Unit 2: Cutting tool materials

Tool materials & its related terminologies: -types of tool materials, Tool wear, Factors causing wear, tool life, variables affecting tool life, Optimal cutting speed.

A cutting tool plays very important role in machining. The shape of work piece, its surface finish and some other properties are directly dependable on the tool material and its design. A proper designed tool with appropriate material gives better surface finish and high accuracy. A cutting tool should have the following;

- It should have high hot hardness.
- High Wear Resistance.
- Tool should have high Toughness and hardness.
- It should have high thermal conductivity.
- Tool works at high temperature during cutting so it should have low coefficient of thermal expansion.
- Tool should have high strength.
- It should have Low coefficient of friction and should be chemically stable.

Many types of tool materials, ranging from high carbon steel to ceramics and diamonds, are used as cutting tools in today's metalworking industry. It is important to be aware that differences do exist among tool materials and it is not necessary that the most expensive tool is always the best tool.

When a tool change is needed or anticipated, a performance comparison should be made before selecting the tool for the job. The optimum tool is not necessarily the least expensive or the most expensive, and it is not always the same tool that was used for the job last time. The best tool is the one that has been carefully chosen to get the job done quickly, efficiently, and economically.

A cutting tool must have the following characteristics in order to produce good quality and economical parts:

1. **Hot hardness:** Generally, hardness is measured at room temperature. But the term Hot hardness indicates that the hardness at elevated temperature. We know that the hardness decreases as temperature increases. In metal cutting, heat is generated during the process. The tool material must be able to maintain its hardness, wear resistance and strength at

such a high elevated temperature, which ranges nearly 600°C to 1800°C. Fig. blow shows the variation of hardness of different tool material with increase in temperature.

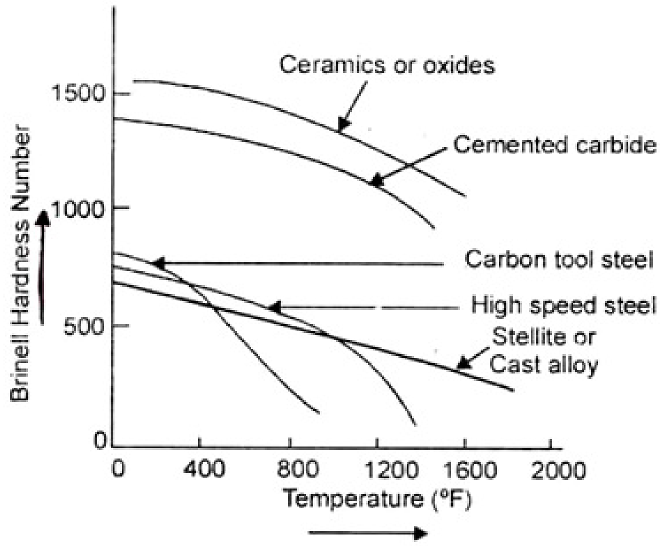


Fig. Variation of Hardness with Temperature.

2. **Wear Resistance:** The term wear means loss of material. As tool continues cutting, its cutting edge which is always in touch with the workpiece and the rake face (over which the chip flows) lose their material gradually with time. Therefore, the tool material must have wear resistance, so that an acceptable tool life is obtained before the tool is indexed or replaced.
3. **Chemical stability or inertness:** Tool material must have chemical stability or inertness with respect to the work material, so that any undesirable reactions between tool material, and work material are avoided.
4. **Toughness:** It actually implies a combination of strength and ductility. The material must have sufficient toughness to withstand shocks and vibrations to prevent breakages.
5. **Shock resistance:** Tool material must have high resistance against thermal and mechanical shocks, especially in intermittent cutting in which tool-work engages and dis-engages at regular intervals.
6. **Low friction:** Tool material must have low coefficient of friction. So that the heat generated will be lower, and tool life increases.
7. **Cost and easiness in fabrication:** The cost and easiness of fabrication should have within reasonable units.

TYPE OF CUTTING TOOL MATERIALS

There are many types of cutting process done in different conditions. In such conditions along with the general requirements of the cutting tool, they need some unique properties. To achieve this properties, the cutting tools are made up of different material. The material chosen for a particular application depends on the material to be machined, type of machining, quantity and quality of production. According to the material used the tools are classified into

1. Carbon steel tool
2. Stellite
3. High speed steel tool (HSS)
4. Coronite
5. Cemented carbide
6. Ceramics tool
7. Cermets
8. Cubic boron nitride Tool (CBN)
9. Diamond tool
10. Ucon

1. **Carbon tool steel**: Carbon tool steel is one of the inexpensive metal cutting tools used for the low-speed machining operation. These plain carbon steel cutting tool have the composition of 0.6-1.5 % carbon and very small amount (less than 0.5 %) Mn, Si. Other metal like Cr, V are added to change the hardness and grain size. High carbon steels are abrasion resistant and have the ability to maintain sharp cutting edge. Carbon tool steels possess good machinability. This material loses their hardness rapidly at a temperature about 250^{o}C. Therefore, it cannot be used for high temperature application. It does not prefer in a modern machining operation.

2. **High Speed Steel (HSS)**: High speed steel is very common tool material which is an alloy of steel tungsten, Chromium and Vanadium. It contains 18% Tungsten, 4% Chromium and 1% Vanadium. This material is deep hardening and can be quenched in oil, air or salt. It gives a higher metal removal rate. It loses its hardness at a moderate temperature about 650°C. Therefore, a coolant should be used to increase tool life. It can use many times by re-sharpening. Some surface treatment is done on the HSS to improve its property.

According to the composition of material, it can be divided into two major types.

1. Tungsten type steels in which tungsten is used as the major alloying element.

2. Molybdenum type steel in which tungsten is partially or completely replaced by molybdenum. It is cheaper than tungsten type steel and has greater toughness at the same level of hardness.

Surface treatment used in the HSS
Super finishing - Reduce friction.
Nitriding - Increase wear resistance.
Chromium electroplating - Reduce friction.
Oxidation - Reduce friction
High-speed steel tools are used in drills, milling cutters, single point lathe tools, broaches.
Cutting speed range - 30-50 m/min
Temperature - 650°C
Hardness – up to HRC 67
T-Type - Tungsten predominant type
M-Type - Molybdenum dominant type

3. **Stellite:** Stellite is a nonferrous alloy with cobalt, chromium, Tungsten, with molybdenum and boron. Cobalt is used about 38–53 percent, chromium is 30–33 %, tungsten is about 10–20 % and carbon contain is about 1–3%. This material has intermediate properties between HSS and cemented carbide. Its highest working temperature is about 900^{O}C. This tool material is mostly used for rough machining at relatively high speed and feed rate and it can machine more difficult materials such as high tensile steel, stainless steels and heat treated resistant steels.

4. **Coronite:** It is a new cutting material whose properties lies in between those of HSS and cemented carbide. This material consists of fine grain of TiCN evenly dispersed in a material of heat treatable steel. It is used for producing small and medium size drill and milling cutters. It is also used for compounding and coating technology. It is mainly used as core material for HSS or spring steel.

5. **Cemented carbide tools**: The carbide tools are produced by powder metallurgy technique. It consists of tungsten, tantalum and titanium carbide with cobalt as a binder (when the binder is nickel or molybdenum, then it is called cermet). Cemented carbide tools are extremely hard, they can withstand very high-speed cutting operation. Carbide tool does not lose their hardness up to 1000° C. A high cobalt tool is used for a rough cut while low cobalt tool used for finishing operations.
Cutting speed range - 60-200m/min
Temperature - 1000°C
Hardness – up to HRC 90

6. **Ceramics**: Most common ceramic materials are aluminum oxide and silicon nitride. Powder of ceramic material Compacted in insert shape, then sintered at high temperature. Ceramic tools are chemically inert and possess resistance to corrosion. They have high compressive strength. They are stable up to temperature 1800°C. They are ten times faster

than HSS. The friction between the tool face and chip are very low and possess low heat conductivity, usually no coolant is required. They provide the very excellent surface finish

Cutting speed 300-600m/min

Temperature - 1200°C

Hardness – up to HRC 93

7. **Cermets**: Combination of ceramic with metal is known as cermets. This material has high refractoriness of ceramics and high toughness and thermal shock resistance of metal. The usual combination is aluminium oxide with metal (W, Mo, Boron, Ti etc.) in an amount of 10 percent.

8. **Cubic Boron Nitride** (CBN): It is the second hardest material after diamond. They are generally used in hand machines. They offer high resistance to abrasion and use as an abrasive in grinding wheels. Sharp edges are not recommended. Speed 600-800m/min

   Hardness - higher than HRC 95

9. **Diamond**: It is the hardest material known and it is also expensive. It possesses very high thermal conductivity and melting point. Diamond offers excellent abrasion resistance, low friction coefficient and low thermal expansion. It is used in machining very hard material such as carbides, nitrides, glass, etc. Diamond tools give a good surface finish and dimensional accuracy. They are not recommended for machining steel.

10. **Ucon:** It is a new cutting material. Its constitutes are columbium 50%, titanium 30% and tungsten 20%. This has high hardness, high toughness and excellent shock resistance. It is mainly used for steel cutting material and not suitable for cutting cast iron, stainless steel and super alloys containing Ni, Co and Ti as base material. UCON gives 60 percent increases in cutting speed when compared with tungsten carbide.

Different elements used in cutting tool materials and their properties are

Element	**Properties**
Tungsten	Increases hot hardness Hard carbides formed Abrasion resistance
Molybdenum	Increases hot hardness Hard carbides formed Improving resistance
Chromium	Depth hardenability during heat treat hard carbides are formed improving abrasion resistance some corrosion resistance

Vanadium	combines with carbon for wear resistance retards grain growth for better toughness
Cobalt	Increases hot hardness, toughness
Carbon	Hardening element forms carbides

COATED TOOLS

In the early days of tungsten carbide tools, before coatings, tool manufacturers realized the tools would last longer and resist cratering if they put a little bit of titanium carbide (TiC) in the mix when making the tool. This had the desired effect, but the more TiC that was added, the weaker and more brittle the tool became. Then someone hit on the idea of applying a thin layer of TiC to the surface of the tool. It worked. This was in about 1970, a year or so later, tooling companies started using a titanium nitride (TiN) coating, and in 1973, aluminum oxide began to be used. Coating on tools can be done by three types.

1. TiC (Titanium carbide) gives abrasion resistance and prevents the chip from dissolving the tool material, leaving craters.
2. TiN (Titanium nitride) prevents a built-up edge, where the workpiece material sticks to the cutting edge. This spoils the surface finish and also, when the buildup is dislodged, it pulls away part of the coating and maybe the cutting edge. This coating is the familiar gold-colored one.
3. Al_2O_3 (Aluminum oxide) provides resistance to heat in two ways. First, it is an outstanding thermal insulator; second, and more important, it is stable to very high temperatures.

These coatings are applied either by a Chemical Vapor Deposition (CVD) process or Physical Vapor Deposition (PVD).The difference between a CVD tool and a PVD tool is more than just the type of coating. PVD tools have thinner coating while CVD tools have thicker coating, but they also are designed with a medium-sized grain structure. This difference can help select the right tool for a particular application.

TOOL LIFE

The cutting tool life is a important factor of machining the metal. It is defined as the cutting time required for reaching to life or time elapsed between two consecutive re-sharpening. The tool server effectively and efficiently during the life period.

There are three types of tool failures

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.

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.

3. **Gradual wear**: gradual wearing of the cutting edge causes loss of tool shape, reduction in cutting efficiency, accelerated wear, and final tool failure in a manner similar to a temperature failure

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 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

(a) No. of pieces of work machined
(b) Total volume of material removed
(c) Total length of cut.

The tool life is expressed by an equation as

$VT^n=C$ where, V=cutting speed (m/min.), T=time period (min.), C-Taylor`s constant

n = Taylor's exponent depending mainly on cutting tool material
n = 0.05 to 0.1 for H.C steels.
n = 0.1 to 0.2 for H.S.S
n = 0.2 to 0.4 for carbides
n = 0.4 to 0.6 for ceramics
n = 0.7 to 0.9 for diamond

FACTORS AFFECTING 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. 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 tool material changes so the relative increase in the hardness of the work accelerates the abrasive action.

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 material 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.

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

TOOL WEAR

Cutting tools are subjected to an extremely severe rubbing process. They are in metal-to-metal contact between the chip and work piece, under high stress and temperature.

Tool wear is generally a gradual process due to regular operation. Tool wear can be compare with the wear of the tip of an ordinary pencil. According to Australian standard, the tool wear can be defined as “The change of shape of the tool from its original shape, during cutting, resulting from the gradual loss of tool material”.

Tool wear depends upon following parameters:

i. Tool and work piece material.

ii. Tool shape.

iii. Cutting Speed.

iv. Feed.

v. Depth of cut.

vi. Cutting fluid used.

vii. Machine Tool characteristics etc.

Tool wear affects following items:

i. Increased cutting forces.

ii. Increased cutting temperature.

iii. Decreased accuracy of produced parts.

iv. Decreased tool life.

v. Poor surface finish.

vi. Economics of cutting operations.

Types of Tool wear

Cutting tool wear is classified into

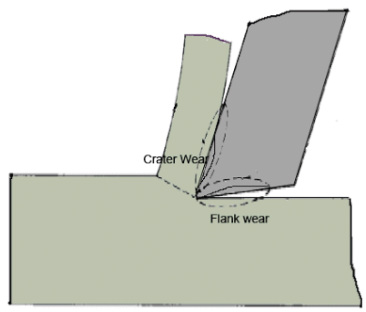
1. Flank wear
2. Crater wear
3. Corner wear

1. Flank wear

Flank wear occurs at the tool flanks, where it contacts with the finished surface, as a result of abrasion and adhesion wear. The cutting force increases with flank wear. It affects the great extent of mechanics of cutting.

2. Crater wear

Crater wear happens on the tool face at a short distance from cutting edge by the action of chip flow over the face at very high temperature. The crater wear is mainly due to diffusion and abrasion. The depth of crater measures the crater wear; the surface measuring instrument can measure it. The cutting edge may break from tool due to excessive cratering.



3. Corner wear (nose wear)

It occurs at tool nose radius. Corner wear shortens the cutting tool, cause a significant dimensional error in machining. It is considered as part of flank wear since there is no distinguishing boundary between them.

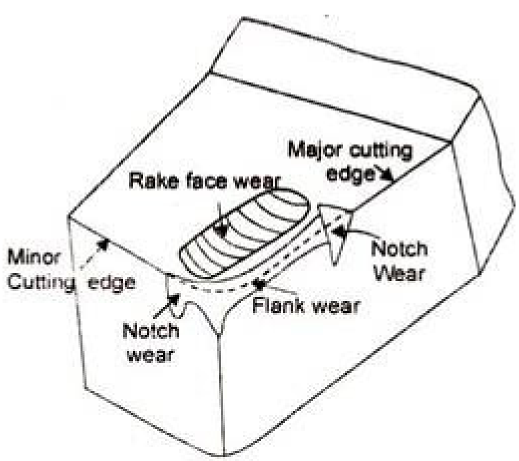


Fig. 9.16. (*a*) Tool Wear Phenomena.

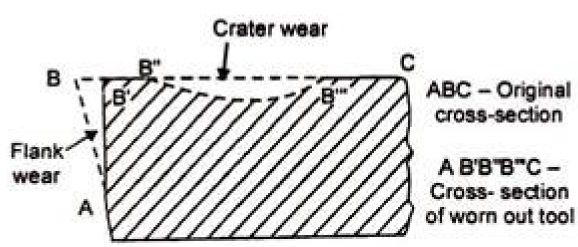


Fig. 9.16. (*b*) Flank and Crater wear.

Optimal cutting speed

Now-a-days 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.

In machining economics, basically 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).

Mathematically, Total Time for Machining (T_m) can be expressed as:

$$T_m = T_c + T_{ct} + T_i$$

Apart from these three time elements and associated cost, cost of the cutting tool is also another factor to consider for any optimization. All these time or cost elements, except handling time, are affected by the variation of cutting speed and feed rate as depicted below.