3 Tool life *T*

3.1 Definition

Tool life *T* is the period of time, expressed in minutes, for which the cutting edge, affected by the cutting procedure, retains its cutting capacity between sharpening operations. The cutting edge remains functional until a certain amount of wear has occurred (3.3).

In drilling and milling, one frequently makes use of the term tool life travel path rather than tool life. Tool life travel path *L* includes the sum of drilling depths, or the sum of machined lengths in case of milling, which were cut with one tool in the period between sharpening operations. The rate of removal of the metal chips produced by the milling tool between sharpening operations is another way to assess the tool life characteristics of milling tools.

3.2 Characteristics of dulling

3.2.1 Cutting materials for which dulling is mainly caused by temperature

In these tools, the cutting edge becomes unusable as a result of the temperature that occurs on the cut surface. This phenomenon applies to tools made of:

tool steel and
high speed steel

With these cutting materials, when tool failure temperature is reached (tool steel 300 °C, high speed steel 600 °C), the cutting edge melts and chips. A cutting edge that is no longer able to cut generates a shiny strip on the workpiece. This phenomenon is called bright braking. The strip emerges if the cutting edge has been melted off and the tool's flank face rubs over the cut surface of the workpiece.

3.2.2 Cutting materials for which dulling is mainly caused by abrasion

Cemented carbide and ceramic fall into this group of cutting materials. For them, there is no characteristic tool failure temperature; instead, wear increases rapidly at the beginning and later continues slowly.

3.2.3 Wear types

3.2.3.1 Flank face wear

For this type, wear at the flank face (Figure 3.1) is measured. The tool is regarded as dull if a certain width of flank wear land *B* has been achieved. The greater *B is*, the greater the offset of the cutting edge SKV. The table below (Table 2) shows the permitted widths of flank wear land for some cutting techniques.

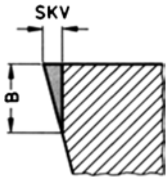

Figure 3.1
Flank face wear with width of flank wear land *B*

Table 3.1 Dimension of the width of flank wear land [3, p. 182]

Technique	*B* in mm
Precision turning	0.2
Finish turning	0.3–0.4
Rough turning Average sectional areas of chip Large sectional areas of chip	 0.6–0.8 1.0–1.5
Finish planing Rough planing	0.3–0.4 0.6–0.8
Finish milling Rough milling	0.3–0.4 0.6–0.8

3.2.3.2 Crater wear

In this kind of wear, the parameters (Figure 3.2) of crater depth K_T, crater width K_B and crater centre distance K_M are measured. The crater coefficient *K* is determined based on crater depth and crater centre distance. The crater coefficient is a measure of the weakening of the wedge; for this reason, it must not go beyond a certain limit.

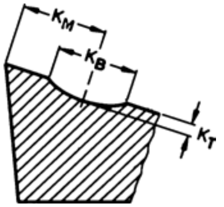

Figure 3.2
Rake face wear with crater depth K_T and crater centre distance K_M

Depending on the material to be removed and the cutting edge material, the permissible crater coefficients range from 0.1 to 0.3.

$$\boxed{K = \frac{K_T}{K_M}}$$

K	crater coefficient
K_T in mm	crater depth
K_M in mm	crater centre distance

For greater cutting speed values, crater wear dominates. Consequently, this wear criterion should be applied generally in the realm of high cutting speed values (*v* > 150 m/min). In practice, however, width of flank wear land is primarily used as the criterion fro determining wear.

Table 3 shows a summary of the most significant wear characteristics:

Table 3 Wear characteristics

Cutting material	Dulling characteristics onthe tool	Effects on the workpiece resulting from
Tool steel high speed steel (SS, HSS)	Melting off and chipping of the cutting edge	Bright strips (bright braking) poor surface quality
Cemented carbide ceramic	Abrasion on the flank face and rake face	Dimensional deviation, worsening of the surface quality

In addition to wear characteristics on the tool and workpiece, we may observe that the cutting forces and the machine input power required for cutting increase as a function of wear. For this reason as well, wear on the tools must not exceed the limits specified above.

3.3 Influence on tool life

Tool life *T* and tool life travel path *L* of the cutting tools depend on many factors. The most essential ones are explained below.

3.3.1 Workpiece material

The higher the resistance to shear during cutting off, and the grater the strain hardening when the chip is compressed, the greater the forces affecting the cutting edge. Tool life diminishes as a function of rising pressure and pressing- and bending loads.

3.3.2 Cutting material

The cutting materials' wear characteristics mainly depend on their hardness, compressive- and bending strength, temperature resistance, and toughness. Increasing hardness diminishes abrasion. Great compressive- and bending strength, in particular at higher temperatures, improve edge strength. The higher the critical temperature, at which, for example, cutting edges made of high speed steel fail or cutting edges made of cemented carbide chip, the more frictional heat the cutting material is able to resist, and, consequently, the higher the permissible cutting speed. Tough cutting materials withstand bumping or vibrating loads better than brittle ones.

Issues that should be particularly taken into consideration are

- the clear identification of the failure temperature in case of tool steels and high speed steels,

– decrease of toughness, compressive- and bending strength as a function of increasing hardness in cemented carbides.

3.3.3 Cutting edge shape

With a large wedge angle and small rake angle, the stressed cross section of the cutting edge is larger, the forces transmitted increase accordingly, and wear is less than in the case of thin, pointed cutting edges.

3.3.4 Surface

A poor surface, such as one prepared using excessively rough grinding wheels, generates notchy cutting edges that tend to chip. Hard and heterogeneous workpiece surfaces, e.g. with cast- or forged exteriors, cause bumping or vibrating loads on the cutting edge and, when the cutting material is brittle, they diminish tool life.

3.3.5 Stiffness

Unstable workpieces, clamping fixtures, tools and/or components of machine tools reduce the limit of allowable chattering and thus damage brittle cutting materials.

3.3.6 Sectional area of chip

Cutting force and thus the load affecting the cutting edges rises as a function of increasing sectional area of chip. Here, feed affects wear to a greater extent than infeed.

3.3.7 Coolants and lubricants

Depending on their composition, metalworking fluids (coolants and lubricants) have a more or less cooling or lubricating effect. At low cutting speed values, tool life may be improved predominantly by lubrication, at high cutting speed values, predominantly by cooling.

3.3.8 Cutting speed

Cutting speed is the parameter with the strongest influence on tool life ***T*.** Tool life curves illustrate the tool life as a function of the cutting speed. It follows from this that tool life strongly decreases as cutting speed increases.

3.4 Calculation and representation of tool life

Tool life can be computed according to the equation below:

$$\boxed{T = \frac{1}{C^{\mathrm{k}}} \times v^{\mathrm{k}}} \qquad \text{(Taylor equation)}$$

T	in min	tool life
C	in m/min	cutting speed for $T = 1$ min
k		constant

Figure 3.3
Tool life T as a function of cutting speed v_c

As the equation shows, the tool life curve (see Figure 3.3) is an exponential function. From this we learn that tool life strongly decreases as cutting speed increases.

If we represent the tool life curve in a log-log network (Figure 3.4), then we obtain a straight line in the practical working range. This straight line is called

T-v curve.

From this T-v curve, we can obtain the corresponding tool life for any cutting speed.

Position and angle of inclination in the tool life curve change as a function of the influencing parameters described.

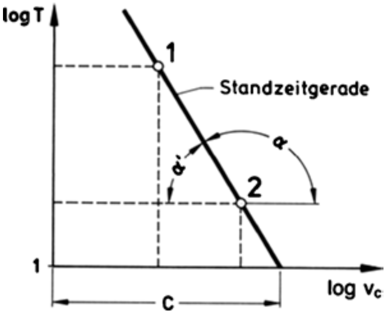

Figure 3.4
Tool life
Logarithmic representation of the function $T = f(v_c)$

Since feed f and depth of cut a_p also affect tool life, to determine the cutting speed v_c, we apply the extended Taylor equation.

$$v_c = C \cdot f^E \cdot a_P^E \cdot T^G \quad \boxed{\left(G = \frac{1}{K}\right)}$$

When C is replaced with v_{c111}, then we obtain

$$\boxed{v_c = v_{c111} \cdot f^E \cdot a_P^F \cdot T^G}$$

v_{c111} in m/min cutting speed for f = 1 mm/U, a_p = 1 mm, T = 1 min
f in mm feed
a_p in mm depth of cut
T in min tool life

In tables of reference provided by the manufacturers of cemented carbide, there are specifications for v_{c111} values and numerical values for the exponents E, F and G for certain groups of materials that may be machined and for various types of cemented carbide.

These values have been added to the tables with ready-to-use reference values – Nos. 7.5 and 7.6 in this textbook.

3.5 Length of tool life and allocation of the cutting speed

In order to place tool life in the production process, tool life for various machines may be classified (with some limitations) as follows:

Production machines with short setup times e.g. numerically controlled machines	T = 15 to 30 min
Machines of average setup time, autonomous machines e.g. turret lathes with cam control	T = 60 min
Machines with long setup times, machines linked to another one (such as curve-controlled automatic lathes) and chained special-purpose machines (e.g. transfer lines)	T = 240 min

T = 15 min	v_{c15}
T = 60 min	v_{c60}
T = 240 min	v_{c240}

The respective cutting speed values assigned are designated as v_{c15}, v_{c60}, v_{c240}, thus, v_{c60} is the cutting speed, at which a tool life of 60 min can be achieved.

The cutting speed values assigned to the permissible tool life values can be taken from tables of reference (see also Chapter 7.8).

3.6 Cost-optimal tool life

The adjustment of optimal tool life values is possible as a result of the development of cutting tool tips that are held in specially designed clamping steel holders and thus are quick to exchange. Consequently, in many cases, the standard tool life values of $T = 60$ min are sacrificed for the benefit of a higher cutting speed and less machine time. Tool life at minimal cost is thus calculated, taking into account tool cost, machine costs per hour, cost of labour, tool positioning time and the material to be cut.

From there, we obtain tool life values $T = 5 - 30$ min with assigned high cutting speed values from 200 to 400 m/min, where cemented carbide is used as the cutting edge material.