Cutting Tool Materials

Cutting tool materials should have:

1. High Strength,

2. High impact strength (Toughness) to resist fracture,

3. High hardness and wear resistance at high temperatures,

4. Low coefficient of friction.

5. Favorable cost.

Cutting Tool Materials

1. High Speed Steel (HSS) (1900)

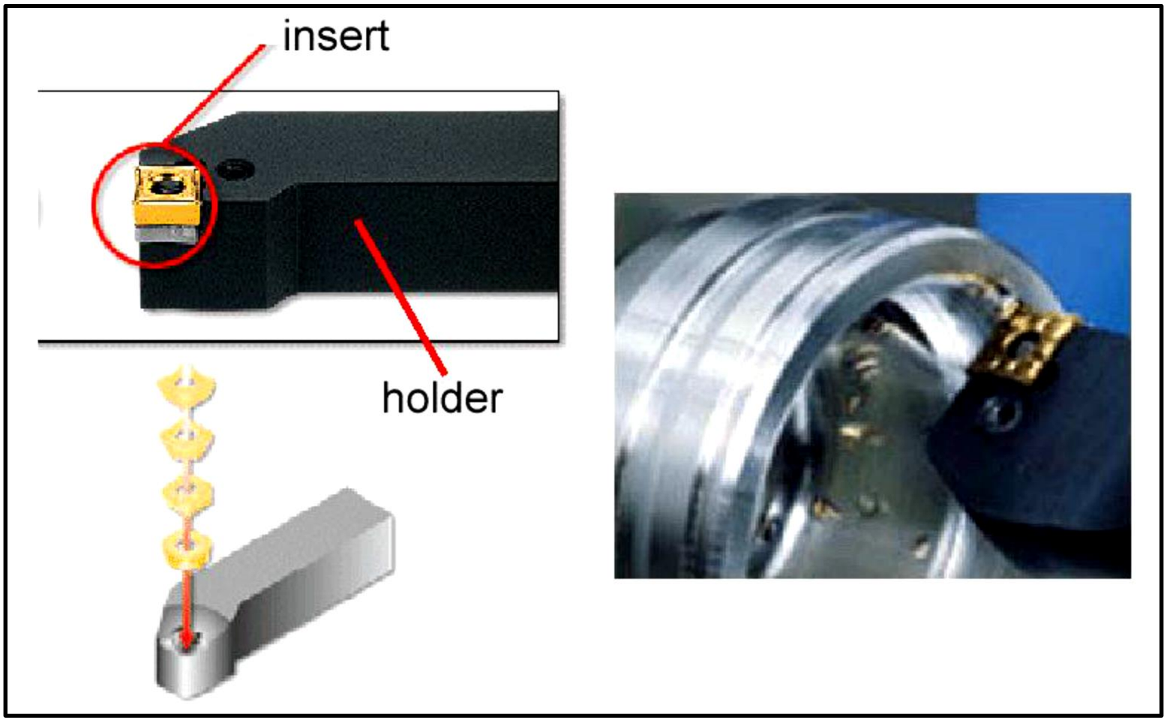
Typical composition of this high alloy steel is 18-4-1 (tungsten 18%, chromium 4%, vanadium 1%). Retains its hardness at temperatures up to 600°C. Compared with tool steel, it can operate at about double the cutting speed with equal life, resulting in its name high-speed steel. HSS is widely used for drills and many types of general-purpose milling cutters and in single-point tools used in general machining. For high-production machining it has been almost completely replaced by carbides and coated tools.

2. TiN Coated High Speed Steel (HSS) (1980)

Coated HSS provides significant improvements in cutting speeds, with increases of ***10*** *to* ***20****% being typical. In addition to hobs, gear-shaper cutters, and drills; HSS tooling coated by TiN includes reamers, taps, chasers, spade-drill blades, broaches, band saw and circular saw blades, insert tooling, form tools, end mills, and an assortment of other milling cutters.* ***Physical vapor deposition*** *has proved to be the most viable process for coating.*

3. Cemented Carbide (Sintered Carbide) (1947)

Nonferrous alloys produced by powder metallurgy. The early versions, which are still widely used, had tungsten carbide as the major constituent and cobalt as a binder. Cemented carbides [made by sintering ~94% Tungsten, ~6% Carbon, and < 1% Cobalt]. Recent types of carbides utilize very fine micro particles dispersed (cemented) in the carbide structure (approx.10% TiC and TaC) for improving toughness and tool life. They can be operated at cutting speeds 200 to 500 % greater than those used for HSS, and they have replaced HSS in many processes.



Many carbide tools are made in the form of throwaway inserts, having three to eight cutting edges, and are held mechanically in tool holders.
When one cutting edge becomes dull, the insert is repositioned to a new edge; when all the edges become dull, it is thrown away.

5. Ceramic (1950s)

Ceramics are made of pure aluminum oxide by powder metallurgy techniques. They can be operated at from two or three times the cutting speed of tungsten carbide, usually requiring no coolant. Usually they are in the form of disposable (throwaway) tips.
Ceramics are usually as hard as carbides but are more brittle, and require more rigid tool holders and machine tools.
Ceramic – Cermet
***Cermets** are best suited for finishing. Approximately 70 percent ceramic and 30 percent*

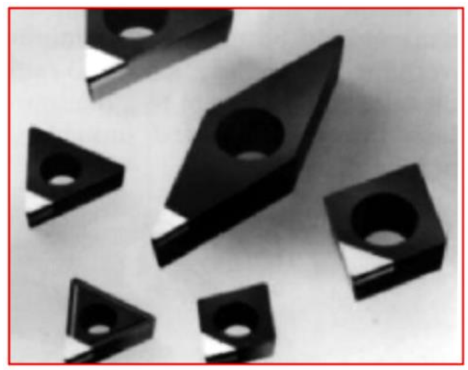
titanium carbide, are pressed into billets under extremely high pressure and temperature. After sintering, the billets are sliced to the desired tool shapes. Subsequent grinding operations for final size and edge preparation, complete the manufacturing process.

5. Diamond

Hardest material known. Diamond is pure carbon, and carbon has a strong affinity for ***iron****, forming iron oxide or carbide; which results in removal of carbon, thus rapid wear of the tool during machining of ferrous workpieces. Therefore, they should only be used on* ***non-ferrous*** *metals. Has limited but important application in machining operations such as in boring. Diamond machining is done at high speeds with fine feeds for finishing, and produces excellent finishes. Diamond particles are used in grinding wheels. Diamond tools are used for truing the grinding wheels.*

Diamond - Polycrystalline Diamond

Some diamond cutting tools are made of a diamond crystal compaction (many small crystals pressed together) bonded to a carbide base. These diamond cutting tools should only be used for light finishing cuts of precision surfaces. Feeds should be very light and speeds are usually high. Rigidity in the machine tool and the setup is very critical because of the extreme hardness and brittleness of diamond.



6. Cubic Boron Nitride (CBN) (1965s)

Man-made tool material.

Similar to diamond in its polycrystalline structure and is Hardest material known other than diamond.

Retains it hardness at elevated temperatures (~ 1000°C).

Still, CBN should mainly be considered as a finishing tool material because of its extreme hardness and brittleness.

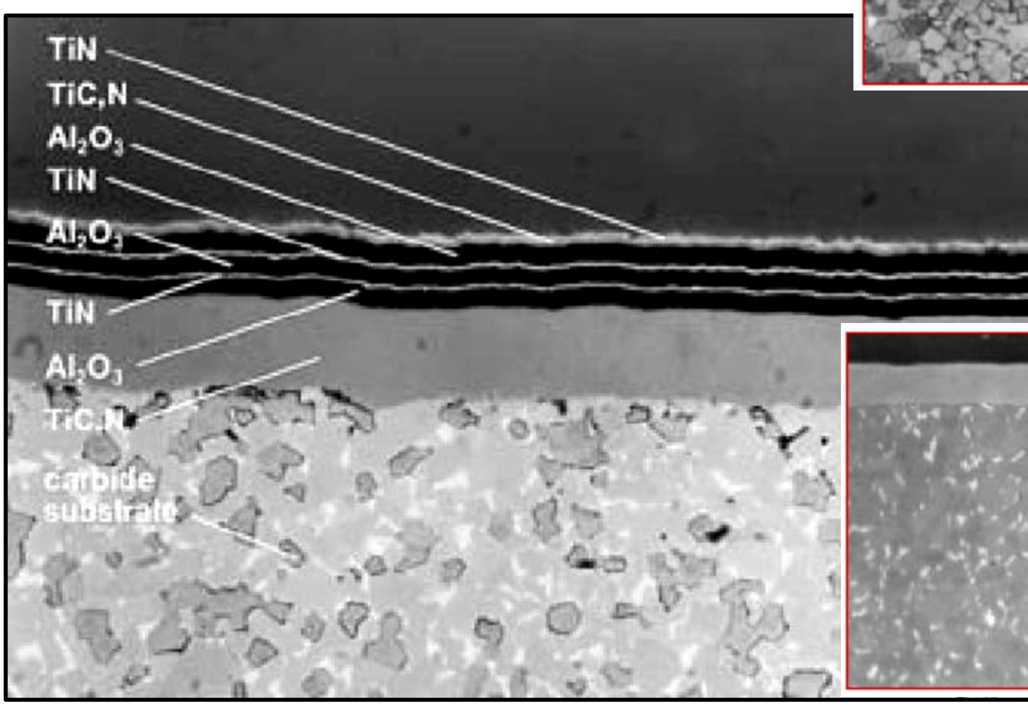
Can be used to machine hard aerospace materials.

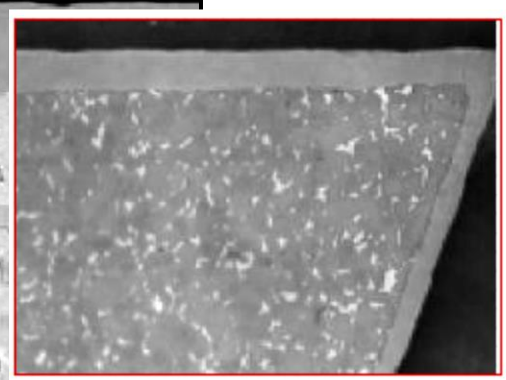
7. Coated Carbide (1972)

A tough, shock-resistant carbide tool is coated with a thin, hard, crater resistant surface material.

● TiC-coated tools have two or three times the wear resistance of the best uncoated tool with the same breakage resistance. This results in 50 to 100 % increase in the speed for the same tool life.

● Ceramic (Al2O3)-coating permits 90 % speed increase in machining of steel. Gives excellent crater wear resistance.





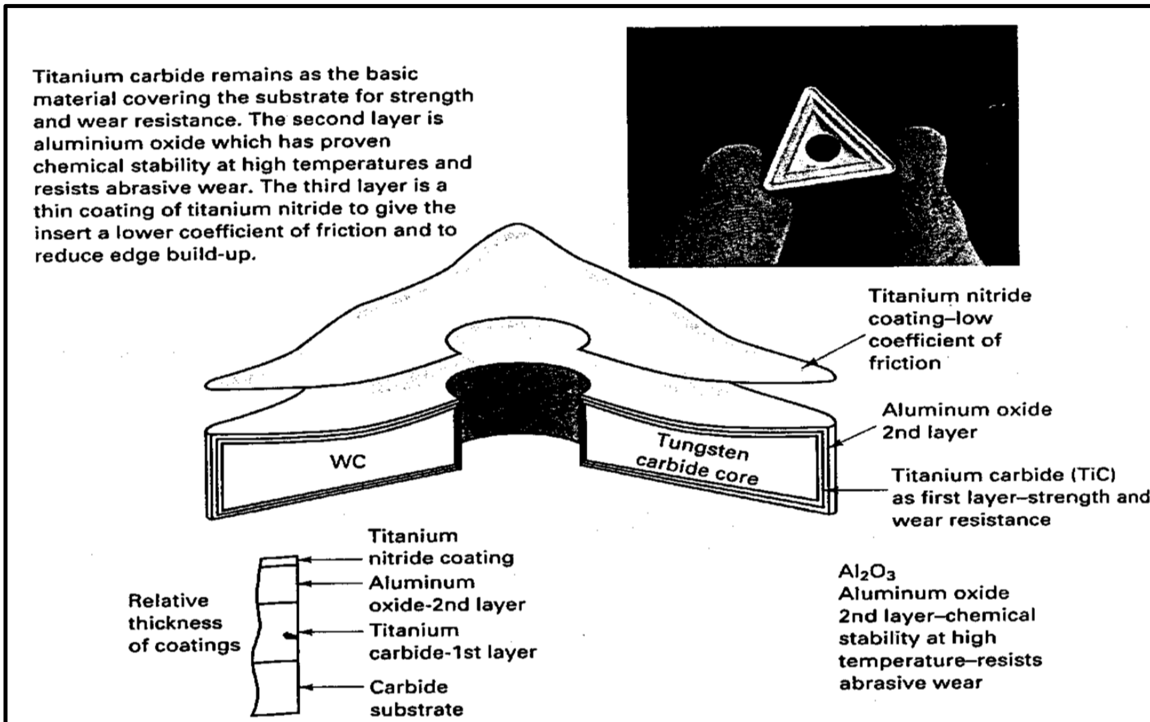
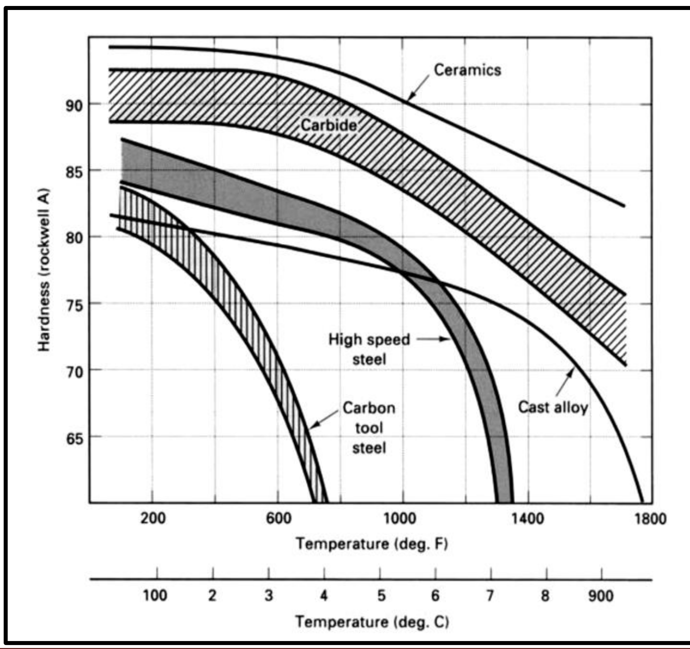
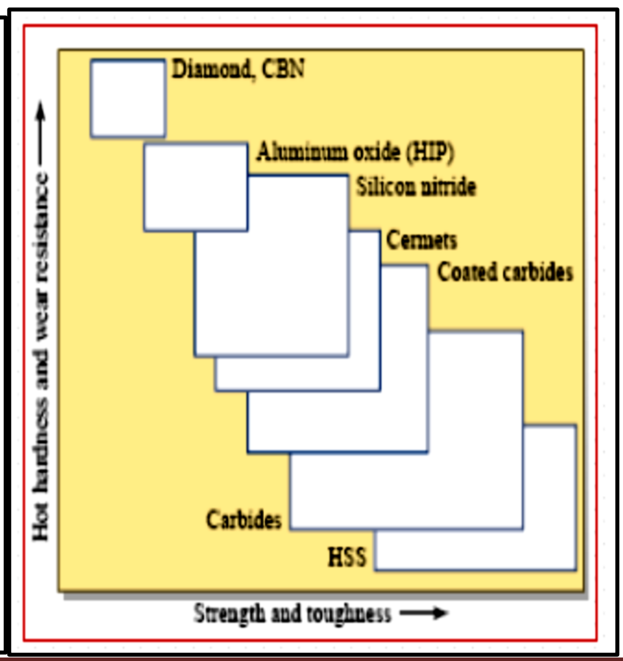


FIGURE 22-6 Triple-coated carbide tools provide resistance to wear and plastic deformation in machining of steel, abrasive wear in cast iron, and built-up edge formation.

Most modern tools use steel shafts with smaller, cutting pieces called inserts. The inserts may be carbide, or coated carbide. The coating is a layer of 5-8 microns, of materials such as tungsten carbide, titanium carbide, titanium nitride, CBN or even diamond.

Hardness - Strength – Toughness





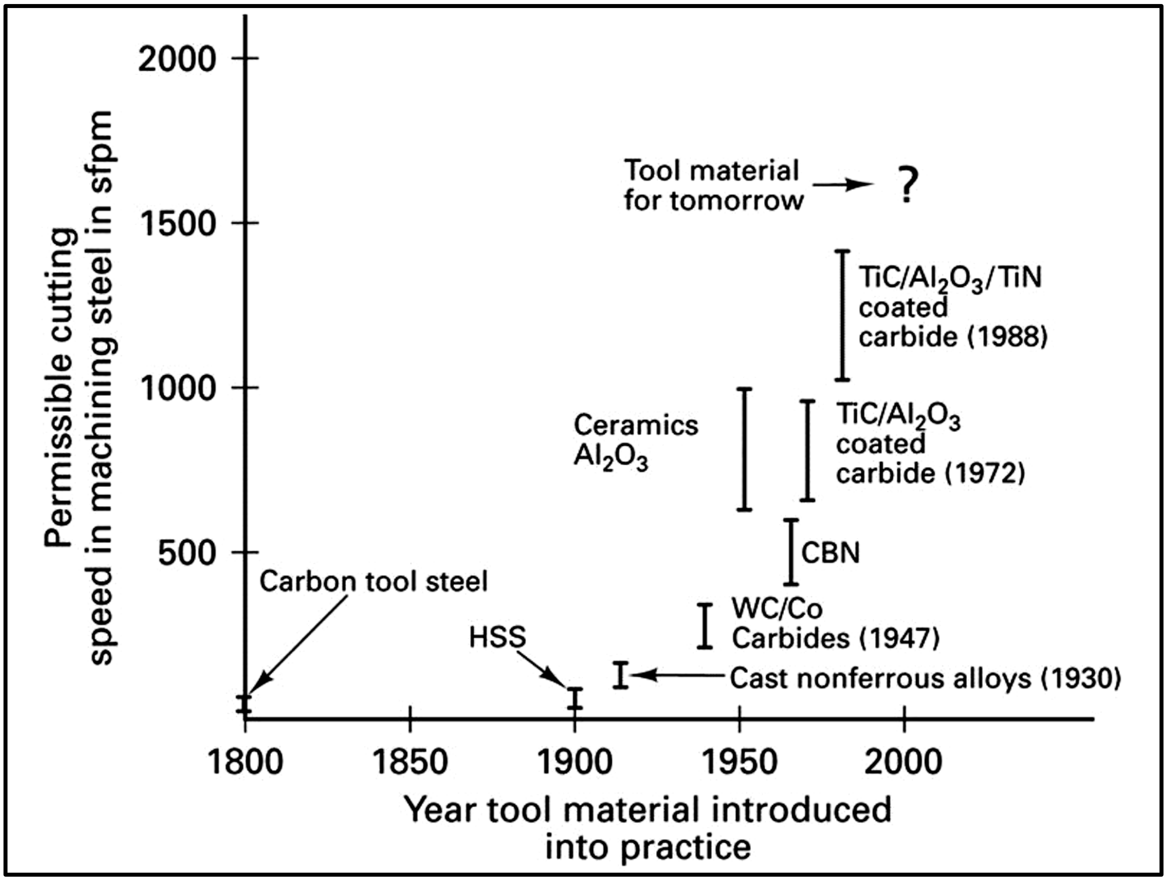


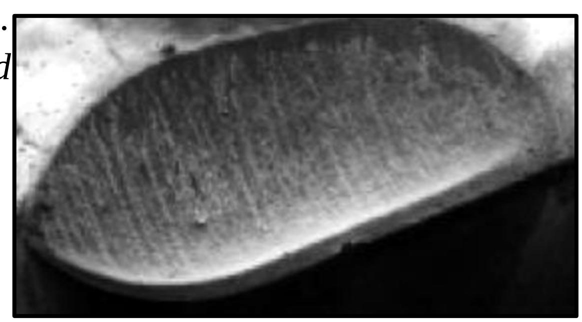
FIGURE ***Improvements in cutting tool materials have led to significant increases in cutting speeds (and productivity) over the years.***

Tool Wear (Failure), and Surface Finish

Cutting involves high stresses, high relative velocity between tool and chip/workpiece, and high temperatures of up to 1000°C. A tool may be said to reach end of its life when a further wear causes one, some or all of the followings.

1. *Loss of dimensional accuracy of the workpiece,*
2. *Excessive surface roughness on the workpiece,*
3. *Increased power requirement of the machine tool,*
4. *Physical loss of the cutting edge of the cutting tool.*

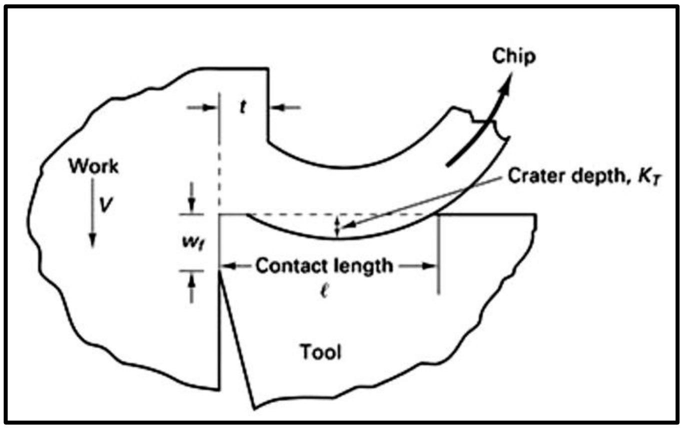
The cutting time accumulated before failure is termed as ***tool life****.*

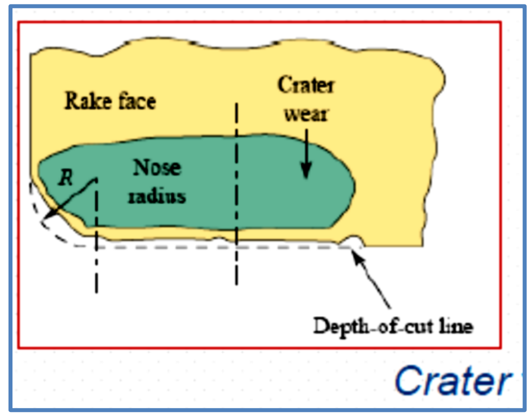


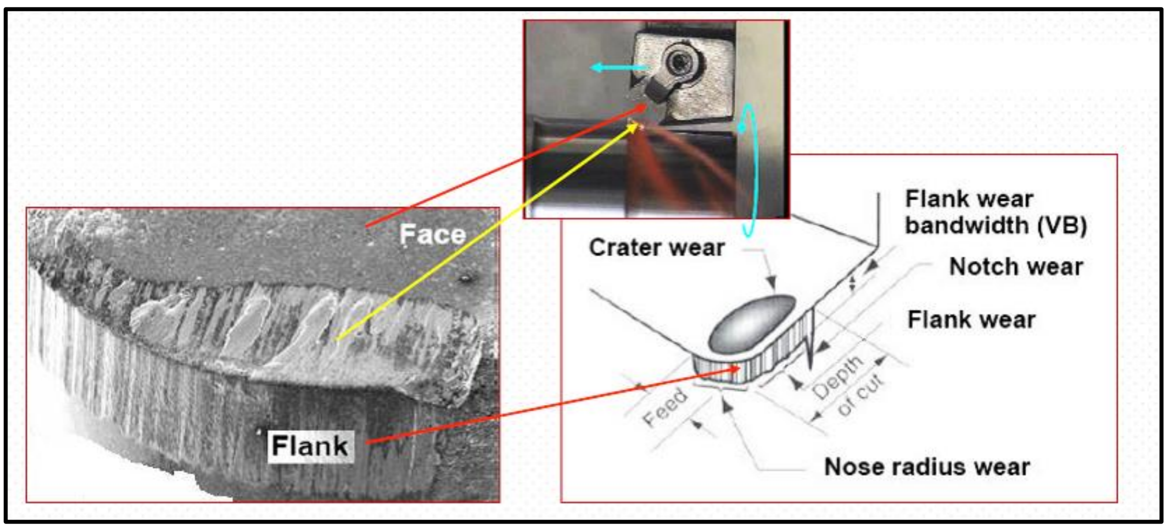
Tool wear*, which is increased by high temperatures which cause the tool material to*

loose its hardness and thus make it more subjected to wear, occurs mainly in two areas.

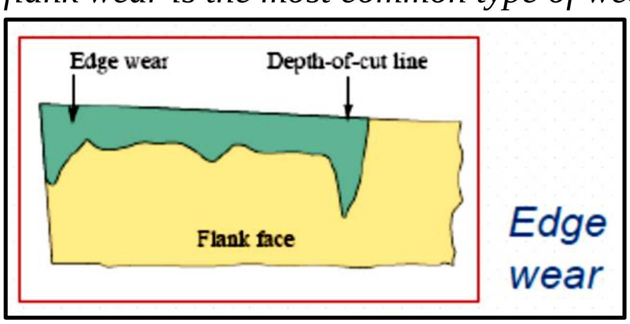
1. *On tool* ***face****, causing formation of craters due to the severe abrasion between the chip and the tool face, being more common on HSS tools in machining ductile materials.*



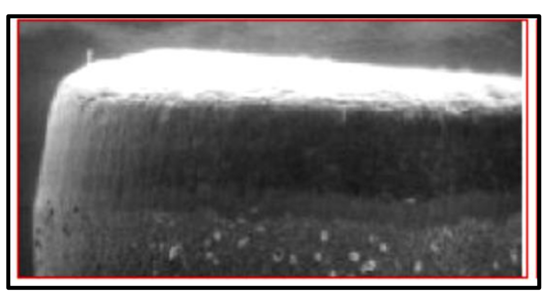




2. *On the* ***flank*** *below the cutting edge, resulting from contact with the abrasive machined surface both in rough and finishing operations. For* ***carbide*** *and* ***ceramic*** *tools flank wear is the most common type of wear.*

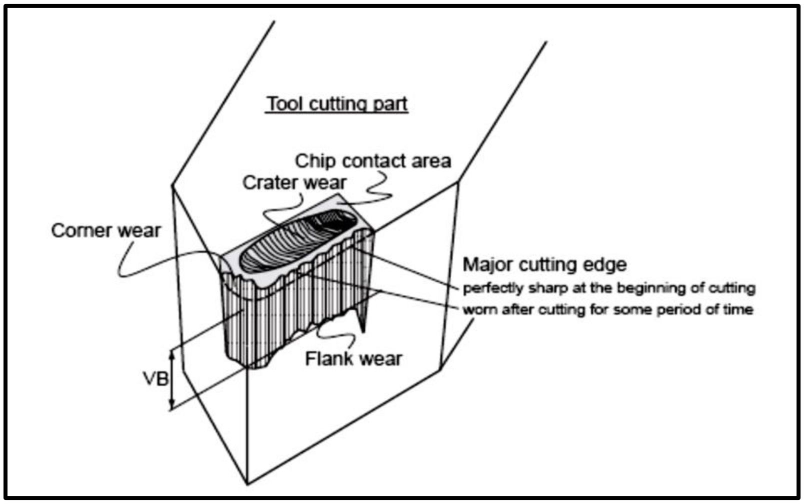


Nose wear

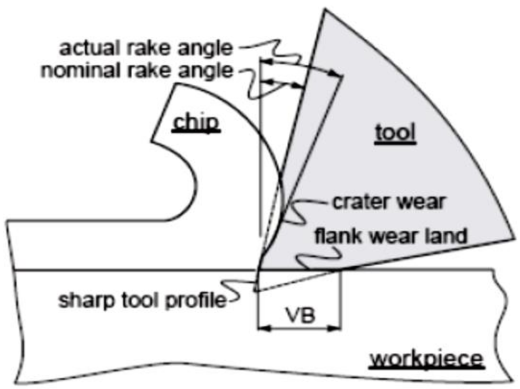


***Tool wear** is also observed at the edge and the nose of the tool areas.*

***3. Edge wear** occurs on the clearance face of the tool and is mainly caused by the rubbing of the newly machined workpiece surface on the contact area of the tool edge. This type of wear occurs on all tools while cutting any type of work material.*
***4. Nose wear (corner wear)** is usually observed after a considerable cutting time, nose wear appears when the tool has already exhibited land and/or crater wear. Wear on the nose of the cutting edge usually affects the quality of the surface finish on the workpiece.*

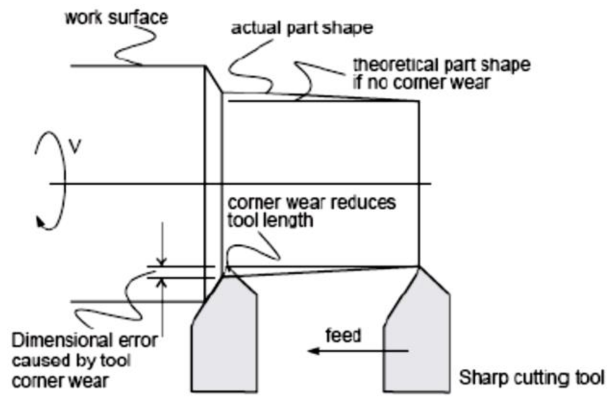


***Flank wear** appears in the form of so-called wear land and is measured by the width of this wear land, VB. Flank wear affects to the great extend the mechanics of cutting. Cutting forces increase significantly with flank wear. If the amount of flank wear exceeds some critical value (VB > 0.5~0.6 mm), the excessive cutting force may cause tool failure.*



Cross-section perpendicular to the major cutting edge of a worn cutting tool showing the effect of crater wear on the tool rake angle and the flank wear land

Corner wear (nose wear) *actually shortens the cutting tool, thus increasing gradually the dimension of machined surface and introducing a significant dimensional error in machining, which can reach values of about 0.03~0.05 mm.*



Top view showing the effect of tool corner wear on the dimensional precision in turning

Tool wear is affected by;

1)workpiece material properties,

2)cutting force-controlled by proper selection of feed and depth of cut.

3)Temperature-related to cutting speed (as cutting speed increase, the temperature of the cutting zone increases which causes a loss in tool properties and decreased tool life).

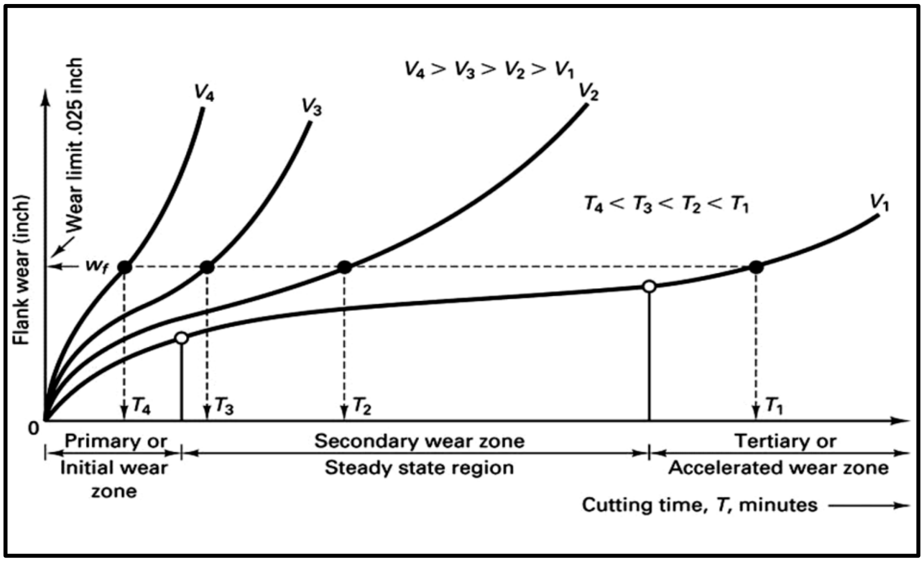


FIGURE *Typical tool wear curves for flank wear at different velocities. The initial wear is very fast, then it evens out to a more gradual pattern until the limit is reached; after that, the wear substantially increases.*

When the tool wear reaches a pre-defined value, the tool is considered to have exhausted its life, and is either thrown, or the cutting edge is sharpened by grinding. Typical criterion for end of tool life include (these are called ***Tool-life criteria***)

1. Catastrophic failure (e.g. tool is broken completely)
2. $VB = 0.3$ *mm* (if wear is uniform in Zone B), or $VBmax = 0.6$ *mm* (if flank wear is non-uniform)
3. $KT = 0.06 + 0.3f$, (where f = feed in mm).