting time) an empirical relation for tool life with cutting speed has been given by Taylor & is known as Taylor’s tool life equation

$$\mathbf{VT^{n}=C}$$

where V = cutting speed, m/min (ft/min); T = tool life in min; and n and C are parameters whose values depend on feed, depth of cut, work material, tooling (material in particular), and the tool life criterion used.

Tayler's Tool Life Equation



TOOL LIFE VS CUTTING SPEED

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Tayler's Tool Life Equation

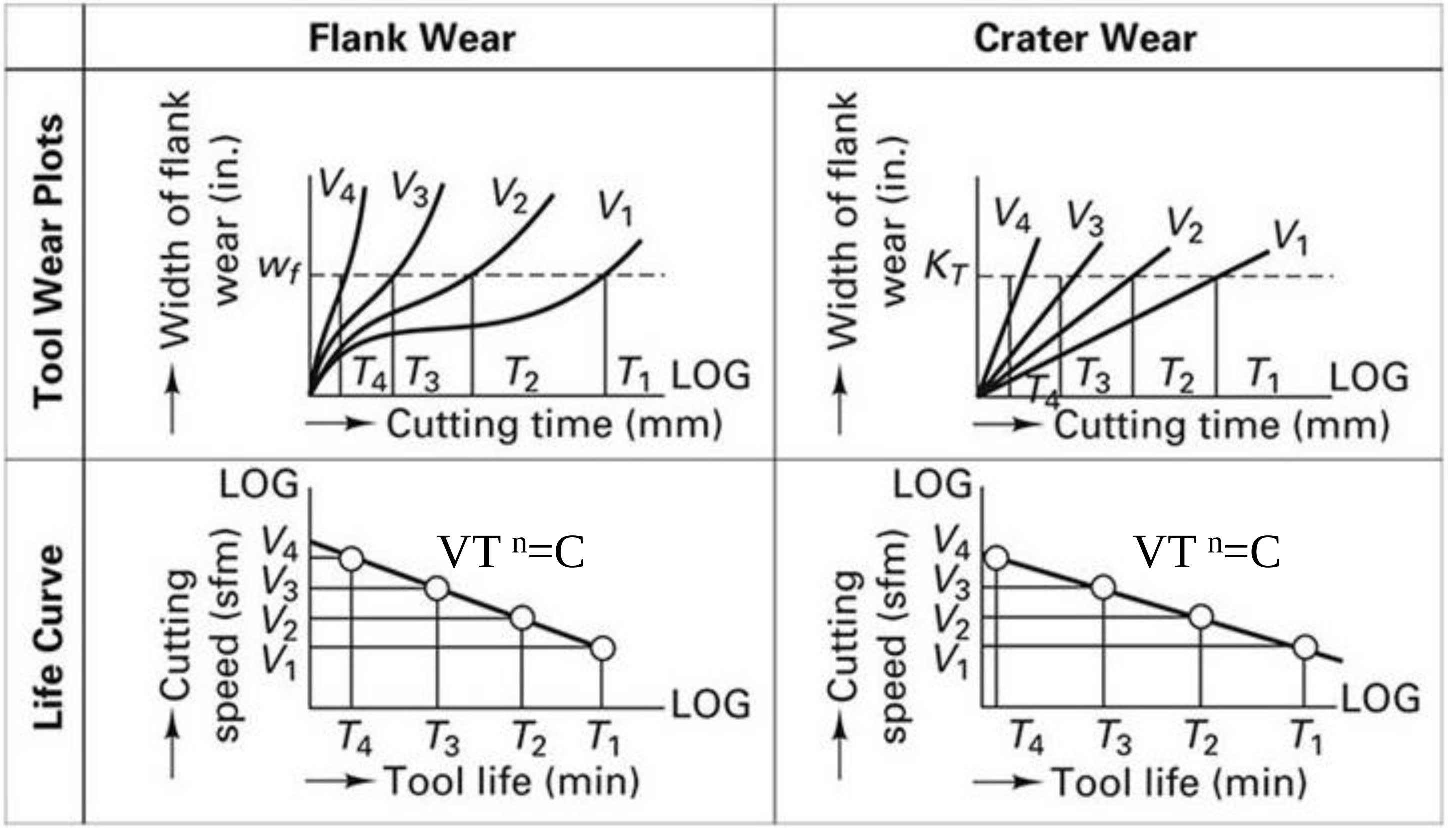
- The value of index 'n' for most combinations of tool & workpiece material can be found in a tabular form in good machining hand books
- Table shows the range of values of 'n' for different combinations of tool-workpieces materials
- The value of 'n' increases with increase in the refractoriness of the tool material

Sl No.	Tool Material	Value of 'n'
1	HSS Tool	0.1-0.18
2	Uncoated Tungsten carbide (WC)	0.2-0.25
3	Ti-C or Ti-N Coated WC tools	0.3
4	Al_2O_3 Coated WC tools	0.4
5	Ceramic Tools	0.4-0.7

Effect of Cutting Parameters on Tool Life

Cutting Speed: Cutting speed refers to the relative surface speed b/w the tool & the workpiece. The life of the tool varies inversely as the cutting speed. As the cutting speed is increases, wear rate increases, so same wear criterion is reached in less time, i.e., tool life decreases with increasing cutting speeds as shown in figure. The relation b/w the cutting speed (V) and tool life (T) is given by Taylor's equation in the form $VT^{n}=C$, where 'n; is the exponential term and 'C' the machining constant.

Effect of Cutting Parameters on Tool Life



Effect of Speed on Tool Life

Effect of Cutting Parameters on Tool Life

Feed: Feed is the amount of material removed for each revolution, or per-pass of the tool over the workpiece. Increasing feed rate increases cutting temperature and flank wear thereby shortening the life of cutting tool. However, effect on the tool life is minimal when compared to cutting speed. The rate of feed given depends on the depth of cut.

Depth of cut: Depth of cut relates to the depth of cutting edge of the tool engages the work. Small depths of cuts result in friction when cutting hardened layer of work metal. Increasing the depth of cut will increase the tool life over an increase in feed rate. But, as long as it is practical & chip formation is satisfactory, it is better to choose a heavy feed rate. Deeper cut is more advantageous than a heavy feed, especially where longer tool life is needed.

Effect of Cutting Parameters on Tool Life

- The relationship b/w various parameters is given by the equation:

$$V = \frac{257}{T^{0.19} f^{0.36} t^{0.8}} \text{ m/min}$$

Where V = cutting speed in m/min, T = Tool life in minutes, f = feed in mm/min, t = depth of cut in mm.

For a give tool life, the relationship among the other variables as:

$$V = \frac{C}{f^a t^b},$$

where C = machining constant and ‘a’ & ‘b’ are indices depending on mechanical properties of workpiece material.

Machinability

Machinability is a term that describes the ease with which a material can be cut with a satisfactory surface finish, long tool life, low force & power requirements and with low cost. For example, low alloyed carbon steel is easier to cut compared to austenitic stainless steels. Hence, the low alloy carbon steel is said to have a comparatively better machinability.

Factors on which Machinability Depends

- Physical properties of work material, like tensile strength, hardness, etc., the more the strength & hardness of the work material, the more difficult it is to cut
- Chemical composition of work material. For example, the higher the carbon content in steel, the more difficult it is to cut. In alloy steels, the presence of elements like chromium, nickel, molybdenum & vanadium, etc., can cause decreased machinability. On the other hand, addition of lead & sulphur improves machinability
- Microstructure of work material. For example, variation in the arrangement of atoms of work material, heat treatment of metals may change crystal structure which affects machinability
- Cutting conditions like tool geometry, use of cutting fluid, selecting proper speed, feed & depth of cut affects machinability
- Rigidity of tool & work holding devices indirectly affects machinability. If not secured rigidly, vibrations may develop causing the tool to have intermittent cutting instead of continuous cutting resulting in decrease in the life of the cutting tool.

Machinability Index

Machinability index or *Machinability Rating* is a factor that attempts to quantify the machinability of various materials. In other words, the machinability of different materials is compared in terms of their indexes as a percentage & given by the equation:

$$\text{Machinability Index (\%)} = \frac{V_i}{V_s} = \frac{cutting\ speed\ of\ metal\ investigated\ for\ 20\ \text{min}\ tool\ life}{cutting\ speed\ of\ a\ standard\ steel\ for\ 20\ \text{min}\ tool\ life}$$

The American Iron & Steel Institute (AISI) determined machinability ratings for a wide variety of materials by running turning tests at 180 surface feed per minute (*sfpm*). It then arbitrarily assigned 160 Brinell B1112 steel a machinability rating of 100%. Any material with a machinability rating less than 100% would be more difficult to machine than the standard B1112 steel, and any material with a value more than 100% would be comparatively easier.

Numerical's

Cutting Fluids

- During metal cutting, as the cutting tool slides in the workpiece material, heat is generated due to the friction b/w the *tool* & *workpiece* material
- Also, as chip slides up the tool face, heat is generated due to friction at the contact points b/w the *chip* & *tool-face*
- The excessive heat thus generated can damage the microstructure of both the cutting tool & the workpiece
- Also, the life of the cutting tool reduces at higher temperatures
- In order to reduce friction or heat generated, cutting fluids are used
- A cutting fluid or coolant is a liquid, added to the cutting zone, in order to reduce the effects of friction b/w the tool-work & tool-chip interface by way of cooling & lubrication

Functions of Cutting Fluids

- Controls the temperature at the cutting zone through cooling & lubrication, which in turn helps in decreasing tool wear & extending tool life
- Cooling & lubricating action of cutting fluid helps in achieving the desired size, shape & finish of the workpiece. The removal of heat by cutting fluid prevents the workpiece from expanding during the machining operation, which would other wise cause size variations as well as damage to the microstructure. Also, proper use of coolants can make higher metal removal rates possible
- Cutting fluid helps to flush away chips & metal fines from the cutting zone thereby *preventing* the tool & the finish of the work surface from becoming marred & occurrence of built-up-edge

Properties of Cutting Fluids

- *High specific heat & High Thermal Conductivity*, so that maximum heat will be absorbed & removed per unit of fluid volume circulated
- *Good lubricating property*, so that a strong protective film b/w the tool face & the workpiece metal can exist. Such a film assists the chip in sliding easily over tool face. Besides reducing heat, a good lubricating fluid lower power consumption & reduces the rate of tool wear, particularly in machining tough & ductile metals
- *Non-Corrosive*, in order to avoid damage to the workpiece & the m/c parts
- *Non-Toxic & Odorless*, in order to provide better working conditions to human operators
- A cutting fluid should have high *flash point* to avoid problems associated with heat damage, production of smoke, or fluid ignition
- *Low Viscosity*, far easy circulation. Low viscosity fluids also allow grit & dirt to settle out of suspension & helps for easy re-circulation through the machining system
- *Highly stable*, in order to resist its decomposition during its storage & use
- In some operations, *fluid transparency* may be a desired characteristics for a cutting fluid. Transparent fluids allow operators to see the work area more clearly during machining operations

Types of Cutting Fluids

- Oil-based fluids
  - Straight oils
  - Soluble oils
- Chemical fluids
  - Synthetic oils
  - Semi-Synthetic oils

Oil-Based Cutting Fluids

Oil-based fluids consist of a diverse range of oil mixture with various additives & compounds to give the required properties to the cutting fluids. Oil-based fluids include straight oil & soluble oils.

Straight Oils:

Straight Cutting Oils (or Neat Oils) are so called because they do not contain water. The cutting fluid is composed of 100% petroleum oil or mineral oil along with some lubricants such as fats, vegetable oil & esters, as well as *extreme pressure (EP)* additives in order to improve specific properties. Generally, additives are not required for light duty machining operations, however, for severe machining operation, where heavy cuts are to be taken, and machining hard materials like titanium, stainless steel etc., EP additives such as sulfur, chlorine or phosphorous compounds are often used. These additives improve the lubricating & wettability property; that is, the ability of the oil to coat the cutting tool, workpiece & the chips.

Straight Oils

Advantages:

- Provides excellent lubricating property b/w the workpiece & cutting tool
- Tool life can be increased
- Good rust protection
- Absence of water eliminates bacterial development & odour problems

Disadvantages:

- Costlier
- Poor heat dissipating properties
- Increased fire risk, and hence its use is limited to low-temperature & low-pressure operations

Soluble Oils

Soluble Oils, also referred as Emulsions, emulsifiable oils or water-soluble oils, are generally comprised of 60%-90% petroleum or mineral oil, emulsifiers and other extreme pressure (EP) additives. Use of soluble oils for a particular application depends on the concentration of water & oil. Lean concentrations containing more water & less oil provide better cooling, but less lubrication. On the other hand, rich concentrations containing less water & more oil provide better lubrication qualities, but poor cooling.

Applications: Soluble oil is suitable for general purpose cutting operations on low & medium tensile steels, free machining of brass bronze & cast iron. It may also be used as a grinding fluid in non-critical applications, however it is not suitable for high tensile or stainless steel or nickel alloys.

Advantages:

- Good lubrication capability
- Suitable for light & medium duty operations involving both ferrous & non-ferrous metals
- Concentration of oil can be varied for heavy-duty applications
- Least expensive among all the cutting fluids

Disadvantages:

- Presence of water makes the oil more susceptible to corrosion, bacterial growth & odourness
- Maintenance cost to retain the desired properties of the oil is relatively high
- Not suitable for high tensile or stainless steel alloys

Chemical Cutting Fluids

Chemical cutting fluids contain little or no oil with pre-concentrated emulsions on low & medium tensile steels, free machining of brass bronze & cast Iron. It may be used as a grinding fluid in non-critical applications, however it is not suitable for high tensile or stainless steel or nickel alloys.

Synthetic Oils

Synthetic oils generally consist of *chemical lubricants* & rust inhibitors dissolved in water. Emulsifiers can be added to create lubrication properties similar to soluble oils, allowing the fluid to act as a lubricant & coolant in heavy duty machining operations. The various synthetic chemicals found in this type of oil include:

a) Amines & nitrates for rust prevention

b) Phosphates & Borates for water softening

c) Soaps & wetting agents for lubrication

d) Glycols to act as blending agents

e) Biocides to control bacterial growth

Synthetic Oils

Advantages:

- Good corrosion control
- Superior cooling properties
- Greater stability when mixed with hard water
- Can be stored for long periods of time without any problems
- Easy maintenance

Application: Used in grinding carbide tools with diamond wheels, ordinary commercial grinding where finish is not very critical, in some CNC machines where stock removal is low etc.,

Disadvantages:

- Synthetic coolants have a tendency to foam. If the rate of coolant flow fro a particular application is high, excessive foaming can be caused, resulting in poor surface finish & reduced tool life
- Lubricating property is not satisfactory
- Ingredients added to enhance the lubricating property can result in component rusting & leave gummy residues on the m/c system
- Synthetic fluids are easily contaminated by other m/c fluids like lubricating oils, & hence need to be monitored & maintained so that it can be used effectively

Semi-Synthetic Oils

Semi-synthetic oils, also referred to as *semi-chemical* fluids are a combination of mineral oil in small amounts varying from 20%-30% in a water-dilatable concentration & certain synthetic chemicals. The synthetic chemicals consists mainly emulsifiers & water; wetting agents, corrosion inhibitors & biocide additives. Since this type of oil includes both constituents of synthetic & soluble oils, they possess properties common to both the types of oils.

Advantages	**Disadvantages**
Better cooling & wettability properties	Water hardness affects the stability of semi-synthetic oils
Can be used for heavy-duty operation	
Generates less smoke & provides better control over bacterial growth. Oil can thus be stored for appreciable length of time	Lubricating property is not satisfactory
Lower viscosity of oil helps easy recirculation of the fluid	
Good corrosion protection	They easily foam

Selection of cutting fluids

- Cutting speed, feed & depth of cut selected
- Type, hardness & microstructure of the workpiece material being machined
- Operating temperature range
- Cost & life expectancy of fluid
- Fluid compatibility with workpiece & machine components
- Ease of storage & handling while in use
- Ease of fluid recycling or disposal
- Shelf-life required

Methods of Cutting Fluids

Apart from selecting the right cutting fluid, it is also important to choose a proper method of circulating the fluid to the cutting zone. The principal methods of applying the cutting fluid include:

- **Flood Application of Fluids**: A flood of cutting fluid is delivered to the cutting zone by means of a pipe, hose or nozzle system
- **Jet Application of Fluid**: A jet of cutting fluid is directed to the cutting zone
- **Mist (spray) Application of Fluid**: The cutting fluid is atomized by a jet of air, & the mist is directed to the cutting zone

In certain machining operations like drilling deep holes, or machining ultra-tough materials, it is very difficult to circulate the cutting fluid into the cutting zone. In such cases, the cutting fluid is supplied through the tool by drilling small holes in the tool.

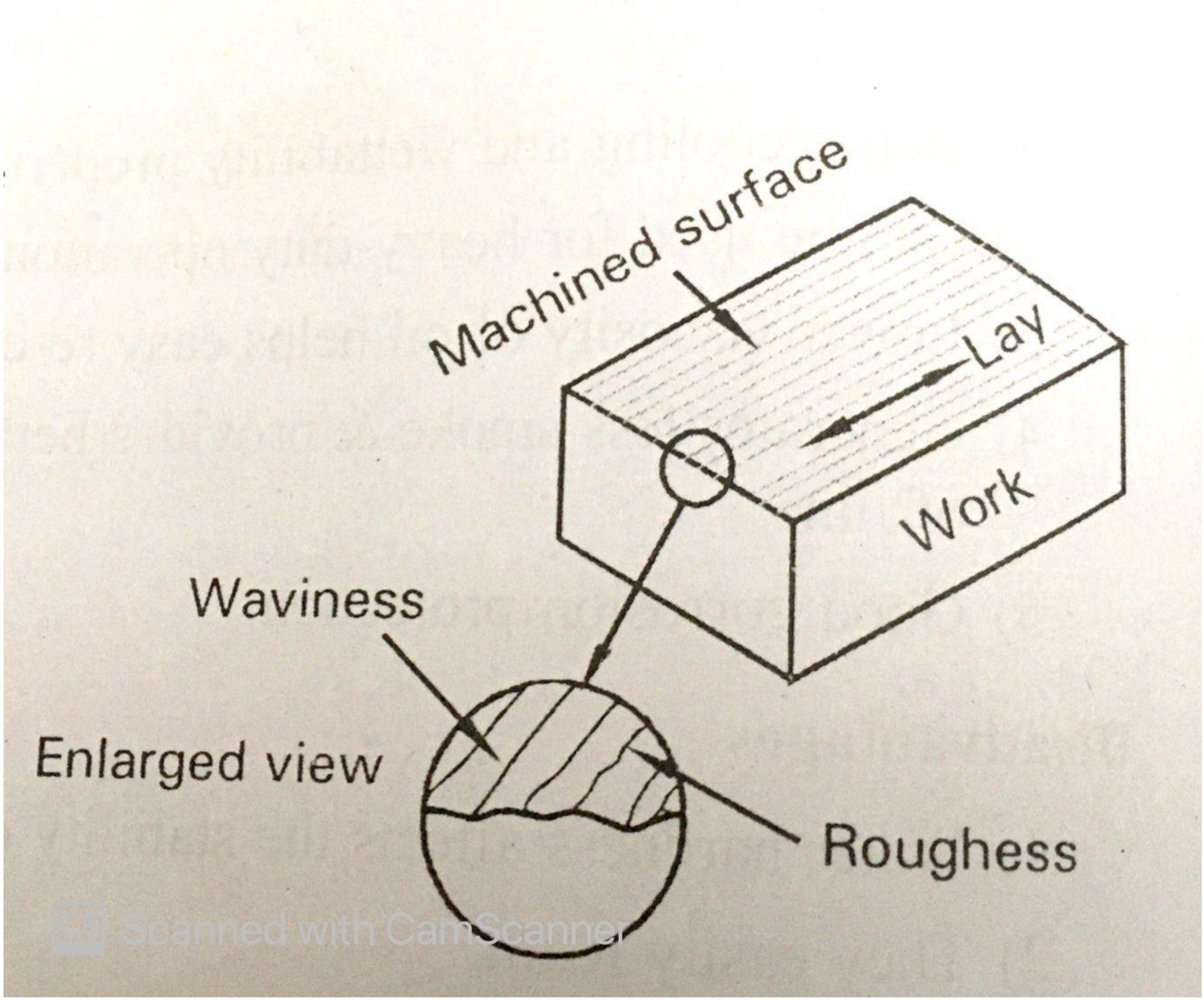
Surface Finish

Introduction to Surface Finish:

Machining processes generate a wide variety of irregularities on the surface of the workpiece. These irregularities are in the form of finely spaced markings (patterns) left by the cutting tool on the workpiece surface. In simple words, the finish obtained on the workpiece after machining is not perfectly smooth. The term *surface finish*, or *texture* or *surface roughness* is used to indicate the local deviations of a work surface from the perfectly flat ideal face (a true plane). The nature of surface is defined by three characteristics as listed below & illustrated in figure.

1. *Roughness* – small, finely spaced surface irregularities (micro irregularities)
2. *Waviness* – surface irregularities of greater spacing (macro irregularities)
3. *Lay* – predominant direction of surface pattern

It is important to note that, no surface is perfectly smooth. All surfaces contain irregularities to some extent. In machining operations, each kind of cutting tool leaves its own individual markings (pattern) on the workpiece surface, and as such by altering the parameters of the machining process, the pattern can be changed.



Surface Finish

Effect of Machining parameters on Surface Finish

Cutting Speed:

- Low cutting speed tends to form BUE on the rake face of the cutting tool, causing the tool edge to become blunt & thereby producing a rough surface on the work parts, friction also increases thus increases power consumption
- Increasing cutting speed improves surface finish due to continuous reduction in formation of BUE, this due to rise in tool temperature & decrease in frictional forces

Feed:

- Increasing feed rate during machining deteriorates surface finish, higher irregularities are formed with higher feed rates
- Slow feed rates give good surface finish, however upto a certain value, & thereafter the surface finish deteriorates, hence a proper feed rate is tio be selected based on the depth of cut

Effect of Machining parameters on Surface Finish

Depth of Cut:

- Increasing the depth of cut during machining process deteriorates surface finish
- High depth of cut implies higher cutting forces, leading to crater & vibrations in m/c tool that impacts the surface finish
- Increasing depth of cut tends to increase waviness height, as a general thumb rule, the depth of cut should be slightly higher than the nose radius of the cutting tool edge

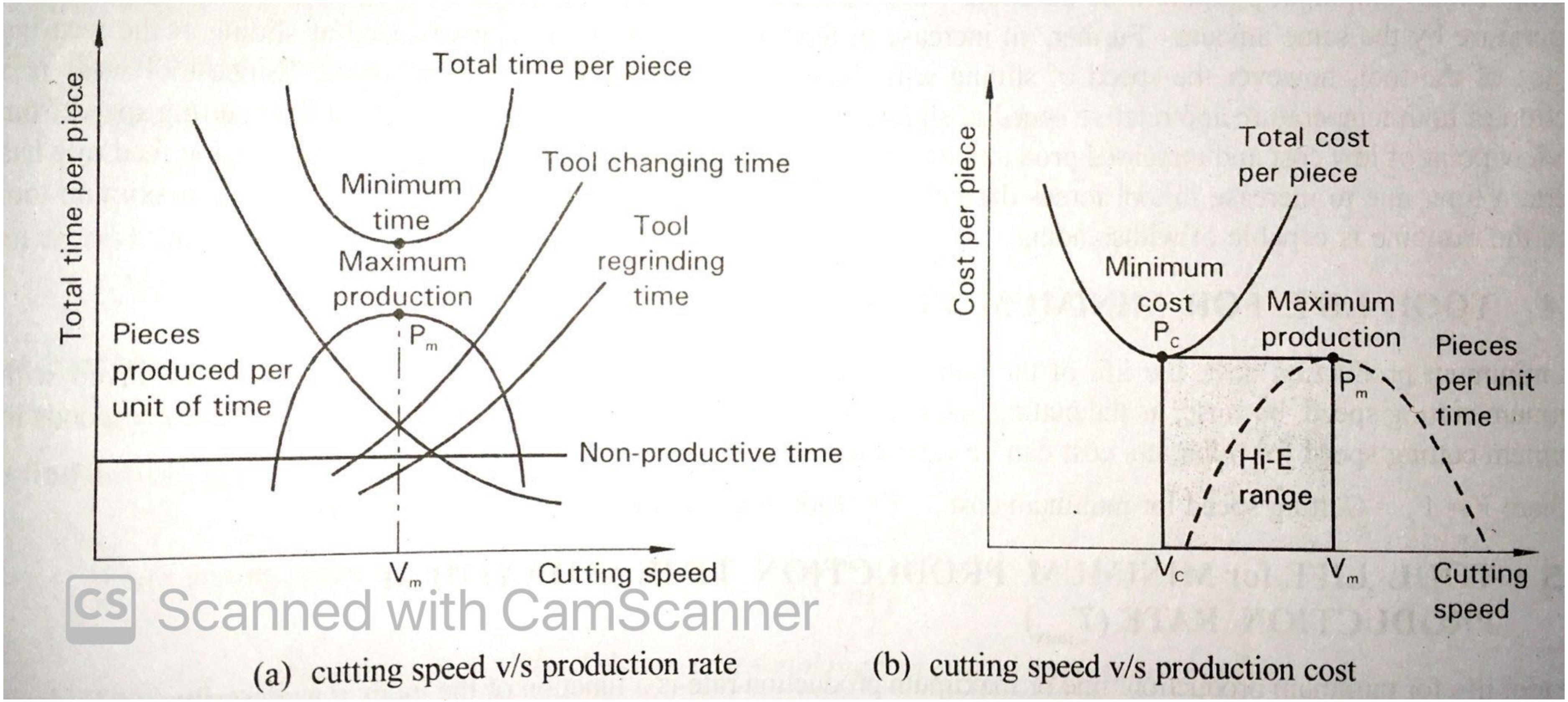
Other parameters influencing surface finish:

1. Tool geometry – nose radius, rake angle, relief angle, side cutting angle & cutting edge
2. Mechanical properties of tool & work materials
3. Type of cutting fluid used
4. m/c tool rigidity & accuracy

Economics of Machining Process

- The ultimate goal of any machining process is to produce a work part of desired shape, size & finish with *low cost* & *minimum time duration*
- These two qualities, which from the primary interest in all machining processes depends on various parameters like speed, feed, depth of cut, tool material, cutting fluid, etc., thereby making an exact economic analysis extremely complicated
- In mass scale production, often one or two operations are performed on a single m/c, and as such, preliminary analysis can be carried out to provide some basic information on the important economic aspects of the machining operation
- Such an analysis can help in choosing optimum cutting conditions apart from allocating human labour & m/c's to perform at an optimum level thereby achieving the economic goal of *highest return with minimum investment*

Choice of Cutting Speed



(a) cutting speed v/s production rate (b) cutting speed v/s production cost

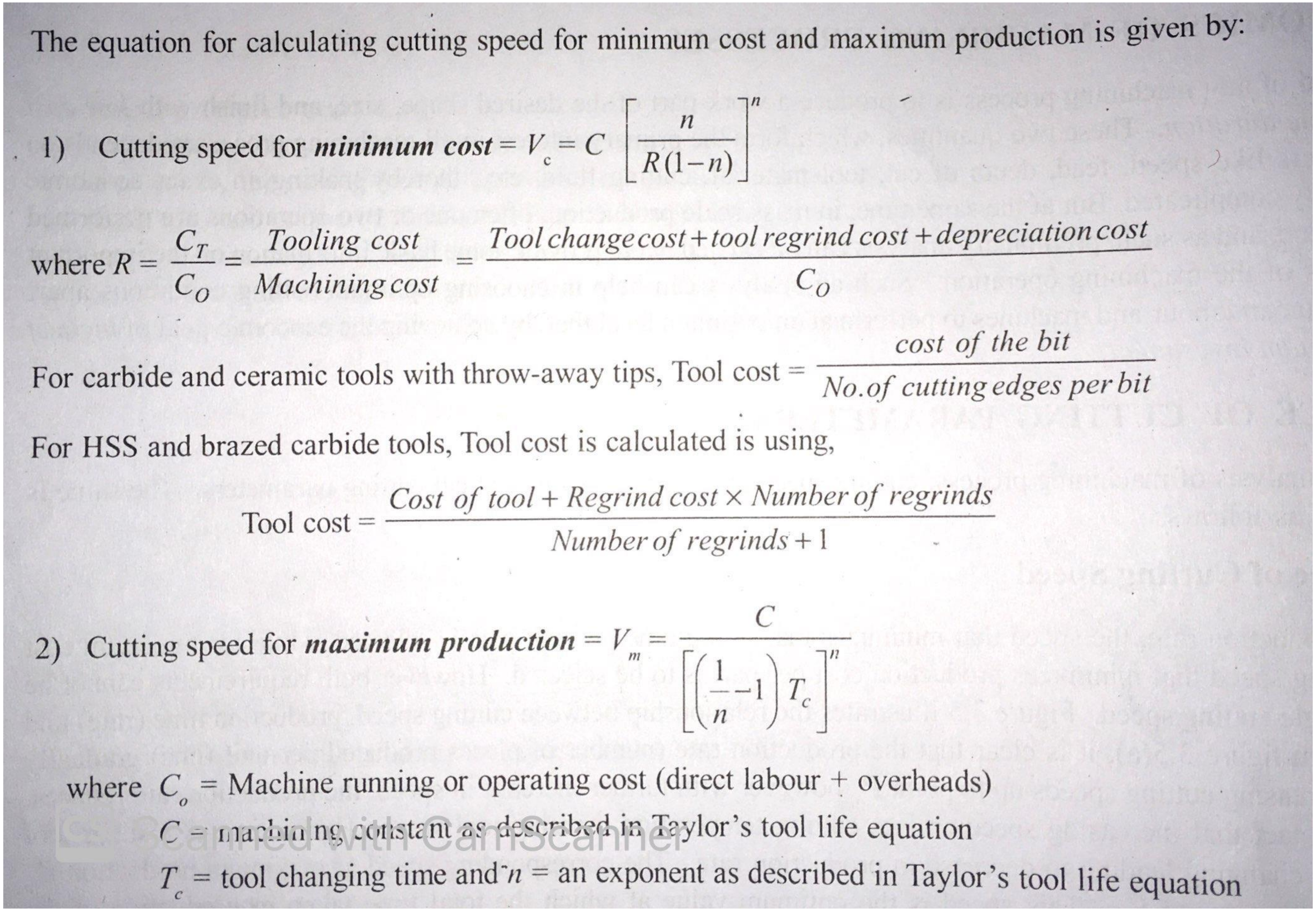
Economic choice for cutting speed

Choice of Cutting Speed

For max production rate, the speed that minimizes machining time per unit part is selected, while for minimum cost per unit, the cutting speed that minimizes production cost per part is to be selected. However both requirements cannot be achieved for a single cutting speed. Figure illustrates the relationship b/w *cutting speed, production time (rate) & production cost*. From figure ‘a’, it is clear that the production rate (no. of pieces produced per unit time) gradually increases with increase in cutting speed up to point ‘P_m’ however with further increase in speed, the production rate decreases. This is due to the fact that increasing speeds raises cutting temperature, causing tool wear. Hence time is lost for tool sharpening or tool change leading to decrease in production rate. The corresponding speed at maximum production ‘P_m’ is the optimum cutting speed ‘V_m’. This speed is the optimum value at which the total time taken in production of the component will be minimum. However, our interest in economic analysis is not satisfied yet, because the goal lies in producing the components at maximum rate & at minimum cost.

Figure ‘b’ illustrates the variation of speed w.r.t., cost per piece produced. It is clear from the plot that the cutting speed ‘V_c’ at which the production cost ‘P_c’ is minimum is different from the cutting speed ‘V_m’ at which the production rate ‘P_m’ is maximum. The region lying b/w these two cutting speeds is known as ***high efficiency rage (Hi-E)*** & any speeds lying in this range are either economical or more productive.

Choice of Cutting Speed



The equation for calculating cutting speed for minimum cost and maximum production is given by:

1) Cutting speed for ***minimum cost*** $= V_c = C\left[\dfrac{n}{R(1-n)}\right]^n$

where $R = \dfrac{C_T}{C_O} = \dfrac{Tooling\ cost}{Machining\ cost} = \dfrac{Tool\ change\ cost + tool\ regrind\ cost + depreciation\ cost}{C_O}$

For carbide and ceramic tools with throw-away tips, Tool cost $= \dfrac{cost\ of\ the\ bit}{No.of\ cutting\ edges\ per\ bit}$

For HSS and brazed carbide tools, Tool cost is calculated is using,

$$\text{Tool cost} = \frac{Cost\ of\ tool + Regrind\ cost \times Number\ of\ regrinds}{Number\ of\ regrinds + 1}$$

2) Cutting speed for ***maximum production*** $= V_m = \dfrac{C}{\left[\left(\dfrac{1}{n}-1\right)T_c\right]^n}$

where C_o = Machine running or operating cost (direct labour + overheads)

C = machining constant as described in Taylor's tool life equation

T_c = tool changing time and n = an exponent as described in Taylor's tool life equation

Relation for cutting speed for minimum cost & maximum production

Choice of Feed

- The choice of feed for economic machining depends on the type of operation: i.e., *roughness* or *finishing operation*
- When a finishing cut is to be taken, the choice of appropriate feed depends on the dimensional accuracy & surface finish required
- In such a case, the choice of feed is in the hands of the design engineer who has specified the surface finish requirement for the component to be produced
- However in roughing operations, the primary objective is to remove material as much as possible from the workpiece material within minimum possible time duration
- It is well known that equal changes in speed & feed affects the tool temperature by the same amount
- Further, an increase in feed will not affect the relative speed of sliding at the wearing function of both temperature & relative speed of sliding, it is advantageous to have a greater feed than cutting speed from a certain limit due to increase in tool forces during machining
- The limiting value of feed depends on maximum tool force the machine is capable of withstanding

Tool Life for Minimum Cost (T_{min})

For minimum production cost, the life of cutting tool must extend for longer periods. This can be achieved with minimum cutting speed, because, as the cutting speed increases, tool wear also increases. The tool life that corresponds to minimum cutting speed for minimum cost can be calculated using Taylor's tool life equation:

$VT^n=C$,

where $V = V_c$ = Cutting speed for minimum cost,

T = Tool Life, C & n or Taylor's constants

Tool Life for Minimum Production time (T_{min}) or Maximum Production Rate (T_{max})

The tool life for minimum production time or maximum production rate is a function of the index ‘n’ as described in Taylor’s tool life equation. The equation is of the form as follows:

$$T_{max} = [\frac{1}{n} - 1]T_c$$

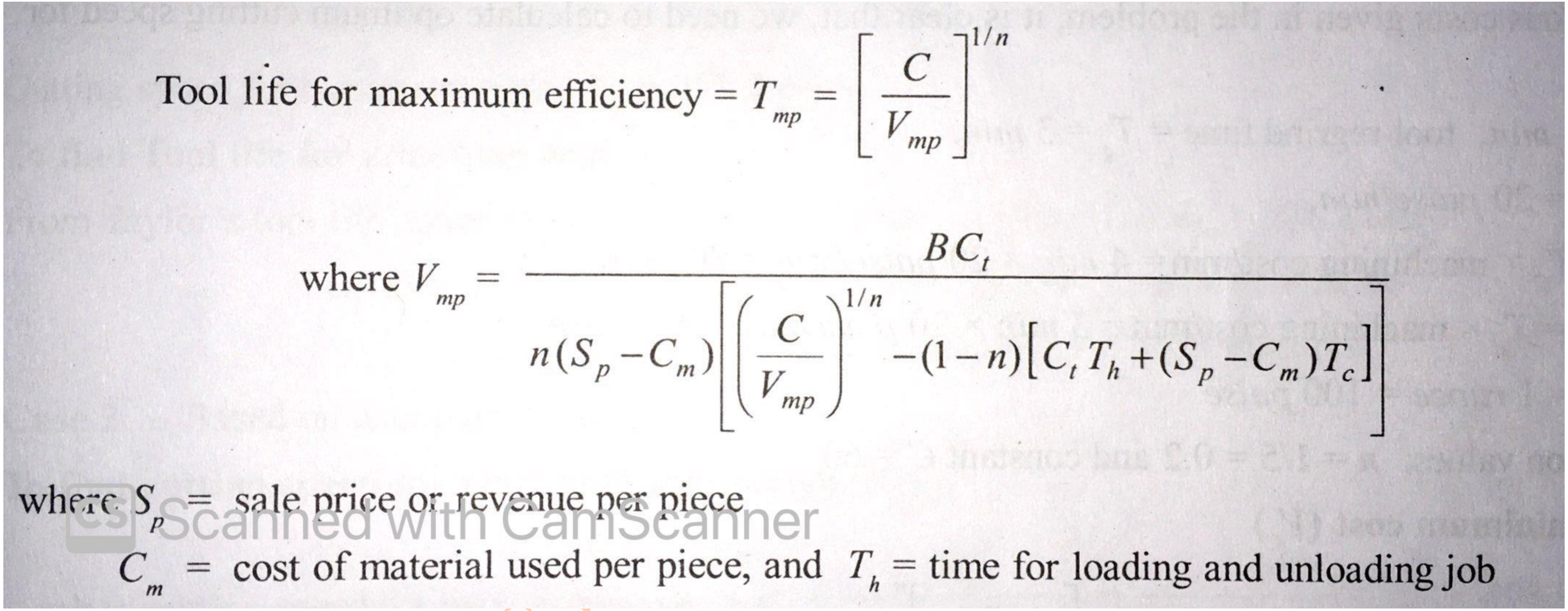
T_c= tool changing Time

T_{max}= can be calculated using Taylor’s equation: VT^n=C, where V = V_m = Cutting speed for maximum production

Tool Life for Maximum Efficiency (Maximum Profit Rate)

The equations discussed w.r.t., the cutting speed & tool life for minimum cost & maximum production do not throw any light w.r.t., maximizing the profit rate. The maximize profit rate depends on the rate of production & on the margin b/w the selling price & cost or production. For example, to achieve minimum cost, the cutting speed has to be minimum, however the production rate may be too low to maximize the profit rate. Thus the cutting speed for maximum efficiency (V_{mp}) would be different from that for minimum cost & maximum production rate.

Tool Life for Maximum Efficiency (Maximum Profit Rate)



Tool life for maximum efficiency = $T_{mp} = \left[\dfrac{C}{V_{mp}}\right]^{1/n}$

$$\text{where } V_{mp} = \frac{BC_t}{n(S_p - C_m)\left[\left(\dfrac{C}{V_{mp}}\right)^{1/n} - (1-n)\left[C_t T_h + (S_p - C_m)T_c\right]\right]}$$

where S_p = sale price or revenue per piece

C_m = cost of material used per piece, and T_h = time for loading and unloading job

Tool Life for Max Efficiency [Max Profit Rate]

Numerical's

THANK YOU