Module
3
Machinability

Lesson
14
Failure of cutting tools and tool life

Instructional objectives

At the end of this lesson, the students will be able to

(i) State how the cutting tools fail
(ii) Illustrate the mechanisms and pattern of tool wear
(iii) Ascertain the essential properties of cutting tool materials
(iv) Define and assess tool life
(v) Develop and use tool life equation.

(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The cutting tool is withdrawn immediately after it fails or, if possible, just before it totally fails.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 Fig. 3.2.1 (a and b) and Fig. 3.2.2 respectively.

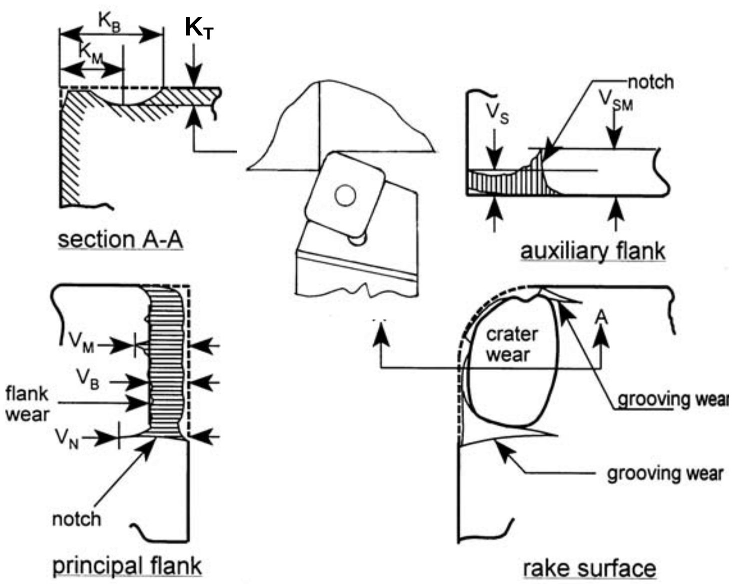


Fig. 3.2.1 (a) *Geometry and major features of wear of turning tools*

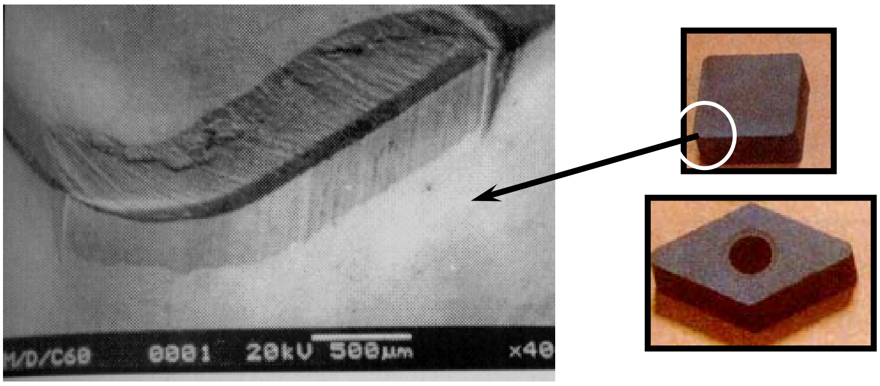
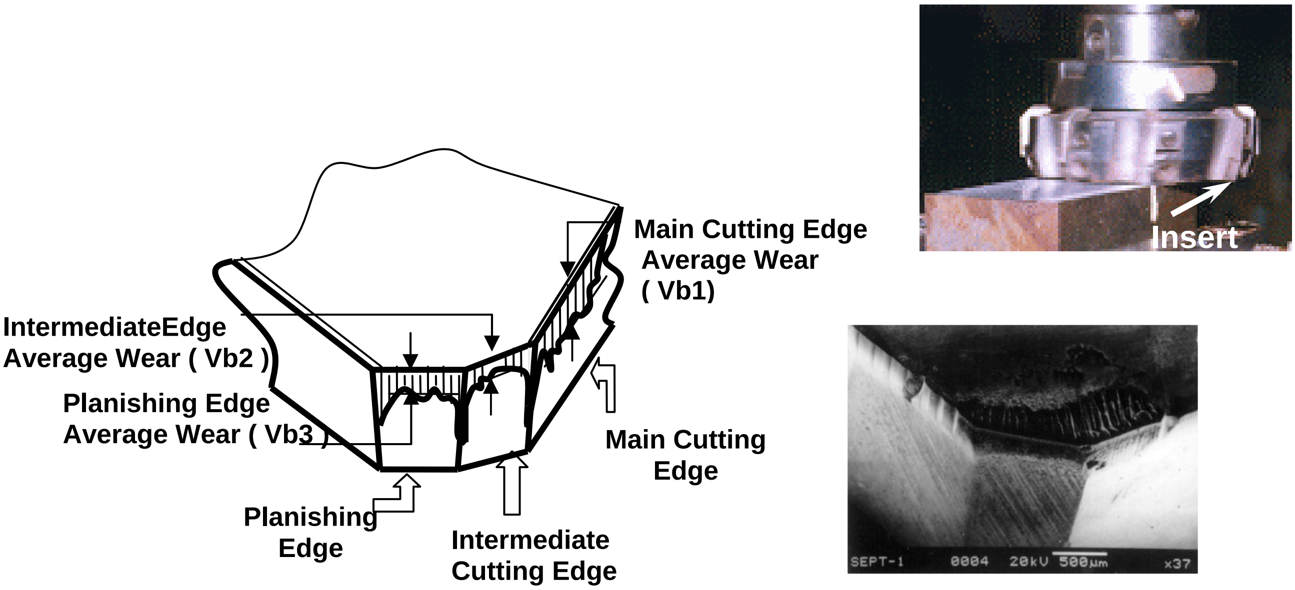


Fig. 3.2.1 (b) Photographic view of the wear pattern of a turning tool insert



(a) (b)

Fig. 3.2.2 *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 :

i) high mechanical strength; compressive, tensile, and TRA
ii) fracture toughness – high or at least adequate
iii) high hardness for abrasion resistance
iv) high hot hardness to resist plastic deformation and reduce wear rate at elevated temperature
v) chemical stability or inertness against work material, atmospheric gases and cutting fluids
vi) resistance to adhesion and diffusion
vii) thermal conductivity – low at the surface to resist incoming of heat and high at the core to quickly dissipate the heat entered
viii) high heat resistance and stiffness
ix) manufacturability, availability and low cost.

iv) 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, **tool 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 :

i) 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.
ii) 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
iii) using optical microscope fitted with micrometer – very common and effective method
iv) using scanning electron microscope (SEM) – used generally, for detailed study; both qualitative and quantitative
v) Talysurf, specially for shallow crater wear.

(v) 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.3.2.3.

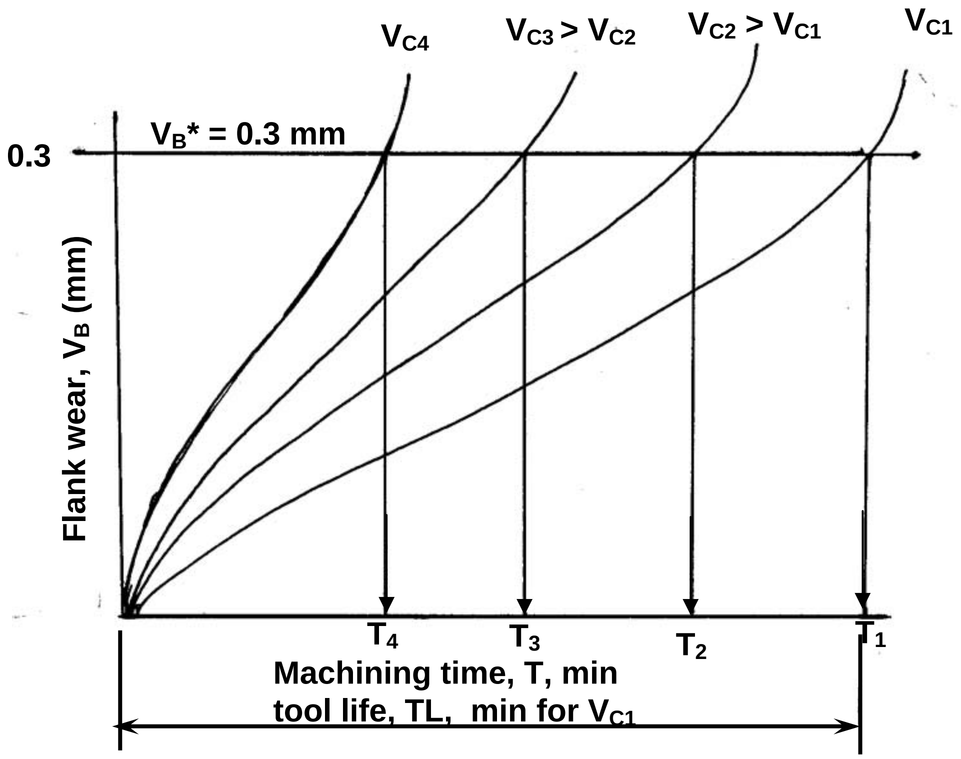


Fig. 3.2.3 *Growth of flank wear and assessment of tool life*

The tool life obviously decreases with the increase in cutting velocity keeping other conditions unaltered as indicated in Fig. 3.2.3.
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. 3.2.4, 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 Fig. 3.2.5.
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.)

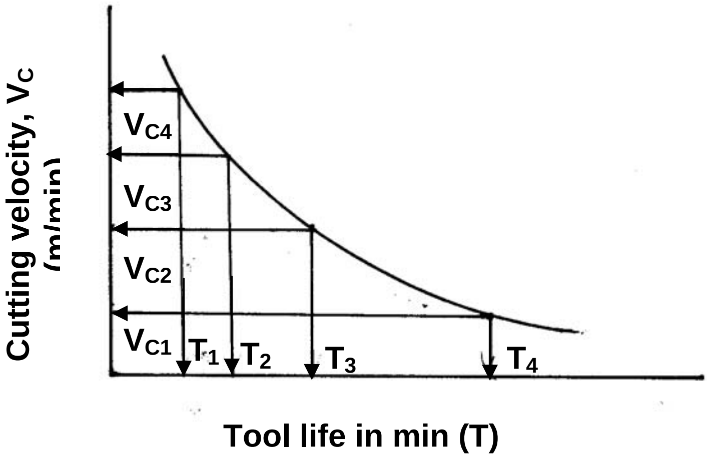


Fig. 3.2.4 *Cutting velocity – tool life relationship*

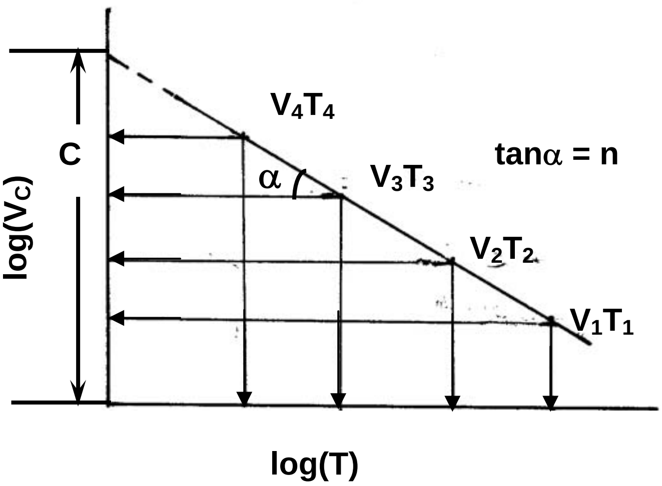


Fig. 3.2.5 *Cutting velocity vs tool life on a log-log scale*

Example of use of Taylor's tool life equation

Problem :

If in turning of a steel rod by a given cutting tool (material and geometry) at a given machining condition (s_o and t) under a given environment (cutting fluid application), the tool life decreases from 80 min to 20 min. due to increase in cutting velocity, V_C from 60 m/min to 120 m/min., then at what cutting velocity the life of that tool under the same condition and environment will be 40 min.?

Solution :

Assuming Taylor's tool life equation, $VT^n = C$

$V_1T_1 = V_2T_2 = V_3T_3 = ... = C$

Here, V_1 = 60 m/min; T_1 = 80 min.

V_2 = 120 m/min; T_2 = 20 min.

V_3 = ? (to be determined); T_3 = 40 min.

Taking,

$$V_1T_1^n = V_2T_2^n$$

i.e,
$$\left(\frac{T_1}{T_2}\right)^n = \left(\frac{V_2}{V_1}\right)$$

or
$$\left(\frac{80\min}{20\min}\right)^n = \left(\frac{120\,m/\min}{60\,m/\min}\right)$$

from which, n = 0.5

Again
$$V_3T_3^n = V_1T_1^n$$

i.e,
$$\left(\frac{V_3}{V_1}\right) = \left(\frac{T_1}{T_3}\right)^n$$

or
$$V_3 = \left(\frac{80}{40}\right)^{0.5} x60 = 84.84\,m/\min \qquad \textbf{\textit{Ans}}$$

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,

$$TL = \frac{C_T}{V_c^x s_o^y t^z}$$

where, TL = tool life in min

C_T — a constant depending mainly upon the tool – work materials and the limiting value of V_B 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.

Exercise – 3.2

Quiz Test

Identify the correct answer from the given four options.

1. In high speed machining of steels the teeth of milling cutters may fail by
   (a) mechanical breakage
   (b) plastic deformation
   (c) wear
   (d) all of the above
2. Tool life in turning will decrease by maximum extent if we double the
   (a) depth of cut
   (b) feed
   (c) cutting velocity
   (d) tool rake angle
3. In cutting tools, crater wear develops at
   (a) the rake surface
   (b) the principal flank
   (c) the auxiliary flank
   (d) the tool nose
4. To prevent plastic deformation at the cutting edge, the tool material should possess
   (a) high fracture toughness
   (b) high hot hardness
   (c) chemical stability
   (d) adhesion resistance

Problems

Problem – 1

During turning a metallic rod at a given condition, the tool life was found to increase from 25 min to 50 min. when V_C was reduced from 100 m/min to 80 m/min. How much will be the life of that tool if machined at 90 m/min ?

Problem – 2

While drilling holes in steel plate by a 20 mm diameter HSS drill at a given feed, the tool life decreased from 40 min. to 24 min. when speed was raised from 250 rpm to 320 rpm. At what speed (rpm) the life of that drill under the same condition would be 30 min.?

Answers of the questions of Exercise – 3.2

Quiz Test

Q. 1 : (d)
Q. 2 : (c)
Q. 3 : (a)
Q. 4 : (b)

Solution to Problem 1.

Ans. 34.6 min

Solution to Problem 2

Ans. 287 rpm.