## Unit- II

Concept of machinability, machinability index, factors affecting machinability, Different mechanism of tool wear. Types of tool wear (crater, flank etc), Concept of tool life.Taylor's tool life equation. ntroduction to economics of machining. Cutting fluids: Types, properties, selection and application methods.

### Machinability

It is already known that preformed components are essentially machined to impart dimensional accuracy and surface finish for desired performance and longer service life of the product. It is obviously attempted to accomplish machining effectively, efficiently and economically as far as possible by removing the excess material smoothly and speedily with lower power consumption, tool wear and surface deterioration. But this may not be always and equally possible for all the work materials and under all the conditions. The machining characteristics of the work materials widely vary and also largely depend on the conditions of machining. A term; 'Machinability' has been introduced for gradation of work materials w.r.t. machining characteristics.

But truly speaking, there is no unique or clear meaning of the term machinability. People tried to describe "Machinability" in several ways such as:

- It is generally applied to the machining properties of work material
- It refers to material (work) response to machining
- It is the ability of the work material to be machined
- It indicates how easily and fast a material can be machined.

In general, that it is difficult to clearly define and quantify Machinability. For instance, saying **'material A is more machinable than material B may mean that compared to B,**

- **'A' causes lesser tool wear or longer tool life.**
- **'A' requires lesser cutting forces and power.**
- **'A' provides better surface finish**

Where, surface finish and tool life are generally considered more important in finish machining and cutting forces or power in bulk machining.

Machining is so complex and dependant on so many factors that the order of placing the work material in a group, w.r.t. favourablebehaviour in machining, will change if the consideration is changed from tool life to cutting power or surface quality of the product and vice versa. For instance, the machining behaviour of work materials are so affected by the cutting tool; both material and geometry, that often **machinability is expressed as "operational characteristics**

**of the work-tool combination”.** Attempts were made to measure or quantify machinability and it was done mostly in terms of:

- **Tool life which substantially influences productivity and economy in machining**
- **Magnitude of cutting forces which affects power consumption and dimensional accuracy.**
- **Surface finish which plays role on performance and service life of the product.**

**Often cutting temperature and chip form are also considered for assessing machinability.**

**But practically it is not possible to use all those criteria together for expressing machinability quantitatively.**In a group of work materials a particular one may appear best in respect of, say, tool life but may be much poor in respect of cutting forces and surface finish and so on. Besides that, the machining responses of any work material in terms of tool life, cutting forces, surface finish etc. are more or less significantly affected by the variation; known or unknown, of almost all the parameters or factors associated with machining process. **Machining response of a material may also change with the processes, i.e. turning, drilling, milling etc. therefore, there cannot be as such any unique value to express machinability of any material, and machinability, if to be used at all, has to be done for qualitative assessment.**

**The relative machining response of the work materials compared to that of a standard metal was tried to be evaluated quantitatively only based on tool life (VB* = 0.33 mm) by an index,**

**Machinability rating (MR)**

**= Speed (fpm) of machining the workgiving 60 min tool life / Speed (fpm) of machining the standard metal giving 60 min tool life x 100**

Fig. shows such scheme of evaluating Machinability rating (MR) of any work material. The free cutting steel, AISI – 1112, when machined (turned) at 100 fpm, provided 60 min of tool life. If the work material to be tested provides 60 min of tool life at cutting velocity of 60 fpm (say), as indicated in Fig. under the same set of machining condition, then machinability (rating) of that material would be,

MR = 60/100 *100 = 60%  or simply 60 (based on 100% for the standard material)

Simply the value of the cutting velocity expressed in fpm at which a work material provides 60 min tool life was directly considered as the MR of thatwork material. In this way the MR of some materials, for instance, were evaluated as,

| Metal | MR |
|---|---|
| Ni | 200 |
| Br | 300 |

| | |
|---|---|
| Al | 200 |
| CI | 70 |
| Inconel | 30 |
| | |

But usefulness and reliability of such practice faced several genuine doubts and questions:

• Tool life cannot or should not be considered as the only criteria for judging machinability

• Under a given condition a material can yield different tool life even at a fixed speed (cutting velocity); exact composition, microstructure, treatments etc. of that material may cause significant difference in tool life

• The tool life - speed relationship of any material may substantially change with the variation in

Material and geometry of the cutting tool
Level of process parameters (Vc, so, t)
Machining environment (cutting fluid application)
Machine tool condition

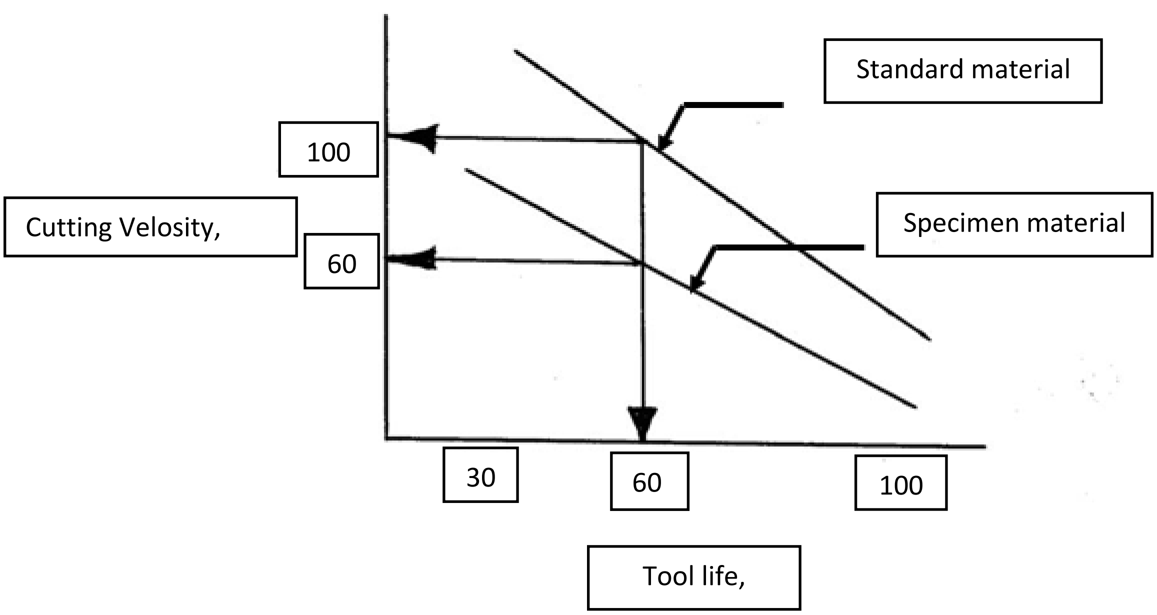



Fig.Machinability rating in terms of cutting velocity giving 60 min tool life

Keeping all such factors and limitations in view, **Machinability can be tentatively defined as "ability of being machined" and more reasonably as "ease of machining".** Such ease of machining or machinability characteristics of any tool-work pair is to be judged by:

- Magnitude of the cutting forces
- Tool wear or tool life
- Surface finish
- Magnitude of cutting temperature
- Chip forms

Machinability will be considered desirably high when cutting forces, temperature, surface roughness and tool wear are less, tool life is long and chips are ideally uniform and short enabling short chip-tool contact length and less friction.

**Role of Variation of the Different Machining Parameters or Factors on Machinability of Work Materials.**

The machinability characteristics and their criteria, i.e., the magnitude of cutting forces and temperature, tool life and surface finish are governed or influenced more or less by all the variables and factors involved in machining such as,

**i. Properties of the work material**
**ii. Cutting tool; material and geometry**
**iii. Levels of the process parameters**
**iv. Machining environments (cutting fluid application etc.)**

Machinability characteristics of any work – tool pair may also be further affected by,

- **Strength, rigidity and stability of the machine**
- **Kind of machining operations done in a given machine tool**
- **Functional aspects of the special techniques, if employed.**

**i. Role of the properties of the work material on machinability**

The work material properties that generally govern machinability in varying extent are:

• The basic nature – brittleness or ductility etc.
• Microstructure
• Mechanical strength – fracture or yield
• Hardness
• Hot strength and hot hardness
• Work hardenability
• Thermal conductivity
• Chemical reactivity

**ii. Role of cutting tool material and geometry on machinability of any work material**

**Role of tool materials**

In machining a given material, the tool life is governed mainly by the tool material which also influences cutting forces and temperature as well as accuracy and finish of the machined surface. The composition, microstructure, strength, hardness, toughness, wear resistance, chemical stability and thermalconductivity of the tool material play significant roles on the machinability characteristics though in different degree depending upon the properties of the work material.

Role of the geometry of cutting tools on machinability

The geometrical parameters of cutting tools (say turning tool) that significantly affect the machinability of a given work material (say mild steel) under given machining conditions in terms of specific energy requirement, tool life, surface finish etc. are: tool rake angles, clearance angle, cutting angles, and nose radius

The other geometrical (tool) parameters that also influence machinability to some extent directly and indirectly are: inclination angle, edge bevelling or rounding, depth, width and form of integrated chip breaker

**(iii) Role of the process parameters on machinability**

Proper selection of the levels of the process parameters ($V_C$, So and t) can provide better machinability characteristics of a given work – tool pair even without sacrificing productivity or MRR.

Amongst the process parameters, depth of cut, t plays least significant role and is almost invariable. Compared to feed (So) variation of cutting velocity (Vc) governs machinability more predominantly. Increase in Vc, in general, reduces tool life but it also reduces cutting forces or specific energy requirement and improves surface finish through favourable chip-tool interaction. Some cutting tools, specially ceramic tools perform better and lastlonger at higher Vcwithin limits. Increase in feed raises cutting forces proportionally but reduces specific energy requirement to some extent. Cutting temperature is also lesser susceptible to increase in so than Vc. But increase in so, unlike Vc raises surface roughness. Therefore, proper increase in Vc, even at the expense of so often can improve machinability quite significantly.

**(iv)Effects of machining environment (cutting fluids) on machinability**

The basic purpose of employing cutting fluid is to improve machinability characteristics of any work – tool pair through:

• Improving tool life by cooling and lubrication
• Reducing cutting forces and specific energy consumption
• Improving surface integrity by cooling, lubricating and cleaning at the cutting zone

The favorable roles of cutting fluid application depend not only on its proper selection based on the work and tool materials and the type of the machining process but also on its rate of flow, direction and location of application.

**Possible Ways of Improving Machinability of Work Materials**

*The machinability of the work materials can be more or less improved, without sacrificing productivity, by the following ways:*

*Favourable change in composition, microstructure and mechanical properties by mixing suitable type and amount of additive(s) in the work material and appropriate heat treatment.*

*Proper selection and use of cutting tool material and geometry depending upon the work material and the significant machinability criteria under consideration.*

*Optimum selection of Vc and So based on the tool – work materials and the primary objectives.*

*Proper selection and appropriate method of application of cutting fluid depending upon the tool – work materials, desired levels of productivity i.e., Vc and So and also on the primary objectives of the machining work undertaken.*

*Proper selection and application of special techniques like dynamic machining, hot machining, cryogenic machining etc, if feasible, economically viable and eco-friendly.*

**Tool wear Mechanism**

Major wear mechanisms

1. Abrasive wear
2. Adhesion wear
3. Diffusion
4. Oxidation
5. Fatigue
6. Chemical decomposing

1. Abrasive wear

- Softer material sliding over the face of hard material may contain appreciable concentration of hard particles
- Hard particles act as small cutting edge like grinding wheel
- Hard particles result worn out of tool material
- Particles of hard material are intermittently turn out from thesurface and dragged along the surface

2. Adhesive Wear

- When softer metal slide over hard metal , parts of soft metal adhere high spots on the metal due to: Friction High temperature Pressure
- The spots result irregular flow of chip over the face and build up of more particles on the tool
- Finally the built up edges will torn from the surface result uneven structure on the tool surface

3.Diffusion

- When a metal is in sliding contact with another metal the temperature at the interface is high
- The high temperature allows the atoms of hard material to diffuse into softer material matrix
- Hence the strength and abrasiveness of the softer material Increase
- Atoms of the softer metal may also diffuse into harder medium, thus weakening the surface of harder material medium
- Diffusion phenomenon is strongly dependent on temperature

4.Oxidation

- Oxidation is the result of reaction between tool face and oxygen Ex. When machining steel work piece with HSS or cemented carbide tool, groove formation is greatly accelerated if the cutting zone is subjected to a jet oxygen.

5. Fatigue Wear

- Will occur when two surfaces slides in contact with other under high pressure
- Roughness of one surface interlocks with those of other.
- Due to friction, compressive force will be produced in one side and tensileon other side, Thesephenomenon cause surface crack.
- The cracks ultimately combines with one another and lead surface crumble

**Types ofWear**

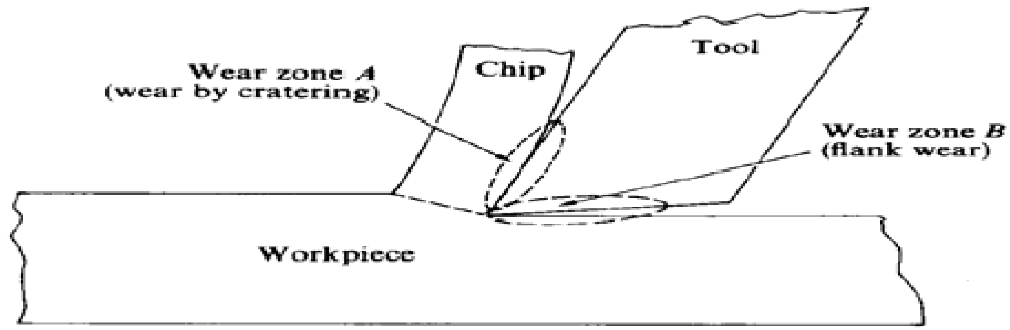
1. Flank wear(wearland)
2. Craterwear
3. Chipping

1. Flank wear(wearland)

•Itproduceswearlandonthesidesand end of aflank

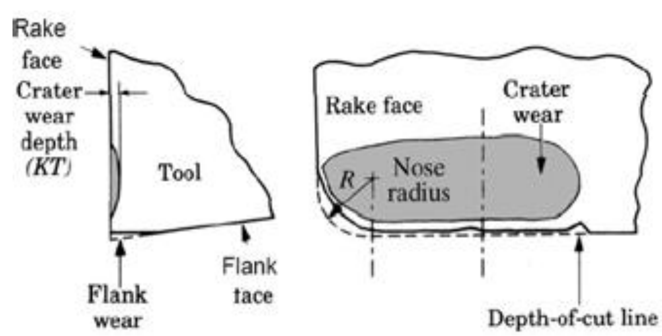
•Tool-work pieceinterface

•Predominant at lowspeed




2. Craterwear

- Itoccursontherakefaceofthetoolinthe form of pit calledcrater
- Predominant at highspeed
- Tool-chipinterface
- Diffusion




3. Chipping

Itrefersthebreakingawayofsmallchipsfromthecutting edgeoftooloraninsertonaccountofimpactorexcessive plastid deformation.

Largechippingcanbecausedbyinterruptedcuttingand sudden shock.

**Toollife**

**Criteria for tool life**

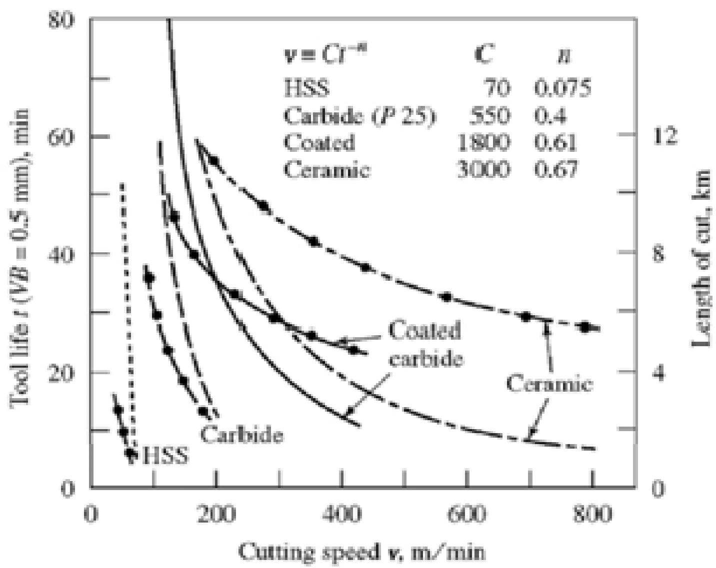
- Change of quality of machinedsurface
- Changeinmagnitudeofcuttingforce
- Change in cuttingtemperature

**Tool Life Prediction**

Taylor's tool lifeequation

$$VT^n = C$$

Where V is the cutting speed, *T* is the tool life, *n* is Taylor exponent.nandCareconstantsdependson workmaterial,feed,depthof cut and cuttingspeed.




Modified Taylor's tool life equation

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

where V is the cutting speed

*f*is the feed

*d*is depth of cut

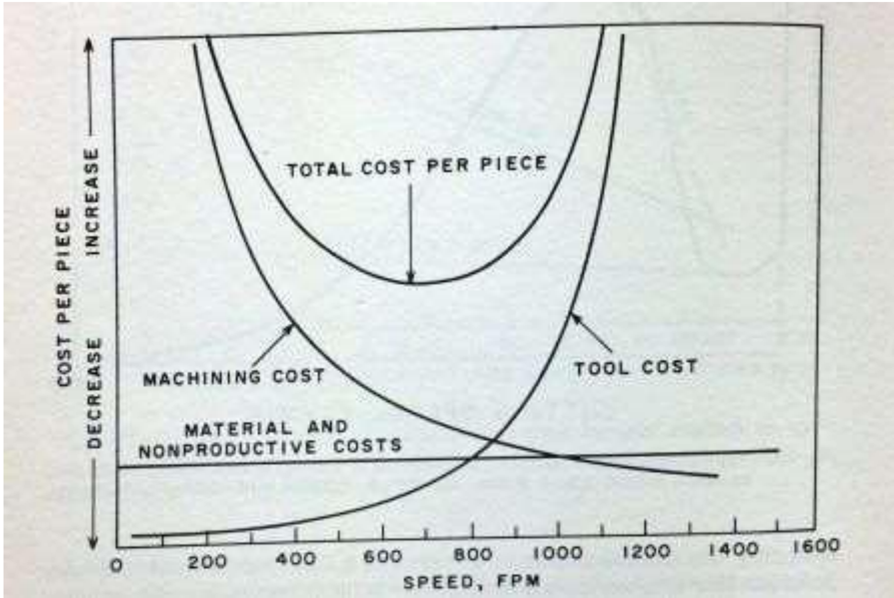
*T* is the tool life,

*n, n1 and n2* are Taylor exponent.

*n, n1 and n2* and C are constants depends on work material, feed and depth of cut and cutting speed.

**Economics of machining**

The economics of precision machining can be understood with four factors: machining cost, material cost, tool cost, and cost of non-productive time (setup costs).




**Purposes of application of cutting fluid in machining and grinding**

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 $SO_2$, $O_2$, $H_2S$, $N_xO_y$ 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 fulfil 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

Odourless and also preferably colourless

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.

**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

**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 benefits 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-tomachine 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~ 20) for stronger steels and starightsulphurised 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 oily 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.

**Methods of application of cutting fluid**

The effectiveness and expense of cutting fluid application significantly depend also on how it is applied in respect of flow rate and direction of application. In machining, depending upon the requirement and facilities available, cutting fluids are generally employed in the following ways (flow):

Drop-by-drop under gravity
Flood under gravity
In the form of liquid jet(s)
Mist (atomised oil) with compressed air

The direction of application also significantly governs the effectiveness of the cutting fluid in respect of reaching at or near the chip-tool and work-tool interfaces. Depending upon the requirement and accessibility the cutting fluid is applied from top or side(s). in operations like deep hole drilling thepressurised fluid is often sent through the axial or inner spiral hole(s) of the drill. For effective cooling and lubrication in high speed machining of ductile metals having wide and plastic chip-tool contact, cutting fluid may be pushed athigh pressure to the chip-tool interface through hole(s) in the cutting tool.