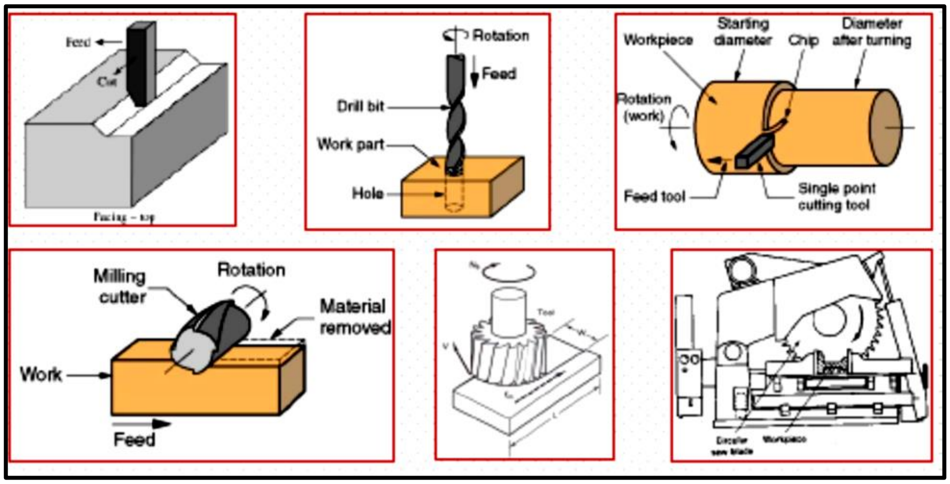
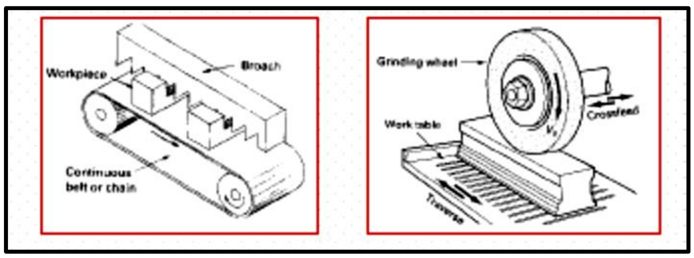
Metal Cutting (Machining)

Metal cutting, commonly called machining, is the removal of unwanted portions from a block of material in the form of chips so as to obtain a finished product of desired size, shape, and finish. There are seven basic machining and chip formation processes

- Turning
- Milling
- Drilling
- Sawing
- Shaping (or planning)
- Broaching
- Grinding and abrasive machining





Important concept: **PROCESS PLANNING**

Fixturing and Location
Operations sequencing
Setup planning
Operations planning

Although the actual machines, tools and processes for cutting look very different from each other, the basic mechanism for causing the fracture can be understood by just a simple model called for *orthogonal cutting*. The objective is to cut away the excess material and obtain the final part. This cutting usually requires to be completed in several steps – in each step, the part is held in a ***fixture***, and the exposed portion can be accessed by the tool to machine in that portion. Common fixtures include *vise*, *clamps*, *3-jaw* or *4-jaw chucks*, etc. Each position of holding the part is called a ***setup***. One or more cutting ***operations*** may be performed, using one or more cutting tools, in each setup. Therefore, setup changes are time-consuming and expensive, and so we should

try to do the entire cutting process in a minimum number of setups; the task of determining the sequence of the individual operations, grouping them into (a minimum number of) setups, and determination of the fixture used for each setup, is called ***process planning***.

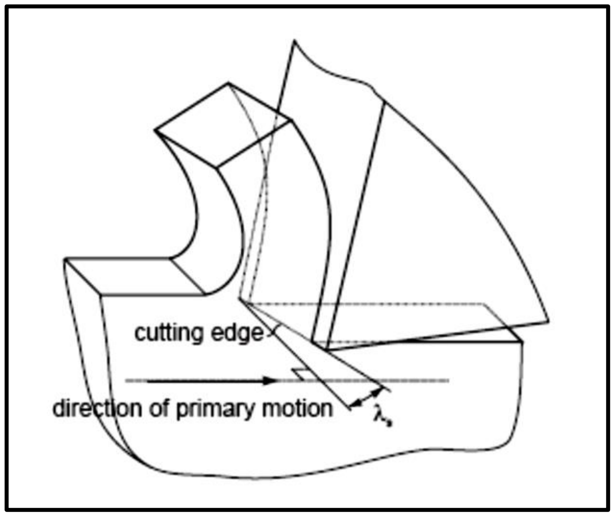
These notes will be organized in three sections: (i) introduction to the processes, (ii) the orthogonal cutting model and tool life optimization and (iii) process planning and machining planning for milling.

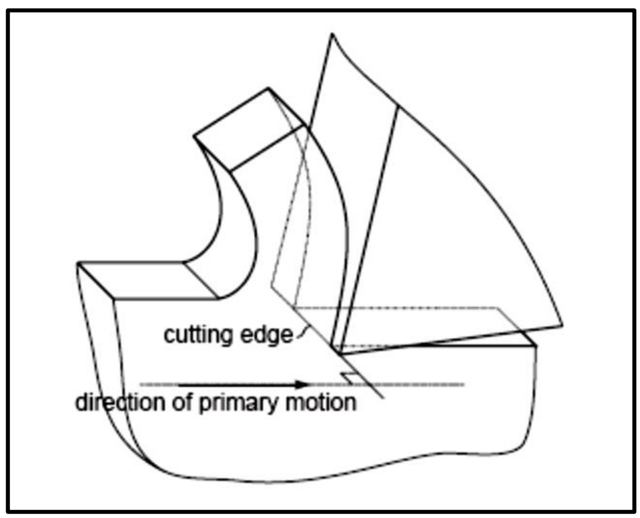
Process Analysis

There are various factors that work together and affect the quality. Therefore, it is of great importance to be able to control the process. In most companies, a series of experimental runs are conducted until the "ideal" working conditions are found to make each part.

Geometry of the single point tool

Oblique Cutting*: The cutting edge is set at an angle (the tool cutting edge inclination λs). This is the case of three-dimensional stress and strain conditions.*

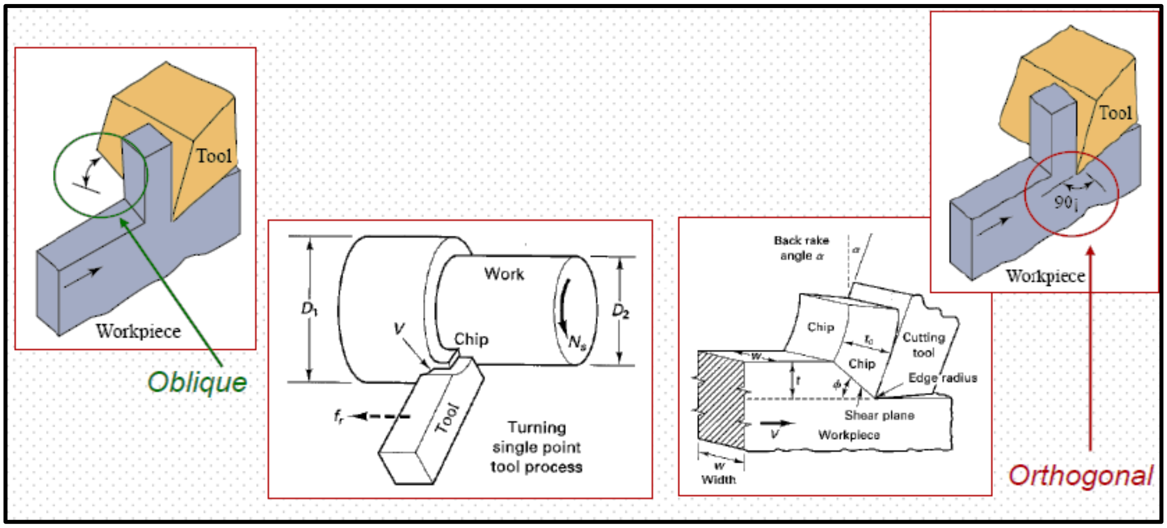




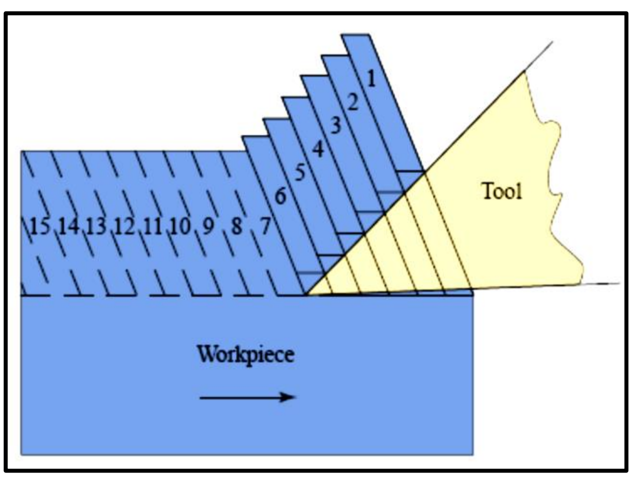
Orthogonal cutting*: The cutting edge is straight and is set in a position that is* **perpendicular** *to the direction of primary motion.*
This allows us to deal with stresses and strains that act in a plane.
In order to better understand this complex process, the tool geometry is simplified from the three-dimensional (oblique) geometry, to

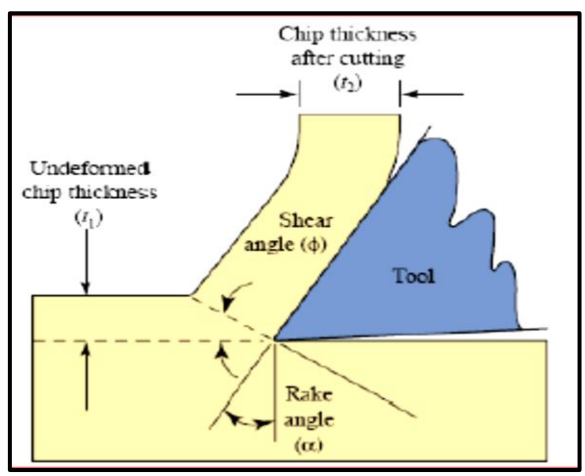
a two-dimensional (orthogonal) geometry.

Probably the simplest model to analyze is the "Single Point Tool, Orthogonal Cutting" model. It is easier to visualize this model in terms of the turning process. Cutting is achieved by moving the tool relative to the part; it is convenient to separate the relative velocity into two components: cutting speed, ***V***, and feed rate***, f***.



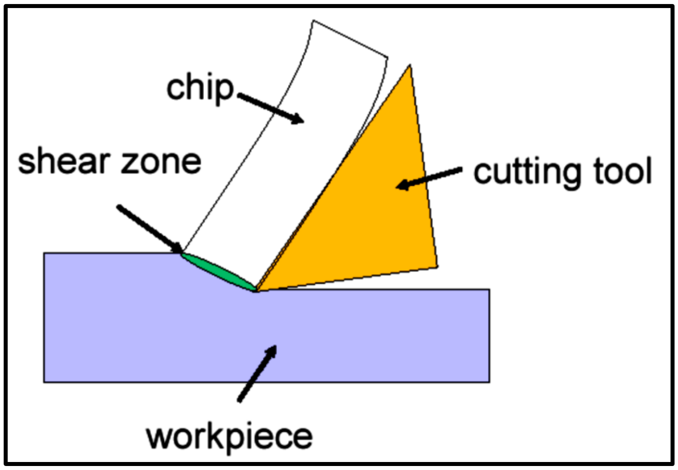
***Chip formation** is a localized shear deformation resulting in the failure of the workpiece material immediately ahead of the cutting edges of the tool due to the force applied to the workpiece by the cutting tool, and relative motion between the tool and the workpiece.*

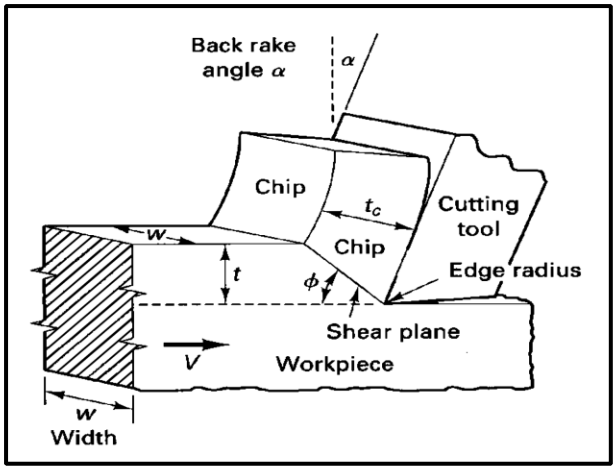




*During **orthogonal** machining, shearing takes place along a plane making an angle, which is called the shear angle* f, *with the horizontal.*

This action transforms a volume of metal with thickness t and w (undeformed chip thickness and width, respectively) into a chip with thickness tc and width w.





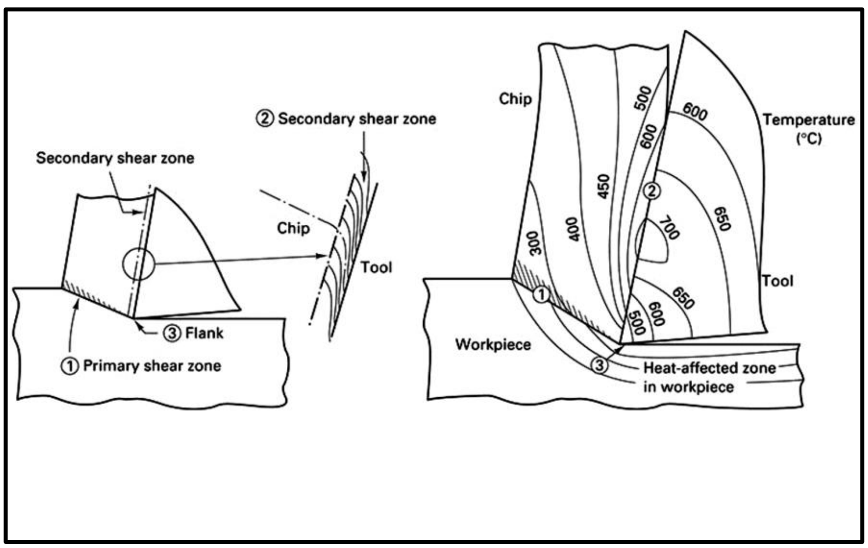
Important observations during metal cutting are:

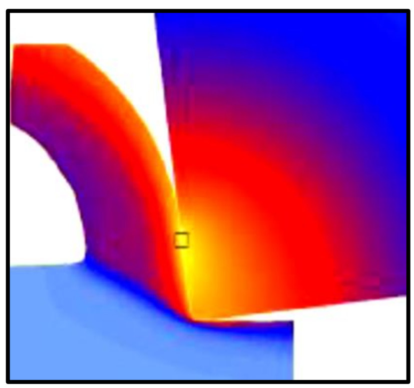
1. *Distortion of the workpiece and the cutting tool due to the cutting force applied by the cutting tool.*

2. *Generation of heat due to the*

- *work required to deform the workpiece and the chip,*
- *friction between the face of the tool and the chip,*
- *friction between the flank of the tool and the workpiece.*

Temperature Distribution





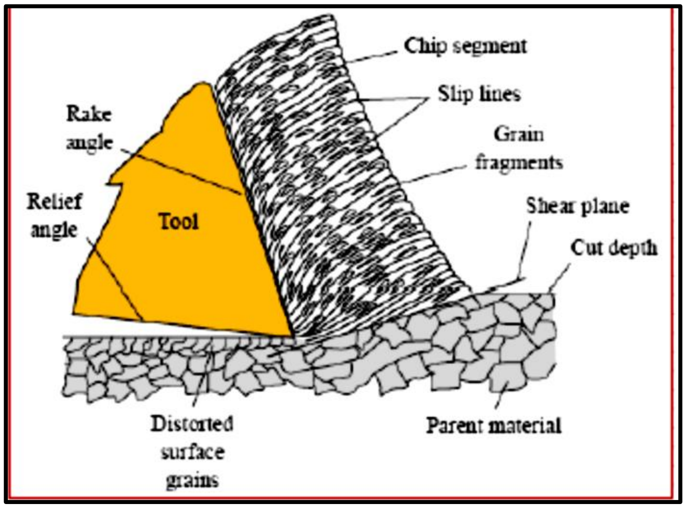
Effects of Work Material Properties

Strength

High-strength materials require larger forces than do materials of lower strength, causing greater tool and workpiece deflections; increased friction force and heat

generation, and temperature; and requirement of greater work input.

On the other hand, hard and abrasive constituents such as carbides in steel accelerate tool wear.



Ductility

Ductility is an important factor.

Highly ductile materials not only permit extensive plastic deformation of the chip during cutting, which increases work, heat generation, and temperature; but they also result in continuous chips which remain in contact longer with the tool face, thus causing more frictional heat generation. Chips of this type are severely deformed and have a characteristic curl (Continuous chips).

Brittle materials cause small segments of chips due to the brittle failure along the shear zone.

Such chips are called discontinuous or segmented chips, and provide fairly good surface finish.

Are also observed when cutting with:

•Small rake angle

•Large depth of cut

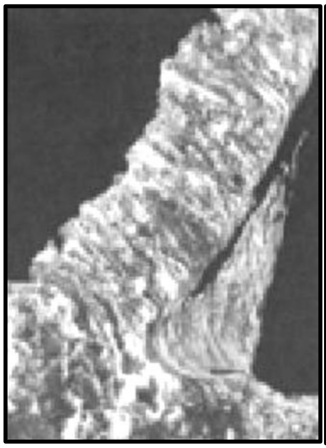
•Machining ductile materials at ● low cutting speed ● large feed

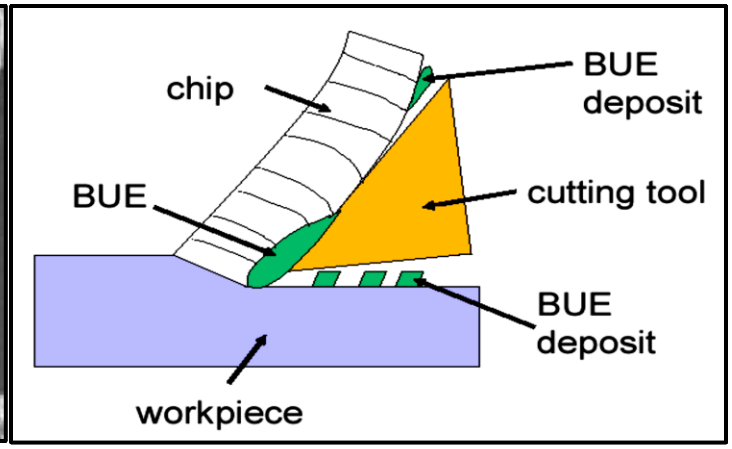
Continuous Chip with Built-up Edge

Built-up Edge During machining, a thin layer of the workpiece material may get deposited on the surface of the tool. Due to high stresses, this layer becomes work-hardened; subsequently, more and more layers can get deposited above it, thus affecting the shape of the tool. Such deposition is called a built-up edge, and causes poor surface finish.

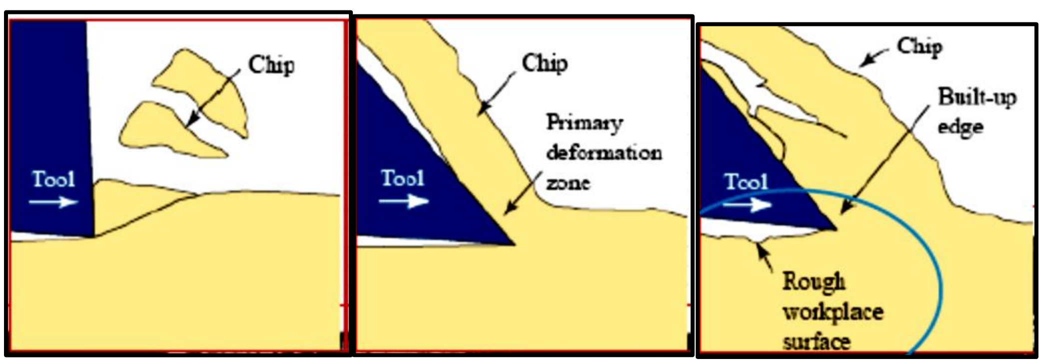
When cutting ductile materials with a high coefficient of friction, the local high

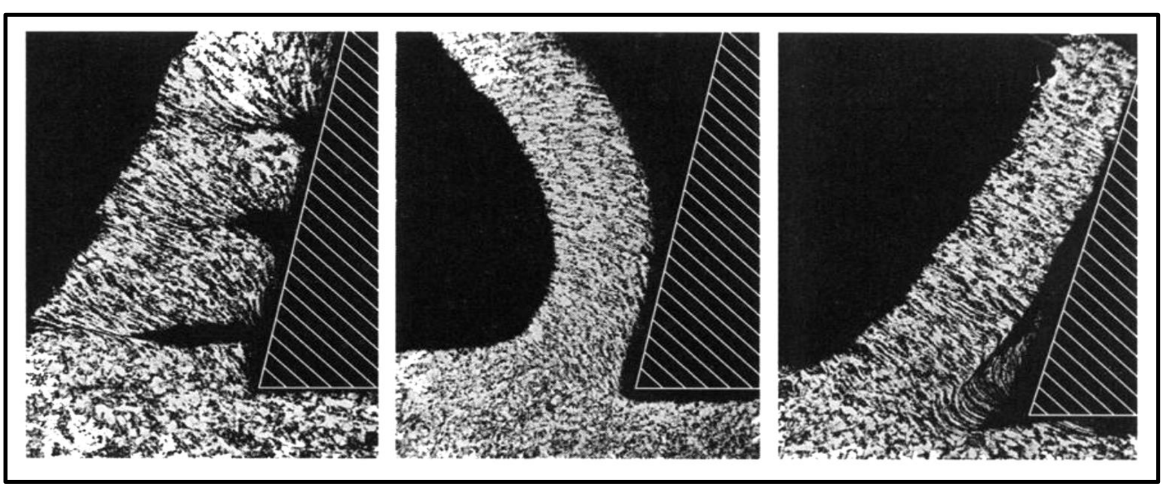
temperature and extreme pressure in the cutting zone cause the work material to adhere or weld to the cutting edge of the tool forming a built-up edge.
When the chip breaks down, the broken pieces are carried away by the underside of the chip and stick on the machined surface.
This type of chip is called continuous chip with built-up edge.
This undesirable occurrence causes vibration, poor surface finish, and shorter tool life.





Types of Chips



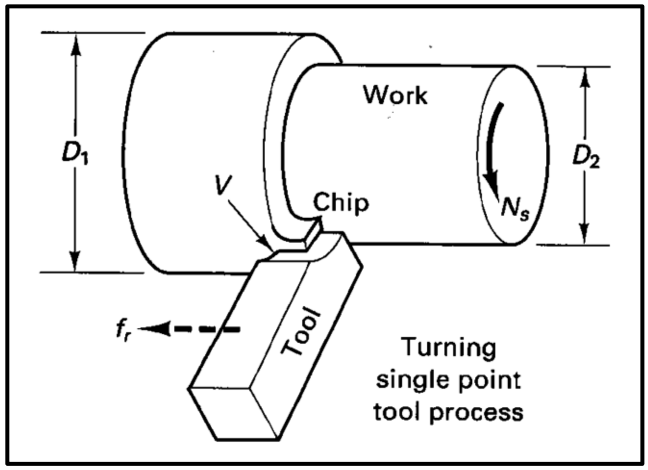


Discontinuous(Segmented) *Continuous* *Continuous with built-up edge*

Formation of built-up edge can be eliminated or minimized by 1) reducing the depth of cut; 2) increasing the cutting speed (while decreasing the depth of cut or/and feed); 3) increasing the rake angle; 4)using a cutting fluid (coolant).

Cutting Tool Geometry - Single Point Cutting Tool

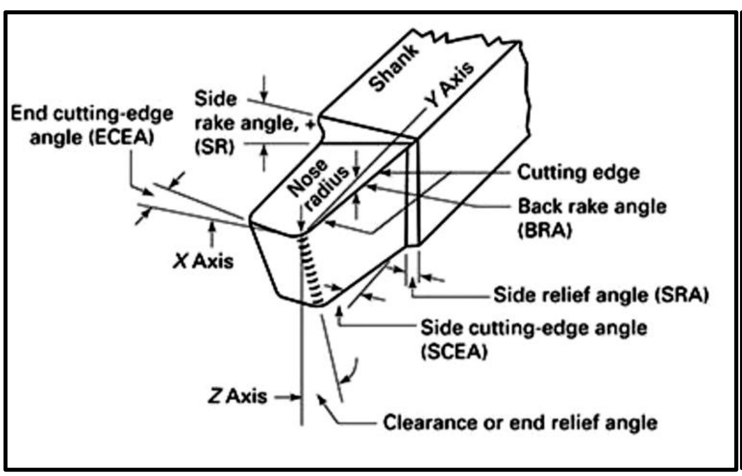
Important surfaces and angles on a typical HSS single-point cutting tool used in shaping or turning operations are:

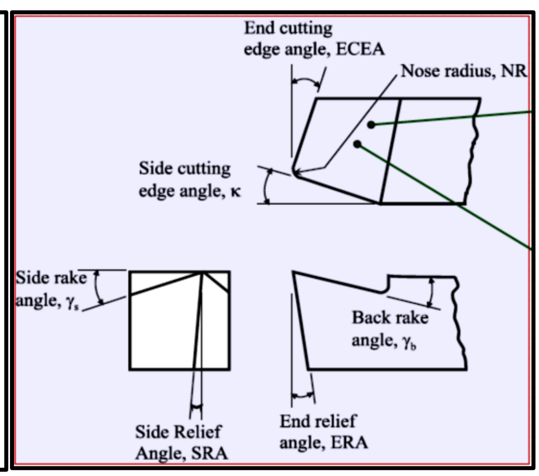


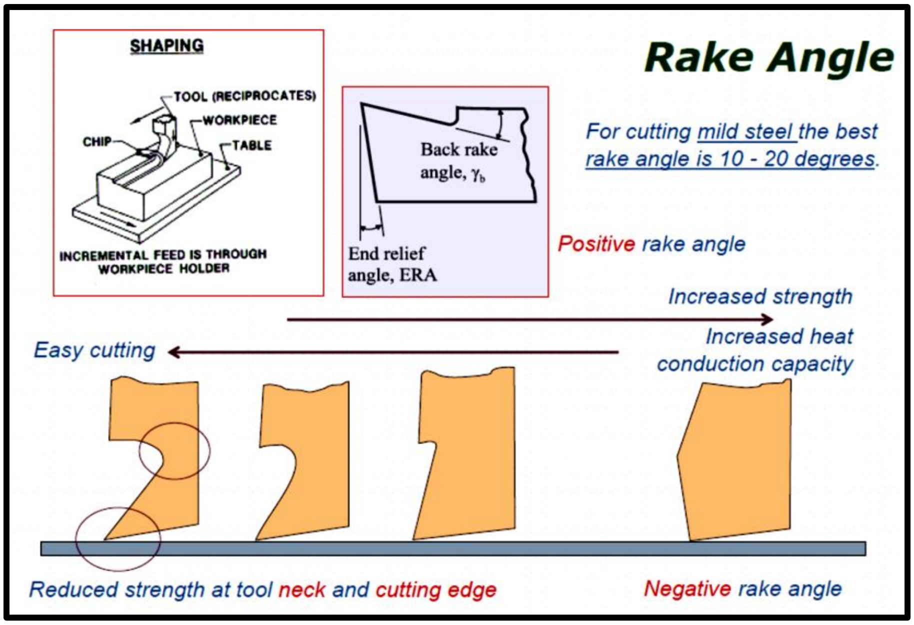
● ***Face*** *is surface of the tool over which the chip flows.*

● ***Flank*** *is the surface of the tool which is in contact with the workpiece.*

- ***Rake angles*** *are used to define the inclination of the face* and its determine the 'knife-edge' of the tool.
- *The* ***face*** *is inclined backwards with respect to the cutting edge, so that the chip is directed upward from the machined surface.*
- ***Relief angles*** *are used to define the inclination of the surfaces of the tool which are in contact with the workpiece (e.g. flank). These surfaces are inclined, so that the rubbing of the tool on to the workpiece is prevented.*
- ***True rake*** *is defined as the inclination of the tool face at the cutting edge as measured in the direction of actual chip flow.*
- The ***clearance angles*** eliminate as much friction as possible
- The ***nose radius*** is essential because it is not possible to make a very sharp leading edge, and even if we make one, such an edge will fracture after very little use.







Small rake angles *cause high compression, tool forces, and friction which result a thick, highly deformed, hot chip.*

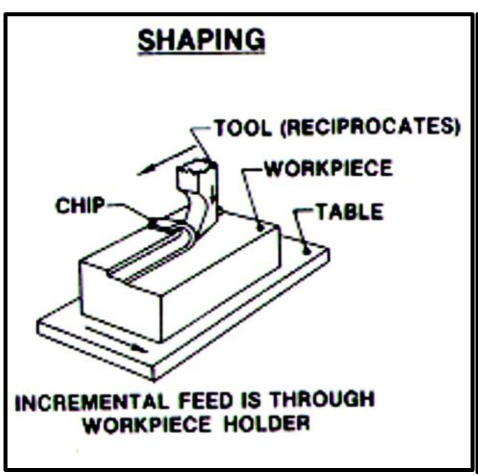
Large rake angles *reduce compression, the forces, and the friction resulting in a thinner, less deformed, and cooler chip.*

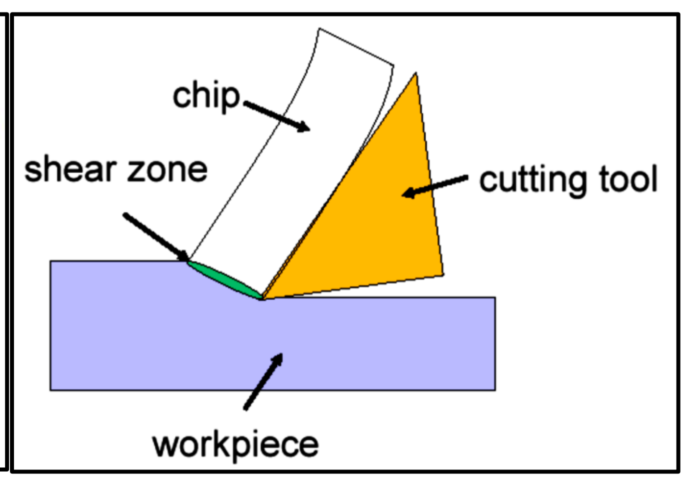
On the other hand ***larger positive rake angles*** *cause reduced strength of the cutting tool due to the reduced tool section and reduced capacity to conduct heat away from the cutting edge.*

In order to provide greater strength at the cutting edge and better heat conductivity, zero or negative rake angles are used on sintered carbide or ceramic cutting tools.

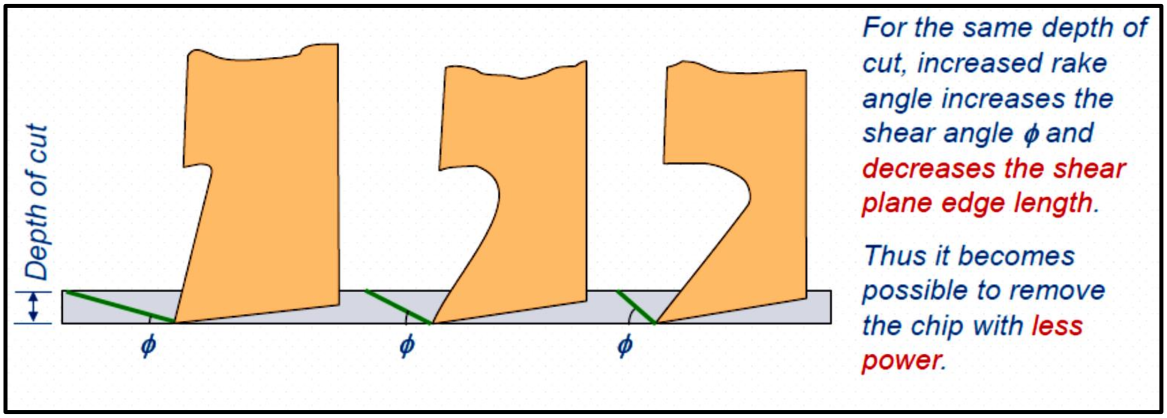
Shear Plane

In very early days, it was believed that the material breaks under tension, due to the "pushing apart" action of a tool; however, several micrograph studies confirmed that in





fact most cutting action is actually due to failure under shear. This is shown in the schematics below. *Angle between tool face and shear plane is about 90 degrees.*



Chip Breakers

As a chip breaker, a groove on the tool face is employed for deflection of the chip at a sharp angle and causing it to break into short pieces that are easier to remove and are not so likely to become tangled (dolaşma, karışma) in the machine and possibly cause damage to personnel.