MODULE-5

TOOL WEAR & TOOL LIFE

LESSON CONTENTS:

Tool Wear, Tool Life: Introduction, tool wear mechanism, tool life equations, effect of process parameters on tool life, machinability, Numerical problems.

Economics of Machining Processes: Introduction, choice of feed, choice of cutting speed, tool life for minimum cost and minimum production time, machining at maximum efficiency.

OBJECTIVES:

- 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.

5.1 Introduction:

We have seen that cutting tools are subjected to

(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, and
(d) sliding of the tool along the newly cut workpiece surface.

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.

There are three possible modes by which a cutting tool can fail in machining:

1. **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)

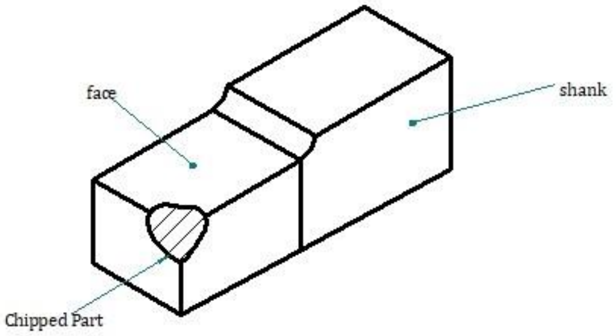


Figure 5.1: Fracture failure

2. **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.

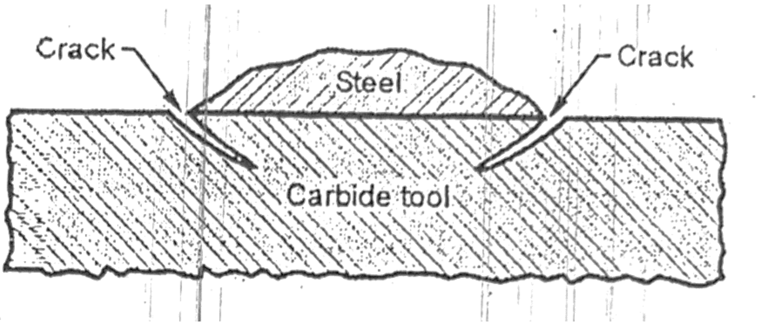


Figure 5.2: Thermal Cracking

3. **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.
    a. **Wear on the flank of the tool:** 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.

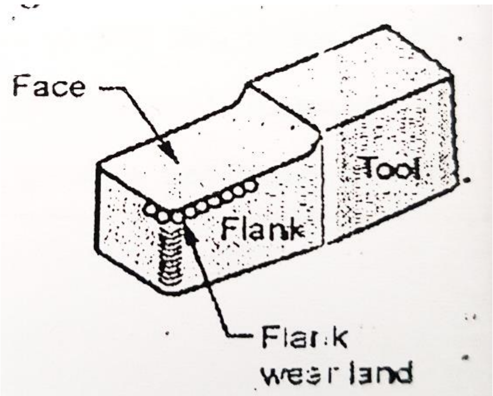


Figure 5.3: Flank Wear

b. **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.

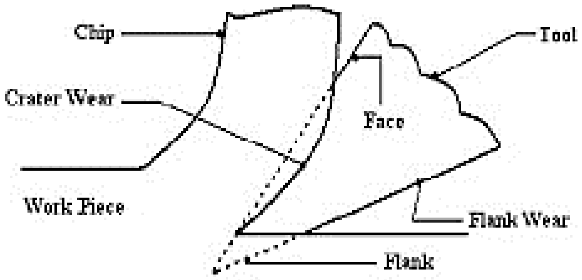


Figure 5.4: Crater Wear

5.2 Tool wear Mechanism:

The mechanisms that cause wear at the tool–chip and tool–work interfaces in machining can be summarized as follows:

- **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.
- **Chemical reactions:** The high temperatures and clean surfaces at the tool–chip interface in machining at high speeds can result in chemical reactions, in particular, oxidation, on the rake face of the tool. The oxidized layer, being softer than the parent tool material, is sheared away, exposing new material to sustain the reaction process.

- **Plastic deformation:** Another mechanism that contributes to tool wear is plastic deformation of the cutting edge. The cutting forces acting on the cutting edge at high temperature cause the edge to deform plastically, making it more vulnerable to abrasion of the tool surface. Plastic deformation contributes mainly to flank wear.

5.3 Tool Life:

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 break-in 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 5.5.

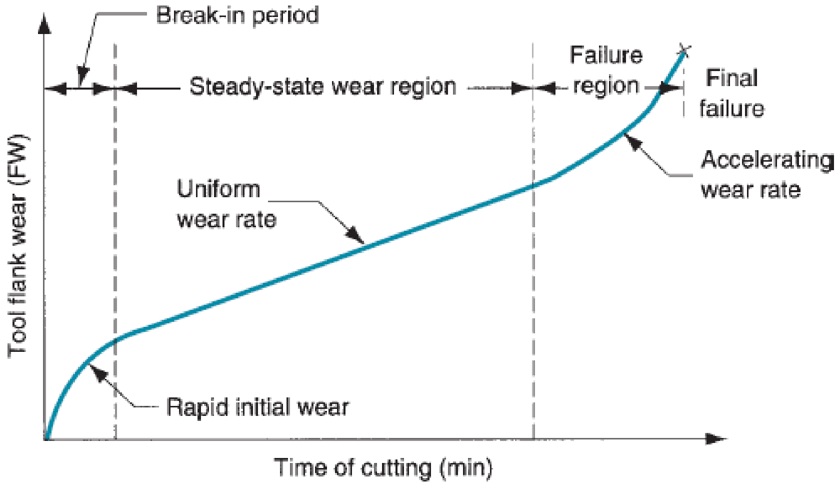


Figure 5.5: relationship between Tool Life Vs cutting time

5.4 Tool Life and Taylors Equation: Tool life is defined as the length of cutting time that the tool can be used between the two successive grinding.

In a classic study by F.W Taylor on the machining of steels conducted in the early 1890, the following approximate relationship for tool life, known as the Taylor tool life equation, was established:

$$\mathbf{V\ T^{n}=C}$$

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.

n= 0.1 for HSS

n= 0.20 to 0.25 for Carbide Tools

n= 0.4 to 0.55 for ceramic tools

5.5 Factors affecting Cutting tool life:

The life of tool is affected by many factors such as: cutting speed, depth of cut, chip thickness, tool geometry, material or the cutting fluid and rigidity of machine. Physical and chemical properties of work material influence tool life by affecting form stability and rate of wear of tools. The nose radius tends to affect tool life.

1. 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.

2. 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.

3. 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.

4. Tool material: Physical and chemical properties of work material influence tool life by affecting form stability and rate of wear of tool.

4. **Cutting fluid:** It reduces the coefficient of friction at the chip tool interface and increases tool life.

5.6 Machinability:

The machinability of a material is usually defined in terms of four factors:
l. Surface finish and surface integrity of the machined part.
2. Tool life.
3. Force and power required.
4. The level of difficulty in chip control.

However, machinability is defined as the ease with which the work material can be machined.

5.6.1 Machinability Index: Machinability index is used for comparing machinability of various materials. Machinability index of free cutting steel serves as a reference to which other machinability indexes are compared.

Machinability index of free cutting steel is taken as 100 and for calculating machinability of any other material, following relation is used:

$$M.I = \frac{Cutting\ Speed\ of\ metal\ for\ 20 min.tool\ life}{Cutting\ speed\ of\ standard\ free\ cutting\ steel\ for 20\ \min of\ tool\ life}\ X\ 100$$

Machinability index as compared to free Cutting steel for other materials are:
Stainless Steel=25%
Low carbon Steel = 55-65%
Copper = 70%
Brass = 180%
Aluminium = 300-1500%
Magnesium = 500-2000%

5.7 Economics of Machining process:

Machining or metal cutting is one important aspect of the production system. Ultimate objective of machining is to give intended shape, size and finish by gradually removing material from workpiece.

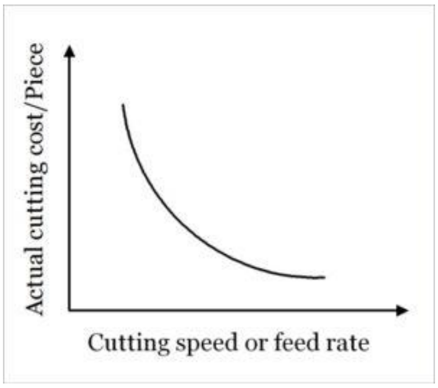
The primary goal of industries is to manufacture the product at a faster rate but at minimal cost and that too without sacrificing product quality. As long as conventional machining is utilized, in order to fulfil first requirement (faster production rate), the cutting speed and feed rate should have to be increased. However, this may lead to reduced cutting tool life due to faster wear rate and higher heat generation. Hence, cutting tool is required to change frequently, which will ultimately impose a loss for the industry as a result of idle time for changing tools. Cost of tool is also not negligible. Therefore, abrupt increase of cutting speed and feed rate is not a feasible solution; rather, an optimization is necessary.

5.8 Overall machining time and cost

Overall or total machining time (T_m) is the summation of three different time elements closely associated with the machining or metal cutting process. These three elements include actual cutting time (T_c), total tool changing time (T_{ct}) and other handling or idle time (T_i). Beside these three time elements, cost of cutting tool is also required to incorporate for any optimization. All these time or cost elements, except handling time, are affected by the variation of cutting speed and feed rate as explained below. Mathematically, total time for machining (T_m) can be expressed as:

$$Tm = Tc + Tct + Ti$$

5.8.1 Actual cutting time (Tc):



Cutting time is the time taken during actual material removal action, i.e., from the beginning of chip production to the end for uninterrupted machining. In case of any planned or unplanned stoppage in cutting, the idle duration will not come under this time element. Therefore, increase in cutting speed and feed rate will result in reduction of actual cutting time as material removal rate (MRR) will increase. Hence, cost associated with cutting time will decrease if speed or feed is increased. The adjacent diagram depicts how cost associated with the actual cutting time varies with speed or feed employed during machining.

If, Lc is the total length of cut (mm), N is the spindle speed (rpm) and s is the feed rate (mm/rev), then estimated uninterrupted cutting or machining time can be expressed as:

$$\text{Actual cutting Time } \boldsymbol{Tc = \frac{Lc}{N.\ S}}$$

In most of the cases, where either workpiece or cutting tool is rotating, the spindle speed (N) and cutting velocity (Vc) are interchangeable. However, cutting velocity also depends on the diameter of the job/cutter (D). Cutting velocity can be expressed, in terms of speed and diameter of job or cutter (whichever is rotating), as follows. For better understanding of this conversion, you may read: Cutting speed and cutting velocity in machining.

$$\textbf{Cutting velocity } V_c = \frac{\pi D N}{1000}$$

In case of turning or milling, actual cutting time can be expressed as:

$$T_c = \frac{L}{N.s}$$

$$T_c = \frac{L}{\left(\frac{1000V_C}{\pi D}\right)s}$$

$$T_c = \frac{\pi D L}{1000V_C}$$

Mathematical Expression for Tool Changing time:

$$T_{ct} = \left(\frac{T_c}{TL}\right) \times TCT$$

Tooling Cost:

$$\text{Tooling cost} = \left(\frac{T_c}{TL}\right) \times K_2$$

5.8.2 Overall Machining Cost:

Since every time elements pertinent to machining contributes towards machining cost, so some factors are required to convert time to cost. On the basis of these factors, time elements can be converted to cost elements and estimation of machining economy becomes easier. Such factors include:

K1 = Cost-time conversion factor for machining

K2 = Cost-time conversion factor for tool sharpening or price of new tool.

Therefore, overall machining cost per piece (Cp)

= (Actual cutting cost/piece) + (Tool changing cost/piece) + (Handling cost/piece) + (Tooling cost/piece)

= K1 {(Actual cutting time/piece) + (Tool changing time/piece) + (Handling time/piece)} + K2 {(Tooling cost/piece)}

$$= K_1 \{T_c + T_{ct} + T_i\} + \left(\frac{T_c}{TL}\right) \times K_2$$

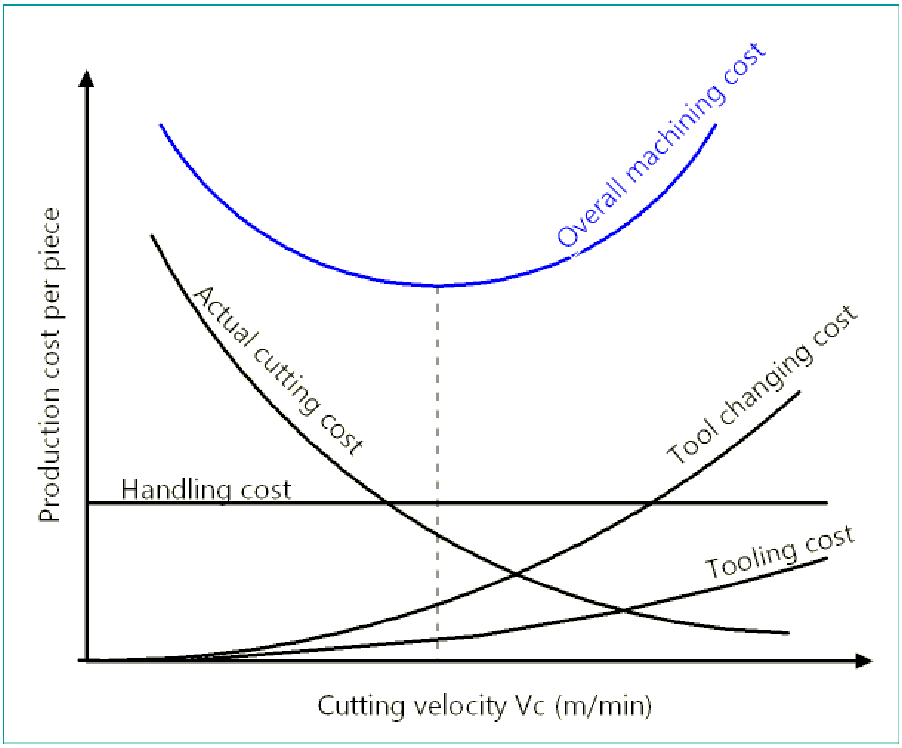


Figure: Effect of variations in cutting speed on various cost factors

5.8.3 Finding out economic condition and Gilbert's Model

Undoubtedly the final thing is to find out the optimum condition for either maximizing profit or minimizing time requirement. For paper based optimization, only cutting velocity or speed is considered in order to keep the analytical process less complicated. Moreover, cutting velocity is the main parameter that affects machining performance. A number of constraints can be handled effectively using computer programming based optimization techniques.

Now there exist a number of objectives for optimization, among which Gilbert's Model (1952) for Maximum Production Rate and Minimum Production Time are more prominent. These models are based on the Taylor's Tool Life equation, which consider only cutting velocity to determine tool life. Various economic models for optimizing machining process parameters for different objectives are provided below.

OUTCOMES:

- Student will able to describe the wear mechanism and different types of wear.
- Student will understand about the factors affecting tool life and Taylor's tool life equation.
- Student will know the importance of machinability and factors affecting to it.
- Student can enumerate the importance of tool life and solve simple numerical problems.
- Student can know the importance of economic point of machining and parameters affecting the machining cost.

QUESTIONS:

1. What are the factors affecting the tool life?
2. What is machinability? Define machinability index.
3. Write a short note on economics of metal machining
4. State a relationship of cutting speed and tool life for minimum cost and maximum production.
5. What do you mean by crater wear and flank wear?
6. Describe briefly tool wear mechanism.
7. A tool life of 80min is obtained at a speed of 30mpm and 8 minute at 60mpm. Determine the following:
   a. Tool life equation.
   b. Cutting speed for 4-minute tool life.
8. The following equation for tool life is given for turning operation $VT^{0.13}f^{0.77}d^{0.37}=C$. A 60 min tool life as obtained while cutting at V=30 m/min, f=0.30mm/rev and depth of cut d=2.5mm. calculate the change in tool life if the cutting speed, feed and depth of cut are increased by 20% of individually and also taken together. What will be their effect on the tool life?
9. A certain cutting tool during rough turning gave a tool life of 1 hour at a cutting speed of 30m/min. what will be the life of the tool when it is used at the same cutting speed for finish turning. Take n=0.125 for rough turning and n=0.1 for finish cut.
10. The tool life for a HSS tool is expressed by the relation $VT^{1/7}=C1$ and for tungsten carbide $VT^{1/5}=C2$. If the tool life for a cutting speed of 24m/min is 128min, compare the tool life of the two tools at a speed of 30 m/min

FURTHER READING:

1. **"Metal cutting principles"**, Milton C. Shaw, Oxford University Press, Second Edition,2005.
2. **"Manufacturing Technology",** Vol 2, P N Rao, McGraw Hill Education, 3rd Edition

3. **"Workshop Technology, Vol-II",** by Hazara Chowdary