Tool wear
cutting speed
power cutting
cutting forces

$$V\,T^n = C$$

$$V_1\,T_1^{\,n} = V_2\,T_2^{\,n} = \ldots\, V_m\,T_m^{\,n} = C$$

Cutting parameters:

1. **Cutting depth**
2. **Feed**
3. **Speed**

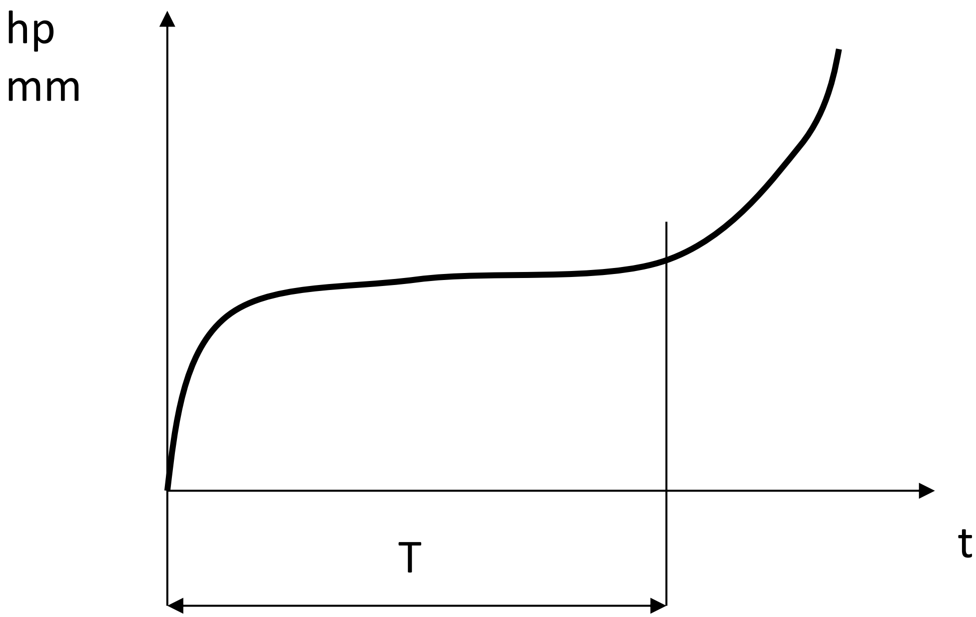
The **Taylor's Equation for Tool Life Expectancy**[1] provides a good approximation.

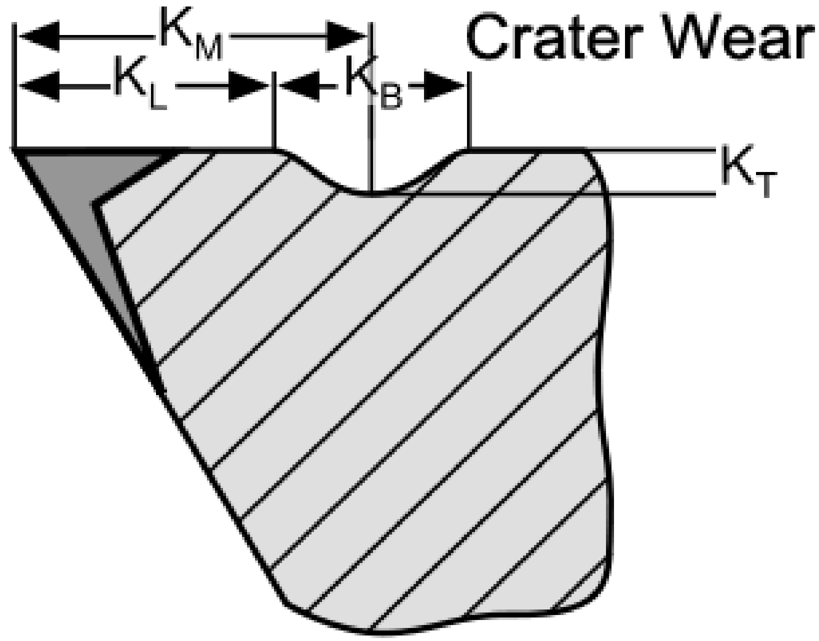
$$V_cT^n = C$$

A more general form ation is

$$V_cT^n \times D^xS^y = C$$

Where:
=cutting speed
T=tool life
D=depth of cut
S=feed rate
x and *y* are determined experimentally
n and *C* are constants found by experimentation or published data; they are properties of tool material, workpiece and feed rate.


hp
mm
t
T

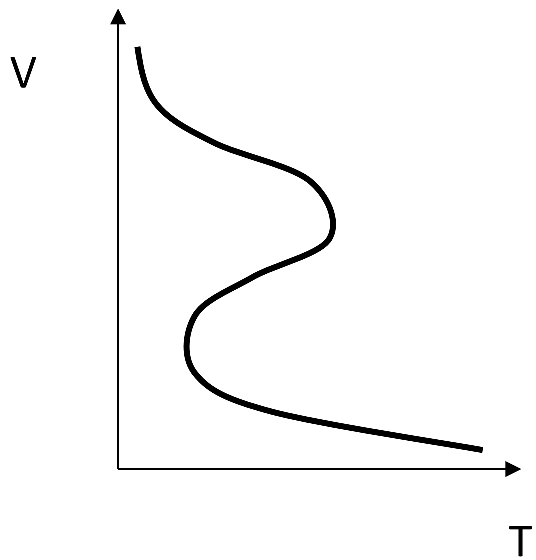


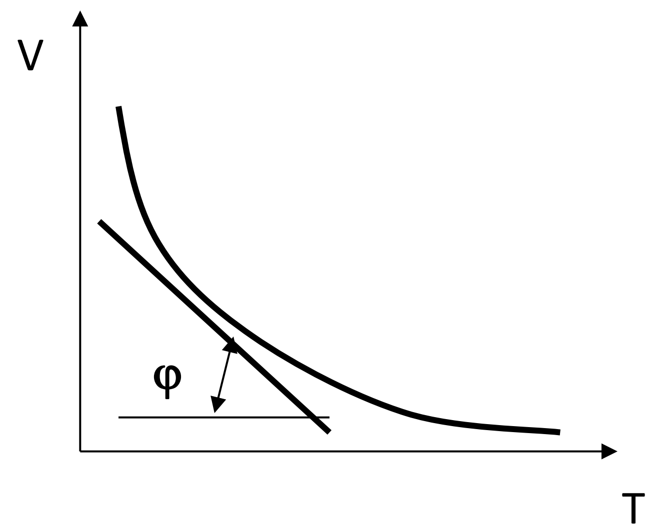
K_M	=	Distance to middle
K_B	=	Width
K_T	=	Depth
K_L	=	Distance to Start
	=	Abrasion Area

Tool wear describes the gradual failure of cutting tools due to regular operation

Types of wear include:

- **flank wear** in which the portion of the tool in contact with the finished part erodes. Can be described using the Tool Life Expectancy equation.
- **crater wear** in which contact with chips erodes the rake face. This is somewhat normal for tool wear, and does not seriously degrade the use of a tool until it becomes serious enough to cause a cutting edge failure.

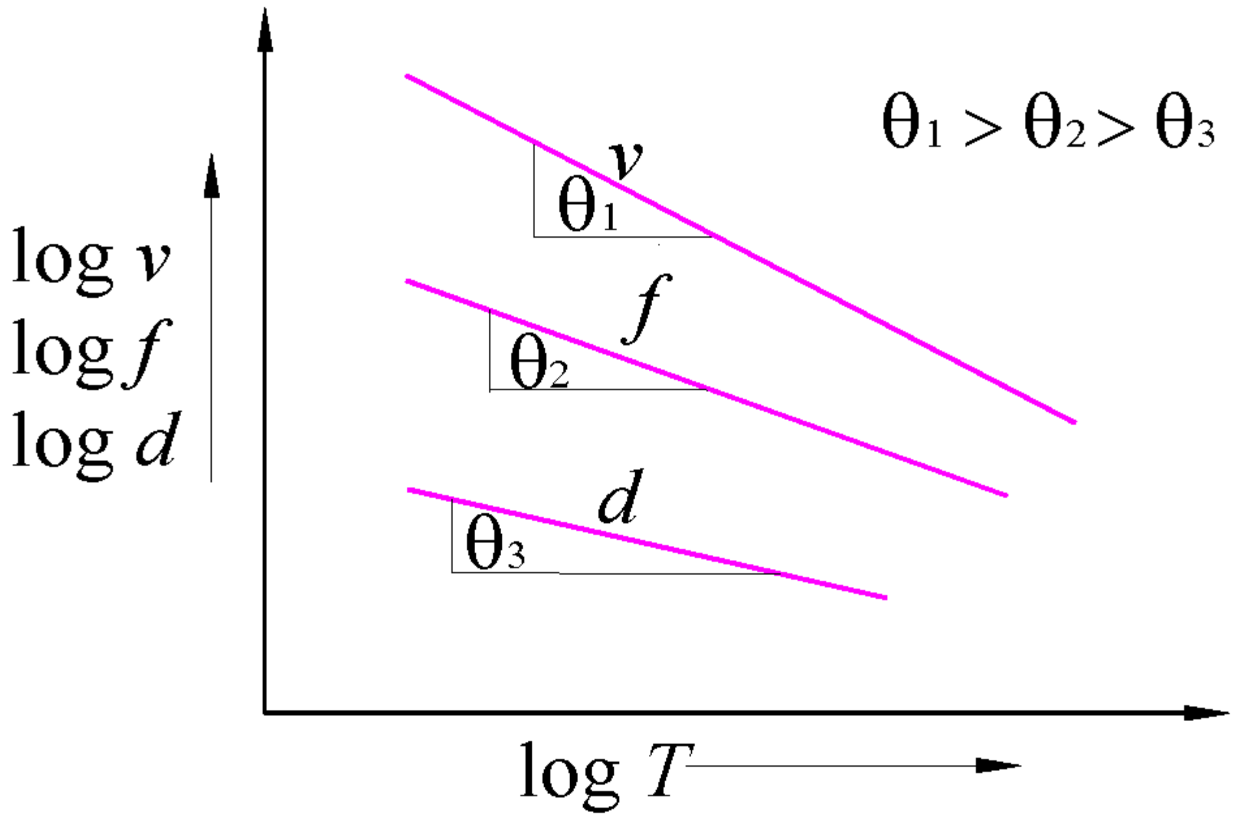




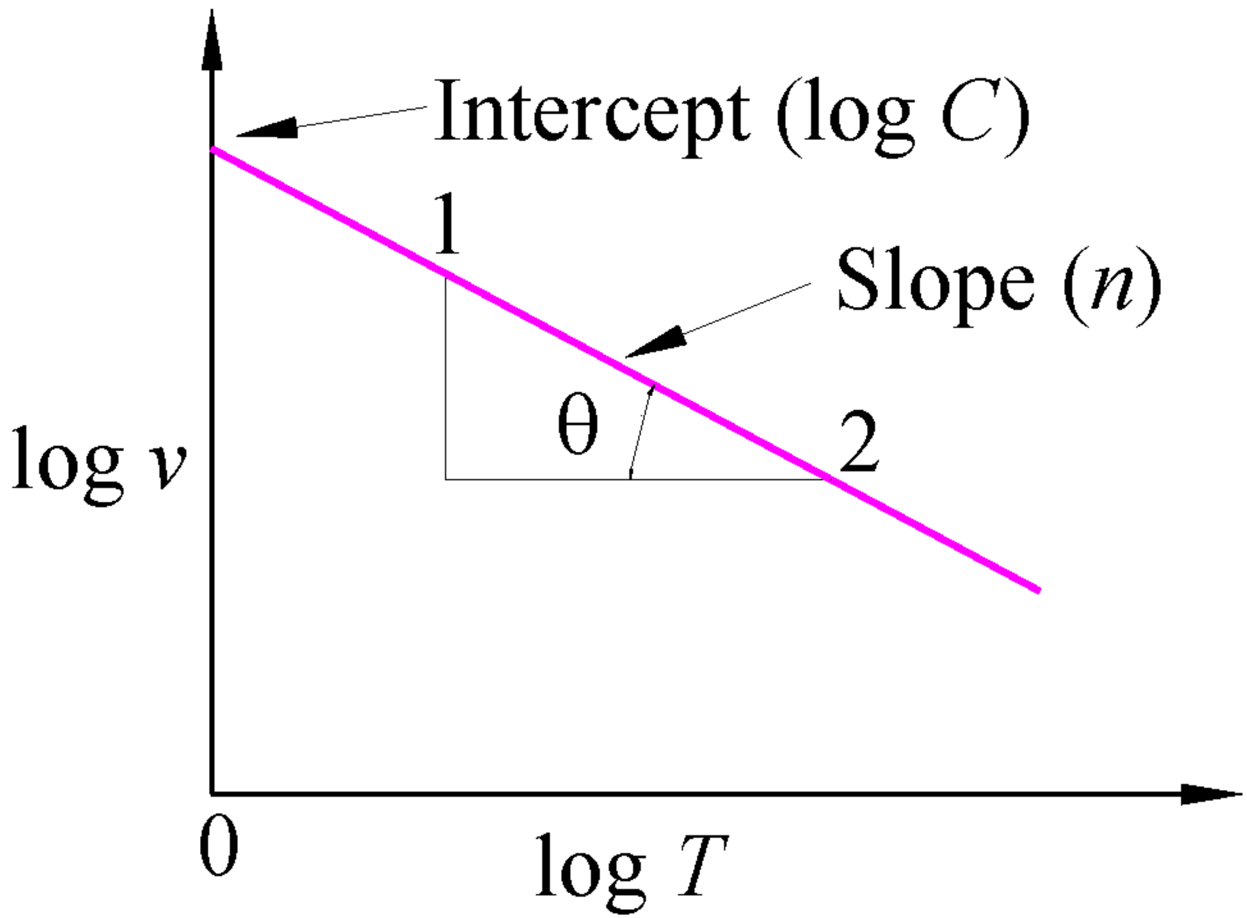
$$T = C / V^{s} \qquad V = C / T^{m} \qquad s = 1/m$$

$$\log V = \log C - m \log T$$

gdzie: $m = \mathrm{tg}\, \varphi$



$$vT^{n} f^{n_1} d^{n_2} = C$$



Intercept (log C)
1
Slope (n)
θ
2
log v
0
log T

Tool life method

Machinability can be based on the measure of how long a tool lasts. This can be useful when comparing materials that have similar properties and power consumptions, but one is more abrasive and thus decreases the tool life. The major downfall with this approach is that tool life is dependent on more than just the material it is machining; other factors include cutting tool material, cutting tool geometry, machine condition, cutting tool clamping, cutting speed, feed, and depth of cut. Also, the machinability for one tool type cannot be compared to another tool type (i.e. HSS tool to a carbide tool).

Economic tool life – the costs of operation are the lowest.

Productivity tool life – the productivity of the tool is the largest regardless of the cost of operation.

The machinability rating of a material attempts to quantify the machinability of various materials. It is expressed as a percentage or a normalized value.

Machinability Rating= (Speed of Machining the workpiece giving 60min tool life)/(Speed of machining the standard metal)

Machinability ratings can be used in conjunction with the Taylor tool life equation:

$$VT^n = C$$

in order to determine cutting speeds or tool life. For example: by AISI (American Iron and Steel Institute), if a material has a machinability rating of 70%, it can be determined, with the above knowns, that in order to maintain the same tool life (60 minutes) the cutting speed must be 70 sfpm (assuming the same tooling is used).

Relationship between cutting (technological) and geometrical parameters:

technological parameters:

a- depth [mm]

f – feed [mm/rev, mm/min]

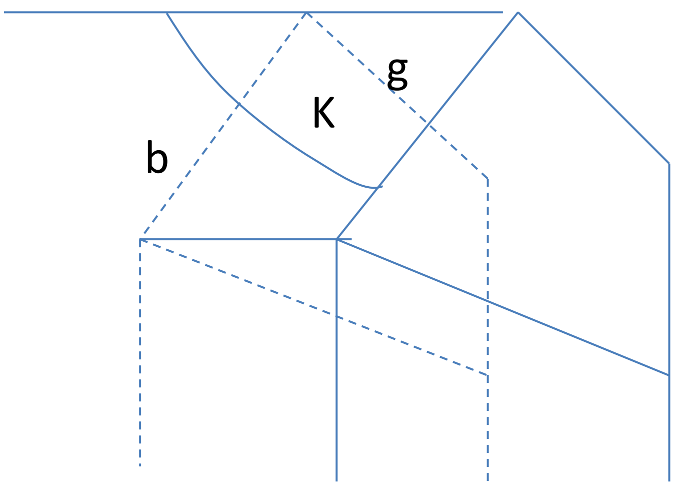
V – speed [m/min]

Geometrical parameters:

g - thickness of cut [mm]

b – width of cut [mm]

s= section of chip [mm2]



K - back rake angle BR

g = f x SinK

b = a/S inK

s= a x b [mm2]

Machinability . .

Machinability= $(v_t / v_s) \times 100\%$

v_s – specific CS for standard material

v_t – specific CS for test material

Machinability is affected by

- Condition of machine/tool
- Cutting conditions
- Type of operation
- work material

Work material	Tool material	n	C
Steel	HSS	0.1-0.16	160-190
	Carbide	0.18-0.2	220-290
Cast Iron	HSS	0.08-0.1	100-180
	Carbide	0.2-0.28	250-325

EXAMPLE 4.1

While machining carbon steel by a tungsten based steel tool, tool life of 50 minutes was observed when machined with a cutting speed of 100 m/min. Determine
(a) General Taylor's tool life equation and
(b) tool life for a cutting speed of 80 m/min. Assume $n = 0.09$.

Work material: carbon steel

Tool material: tungsten based tool steel

EXAMPLE 4.1 .. Solution

Given: $v = 100$ m/min, $T = 50$ min, $n = 0.09$

Taylor's Eqn. $vT^n = C$

or $\log v + n \log T = \log C$

or $\log 100 + 0.09 \log 50 = \log C$

or $C = 142.20$

Hence: $vT^{0.09} = 142.2$

EXAMPLE 4.1 .. Solution

(b)

Given: $vT^{0.09} = 142.2$, v = 80 m/min, T = ?

$$80\,.T^{0.09} = 142.2$$

or $T = 596.57$ min

EXAMPLES

- ***Example 4.3*** A carbide-cutting tool when machined with mild steel workpiece material at a cutting speed of 50 m/min lasted for 100 minutes. Determine the life of the tool when the cutting speed is increased by 25%. At what speed the tool is to be used to get a tool life of 180 minute. Assume n = 0.26 in the Taylor’s expression.

EXAMPLES

- ***Solution:*** Given data: $v1$ = 50 m/min, $T1$ = 100 min, n = 0.26

  For 20% higher speed

  $v2 = 1.25 v1 = 62.5$ m/min

  We know that v1 T1^n = v2 T2^n

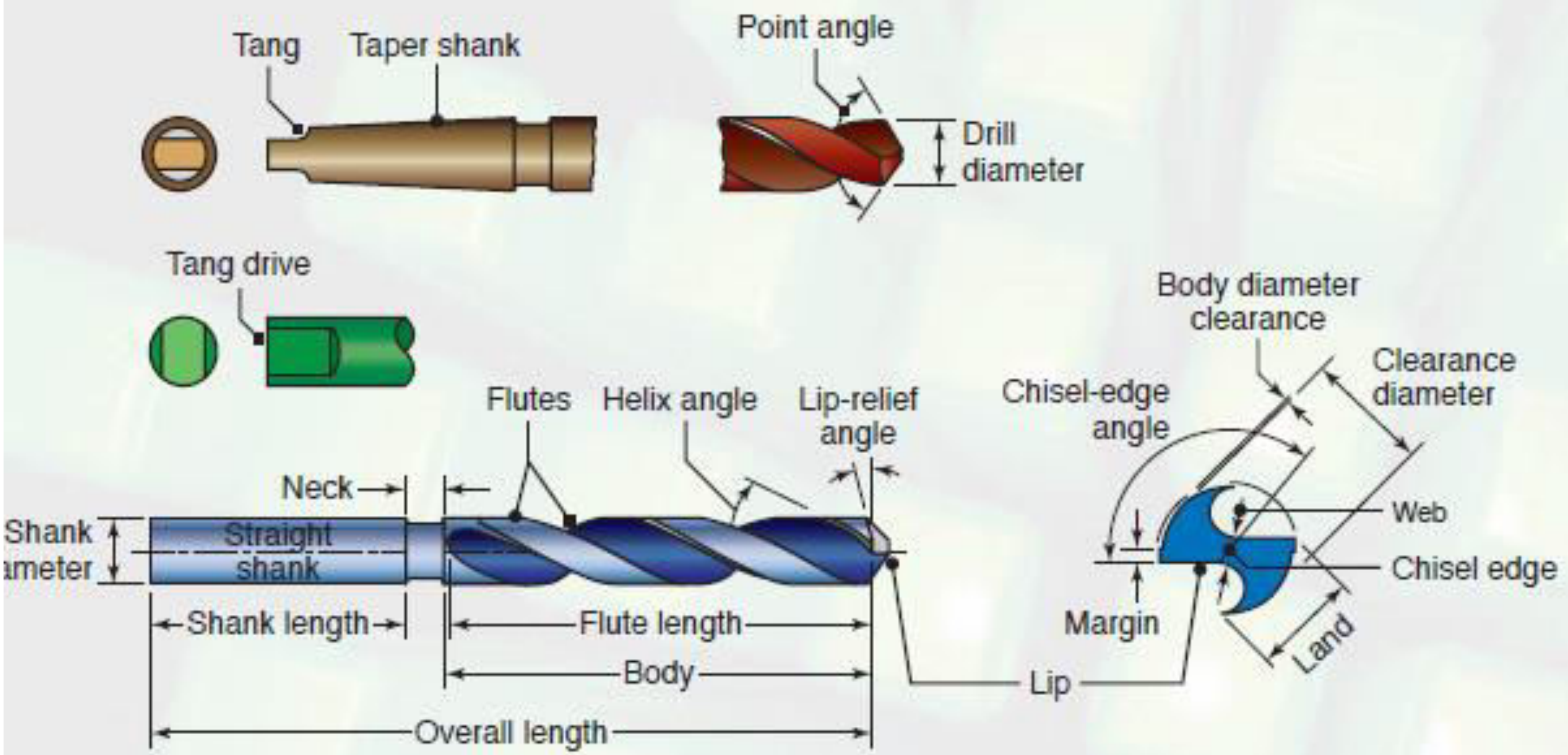
  Substituting the values, we get

  $T2$ = 42.39 minutes

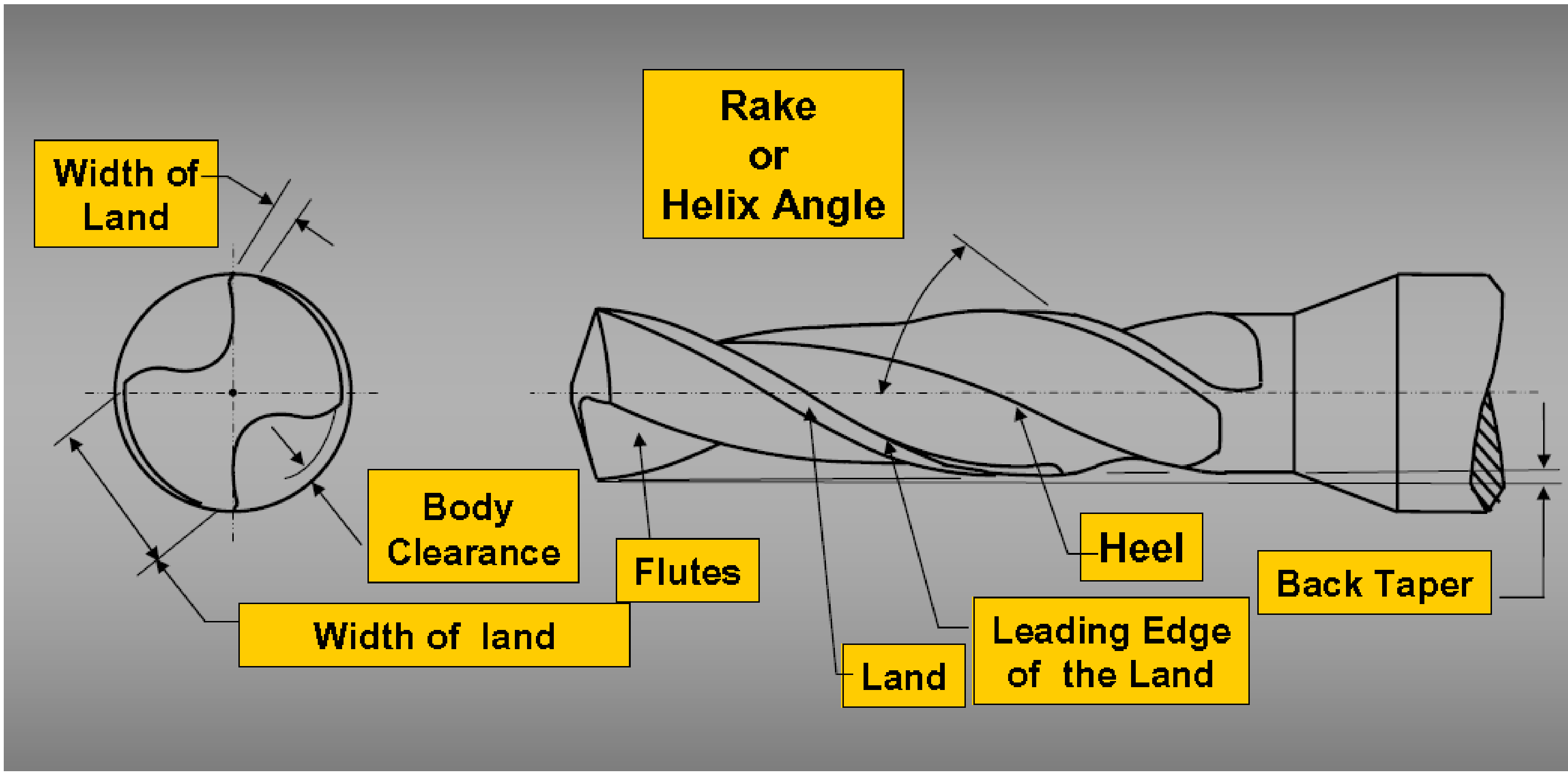
- **Drill Construction:**

    A twist drill is made up of three components:

    - Shank
    - Body
    - Drill point

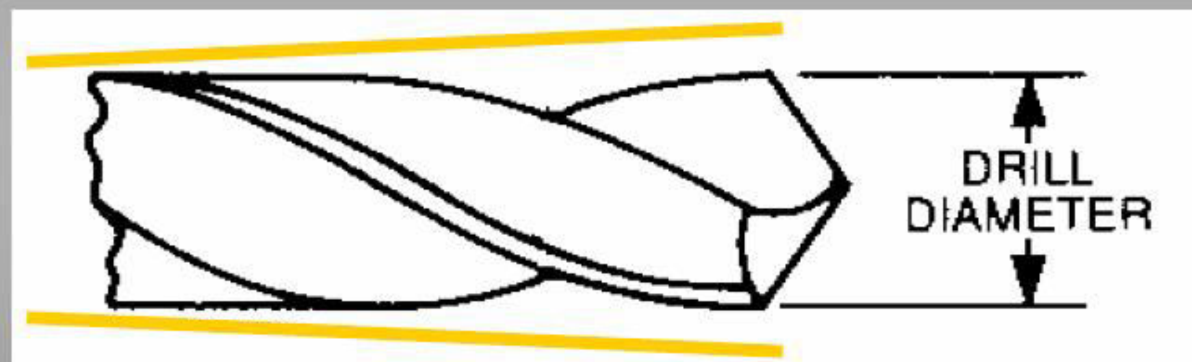


(a) Chisel-point drill


Rake
or
Helix Angle
Width of
Land
Body
Clearance
Flutes
Width of land
Heel
Back Taper
Leading Edge
of the Land
Land

- **Cutting Diameter:**

"Largest diameter measured across the top of the lands behind the point"



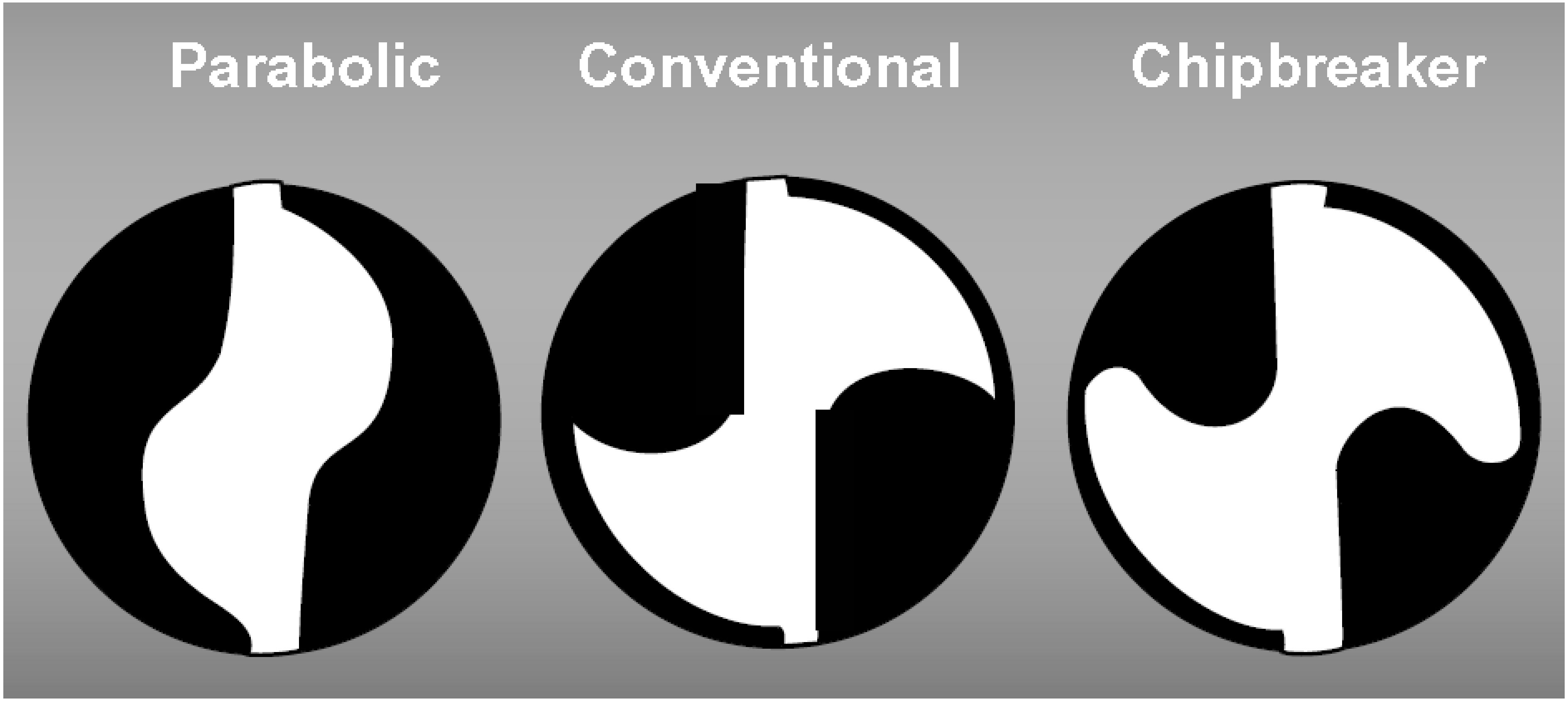
- **Back Taper**
  - The diameter reduces slightly toward the shank end of the drill, this is known as "back taper"
  - Back taper provides clearance between the drill and workpiece preventing friction and heat

Flute Length:

"The length of flute measured from the drill point to the end of the flute runout"

- Flute length determines the maximum depth of drilling

Flute construction



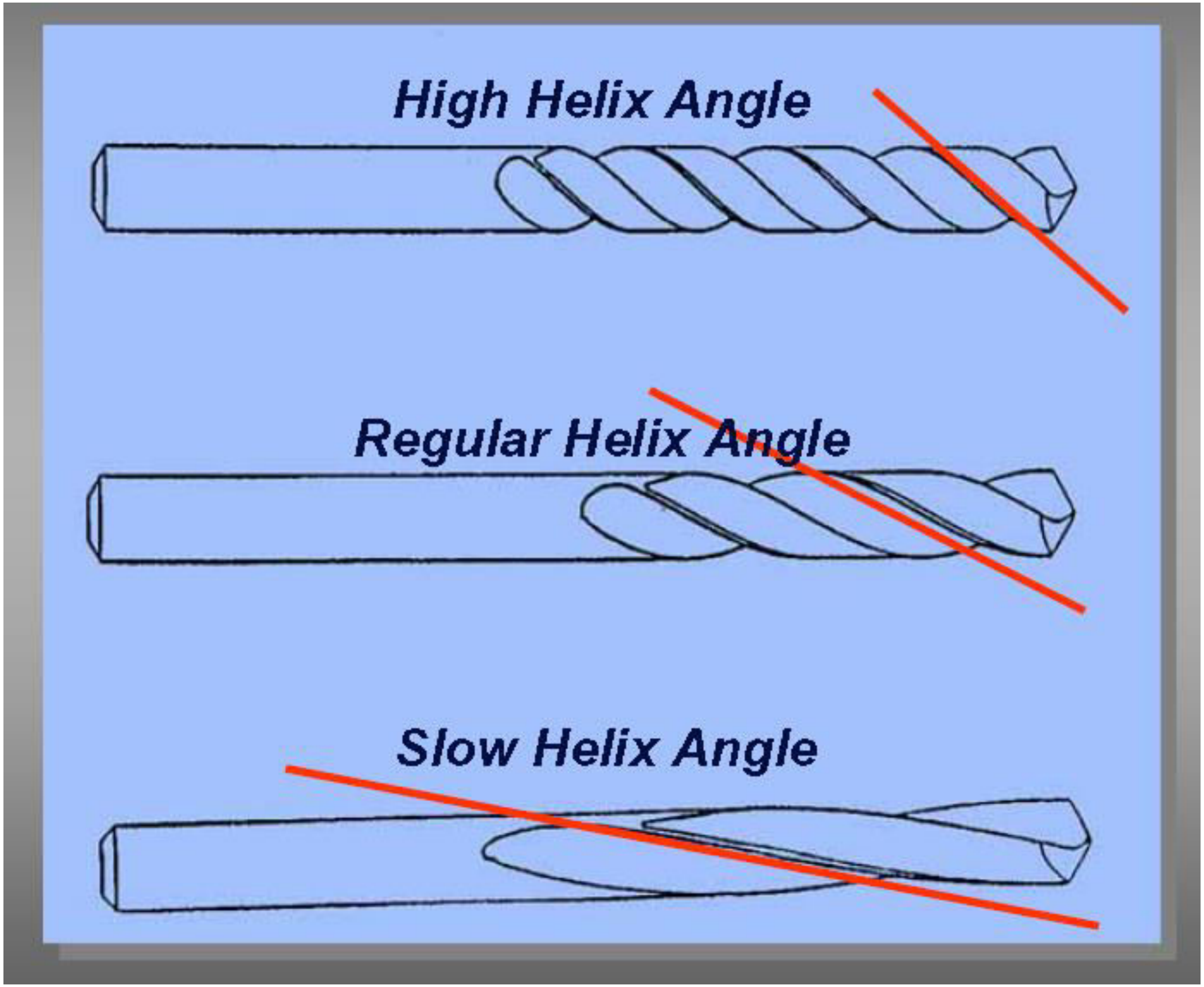
- **Conventional:**
  - Has “J” shaped flute geometry
  - Used in a wide variety of soft and hard drilling applications
  - Drill up to 3 to 4 diameters before pecking
  - Most drills in the industry have this type of construction

- **Chipbreaker**
    - Has special tight radius "J" shaped flute
    - *Tight radius helps to break up chips*
    - Heel is rolled for increased chip space
    - Used in equipment with fixed feeds where long stingy chips are produced

- **Parabolic:**

  "Compound radius, cleared heel flute shape"

Parabolic flutes substantially increase available flute space for chips!


High Helix Angle
Regular Helix Angle
Slow Helix Angle

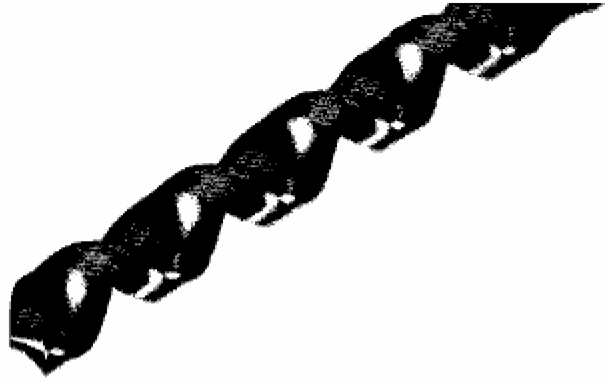
Slow Spiral

- 12° to 22° helix angle
- Used in materials producing broken chips such as brass or bronze, or cast iron
- Also used in horizontal applications where the drill is not rotating

Regular

- 28° to 32° helix angle
- Found on most general purpose and cobalt drills
- Used in a wide variety of drilling applications

Fast Spiral



- 34° to 38° helix angle
- Used on high helix general purpose and deep hole parabolic drills
- For softer ferrous and non-ferrous materials producing stringy chips

- ***How does changing the helix angle effect performance?***

  Fast Spiral Drills

  - Provides greater lifting power for chips, but are weaker
  - Generally used in deep holes

  Slow Spiral Drills

  - Are stronger, but have less lifting power for chips
  - Generally limited to shallow holes

Various Helix Angles

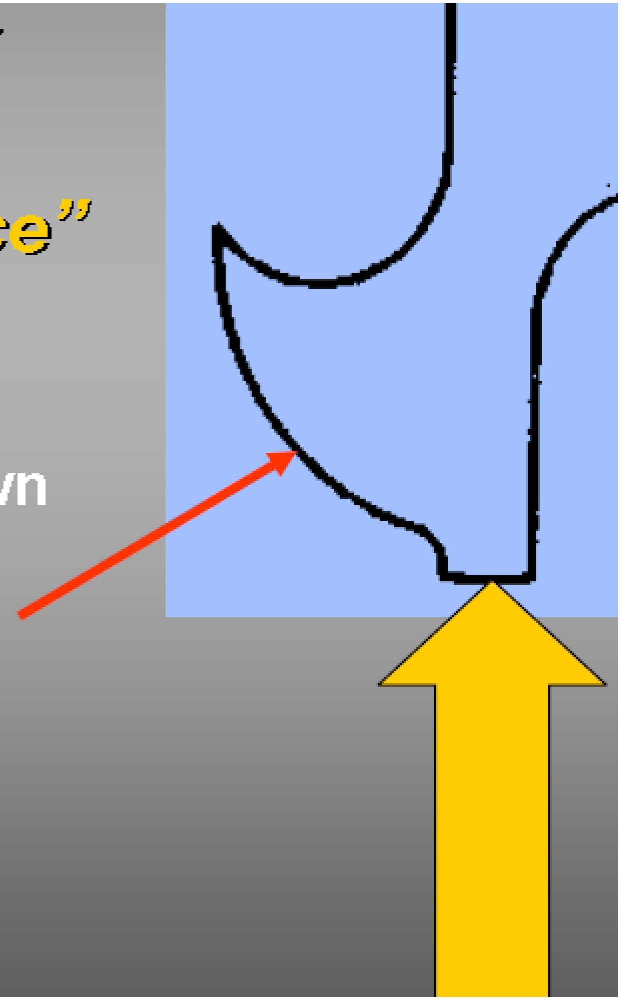
Regular Helix Drill

High Helix Drill

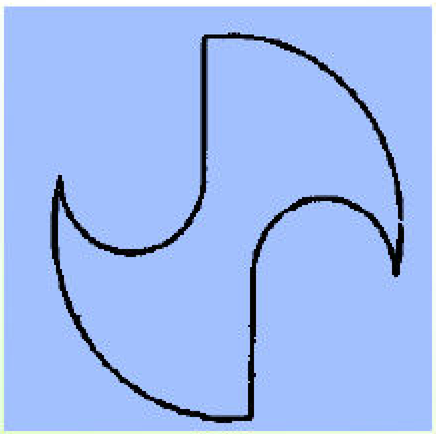
"The cylindrical portion of the land that is <u>not cut away</u> to provide clearance"

- The balance of the land is reduced in diameter, known as "cleared diameter" or "body clearance"

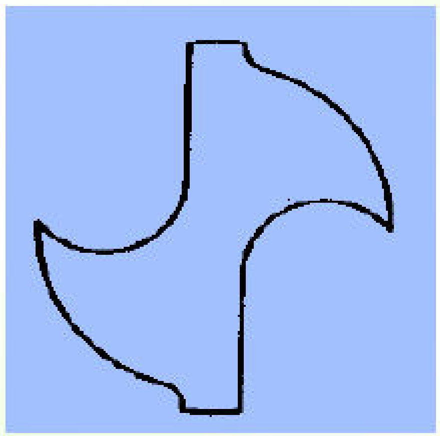
- Body clearance prevents excessive rubbing and friction



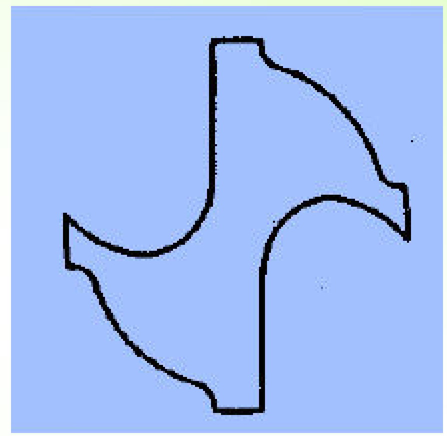
Margins



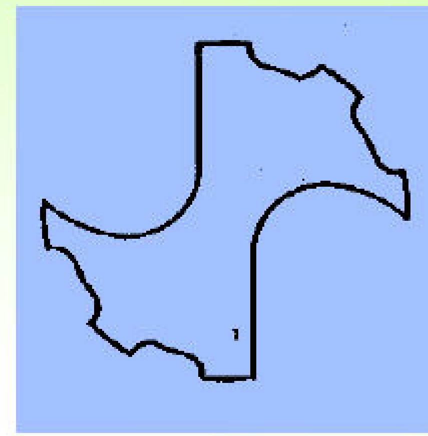
No Margin



Single Margin

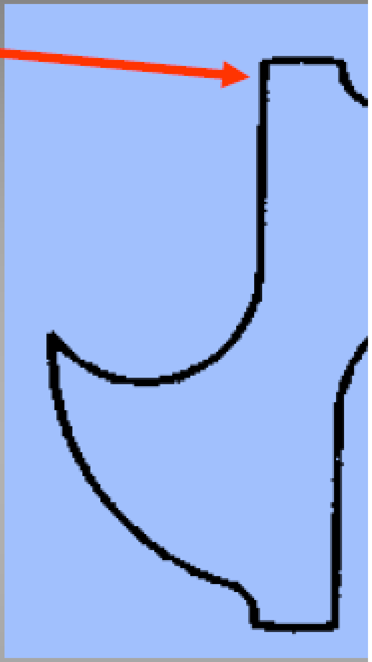


Double Margin

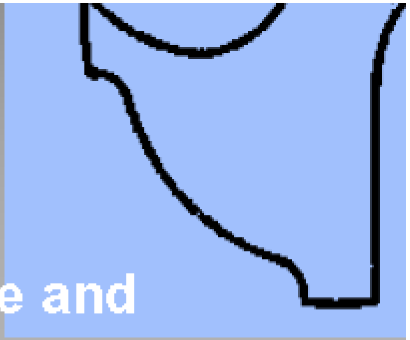


Triple Margin

– Single Margin:



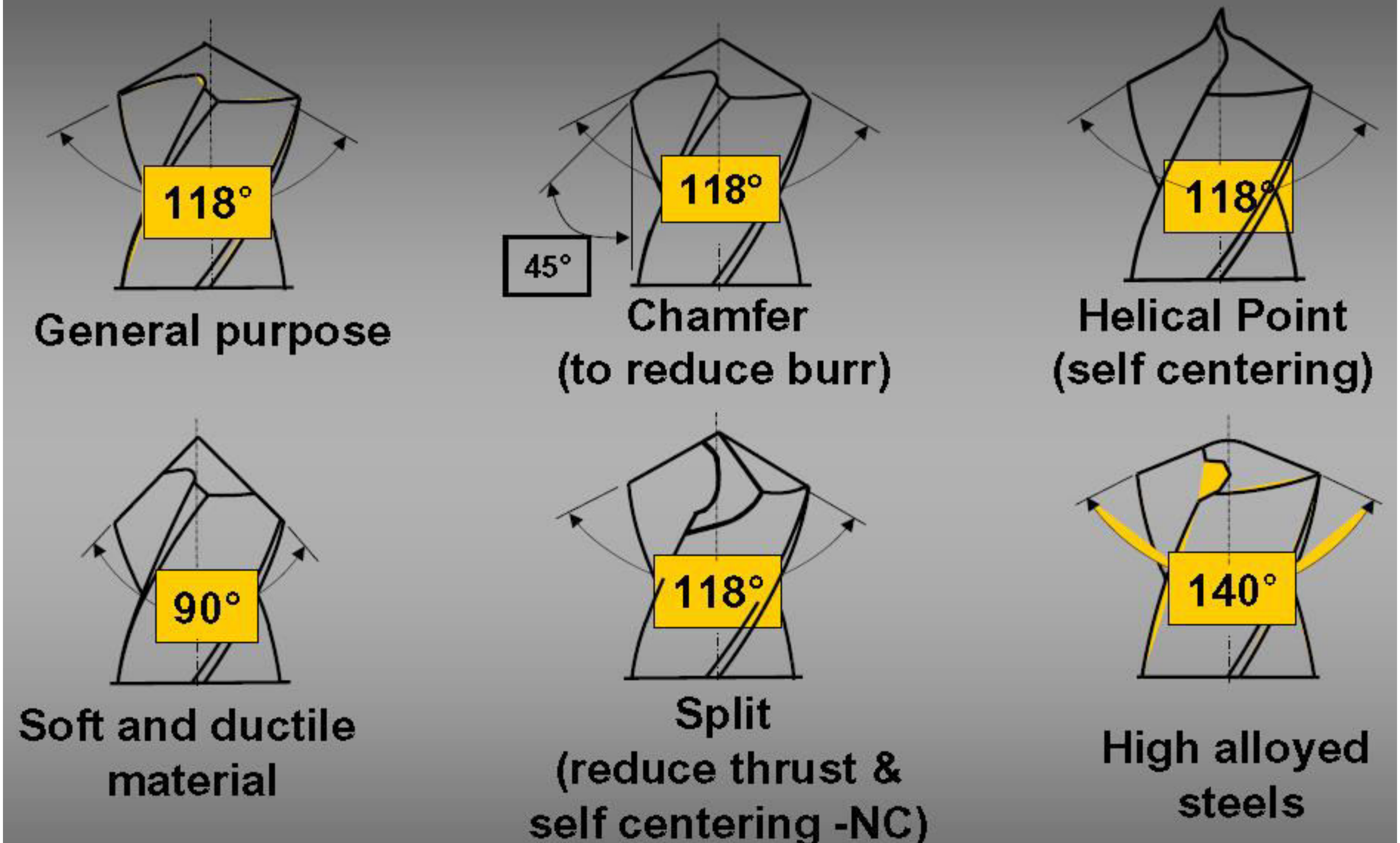
- Has one margin adjacent to the cutting edge
- Single margins create the least amount of rubbing and friction with minimal support in the hole
- Most standard tools are single margin



Double Margin:

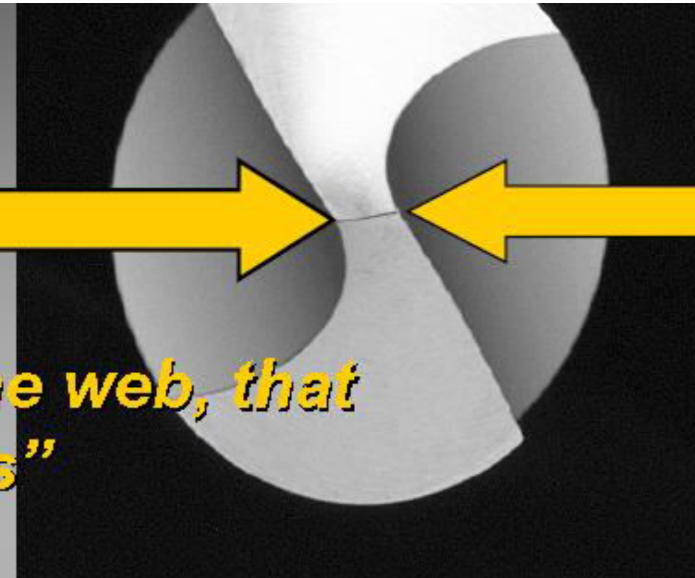
- Has a margin at both the cutting edge and heel
- Used in specialized applications where precision hole size, and finish are required
- The additional margin adds stability and reduced the possibility of chatter, but creates more friction
- Often used when drilling through a bushing for support

Drill Point Angles



- **Chisel Edge**

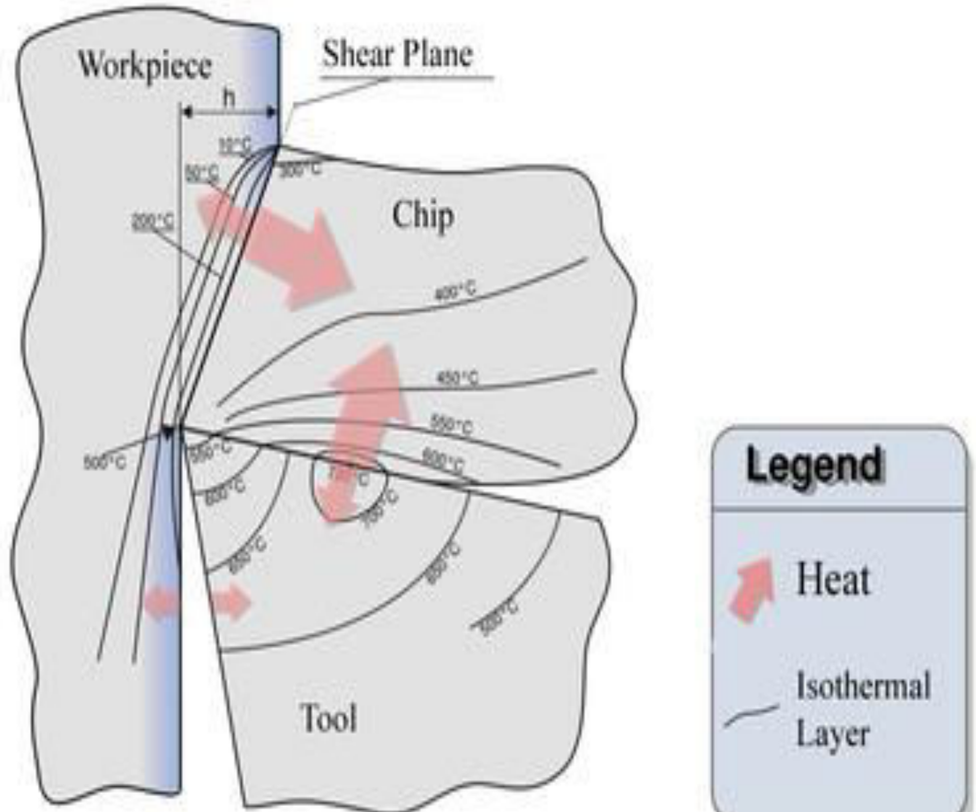
"The edge at the end of the web, that connects the cutting lips"



  - The chisel edge *does not cut* - it penetrates displacing the workpiece material

The chisel edge consumes 60% to 70% of the thrust required!

Temperature considerations



Temperature gradient of tool, workpiece and chip during orthogonal cutting. As can easily be seen, heat is removed from the workpiece and the tool to the chip. Crater wear occurs around the 720 degree area of the tool. At high temperature zones crater wear occurs. The highest temperature of the tool can exceed 700 °C and occurs at the rake face whereas the lowest temperature can be 500 °C or lower depending on the tool...

Several analytical methods to calculate cutting temperature

Method by N. Cook derived from dimensional analysis using experimental data for various work materials

$$T = \frac{0.4U}{\rho C}\left(\frac{vt_o}{K}\right)^{0.333}$$

where T = temperature rise at tool-chip interface; U = specific energy; v = cutting speed; t_o = chip thickness before cut; ρC = volumetric specific heat of work material; K = thermal diffusivity of the work material

Approximately 98% of the energy in machining is converted into heat

This can cause temperatures to be very high at the tool-chip

The remaining energy (about 2%) is retained as elastic energy in the chip

Energy Considerations

Energy comes in the form of heat from tool friction. It is a reasonable assumption that 80% of energy from cutting is carried away in the chip. If not for this the workpiece and the tool would be much hotter than what is experienced. The tool and the workpiece each carry approximately 10% of the energy. The percent of energy carried away in the chip increases as the speed of the cutting operation increases. This somewhat offsets the tool wear from increased cutting speeds. In fact, if not for the energy taken away in the chip increasing as cutting speed is increased; the tool would wear more quickly than is found.

Multi-Criteria of Machining Operation

Malakooti and Deviprasad (1989) introduced the multi-criteria metal cutting problem where the criteria could be cost per part,production time per part, and quality of surface. Also, Malakooti et al. (1990) proposed a method to rank the materials in terms of machinability. Malakooti (2013) presents comprehensive discussion about tool life and its multi-criteria problem. As as example objectives can be minimizing of Total cost (which can be measured by the total cost of replacing all tools during a production period), maximizing of Productivity (which can be measured by the total number of parts produced per period), and maximizing of quality of cutting

For a given material there will be an optimum cutting speed for a certain set of machining conditions, and from this speed the spindle speed can be calculated. Factors affecting the calculation of cutting speed are:

- The material being machined (steel, brass, tool steel, plastic, wood)
- The material the cutter is made from (carbon steel, high speed steel (HSS), carbide, ceramics).
- The economical life of the cutter (the cost to regrind or purchase new, compared to the quantity of parts produced).
- Condition of material (mill scale, hard spots due to white cast iron forming in castings).

Cutting speeds are calculated on the assumption that optimum cutting conditions exist, these include:

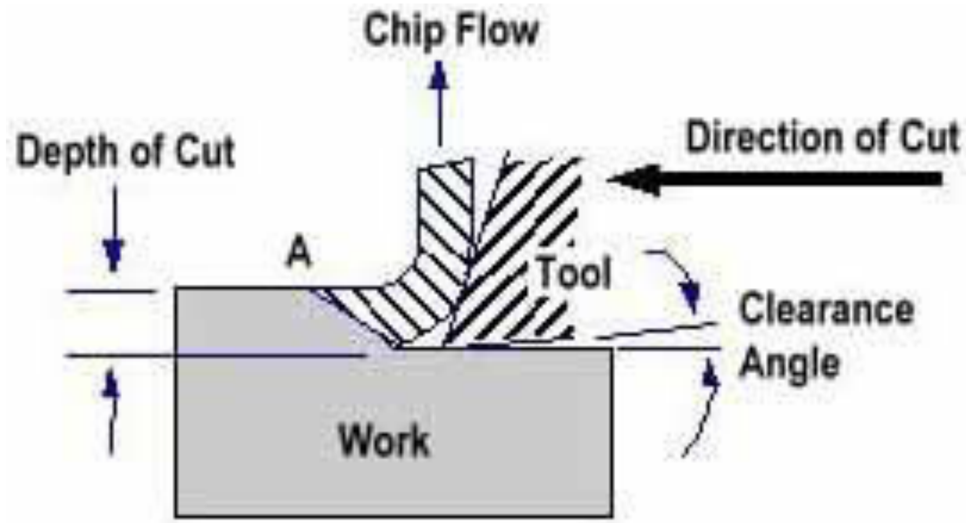
- Metal removal rate (finishing cuts that remove a small amount of material may be run at increased speeds)
- Full and constant flow of cutting fluid (adequate cooling and chip flushing)
- Rigidity of the machine and tooling setup (reduction in vibration or chatter)
- Continuity of cut (as compared to an *interrupted cut*, such as machining square section material in a lathe)

The cutting *speed* is given as a set of constants that are available from the material manufacturer or supplier, the most common materials are available in reference books, or charts but will always be subject to adjustment depending on the cutting conditions. The following table gives the cutting speeds for a selection of common materials under one set of conditions. The conditions are a tool life of 1 hour, dry cutting (no coolant) and at medium feeds so they may appear to be incorrect depending on circumstances. These cutting speeds may change if, for instance, adequate coolant is available or an improved grade of HSS is used (such as one that includes cobalt).

Cutting speeds for various materials using a plain high speed steel cutter		
Material type	Meters per min (MPM)	Surface feet per min (SFM)
Steel (tough)	15–18	50–60
Mild steel	30–38	100–125
Cast iron (medium)	18–24	60–80
Alloy steels	20-37	65–120
Carbon steels	21-40	70–130
Free cutting steels	35-69	115–225
Stainless steels (	23-40	75–130
Bronzes	24–45	80–150
Leaded steel	91	300
Aluminium	75–105	250–350
Brass	90-210	300-700 (Max. spindle speed)

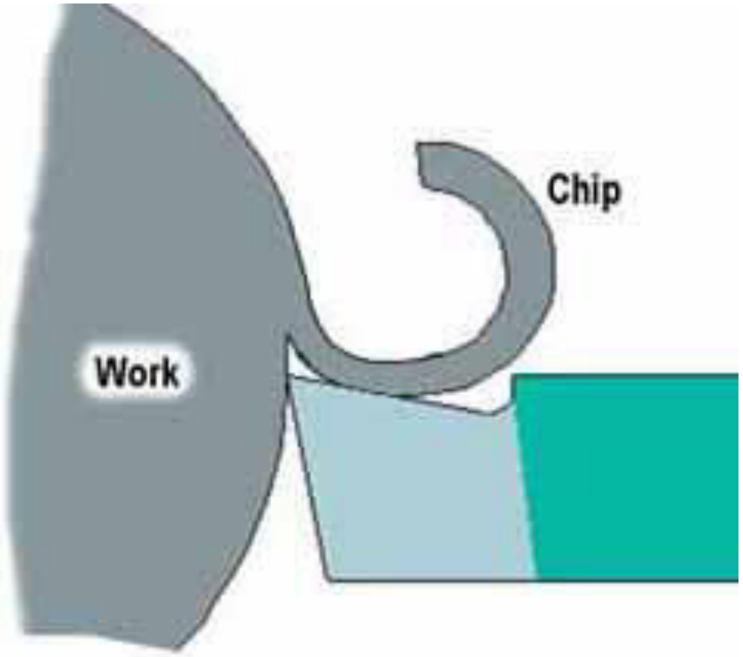
Basic Metal Cutting Theory

The usual conception of cutting suggests clearing the substance apart with a thin knife or wedge. When metal is cut the action is rather different and although the tool will always be wedge shaped in the cutting area and the cutting edge should always be sharp the wedge angle will be far too great for it to be considered knife shaped. Consequently a shearing action takes place when the work moves against the tool.



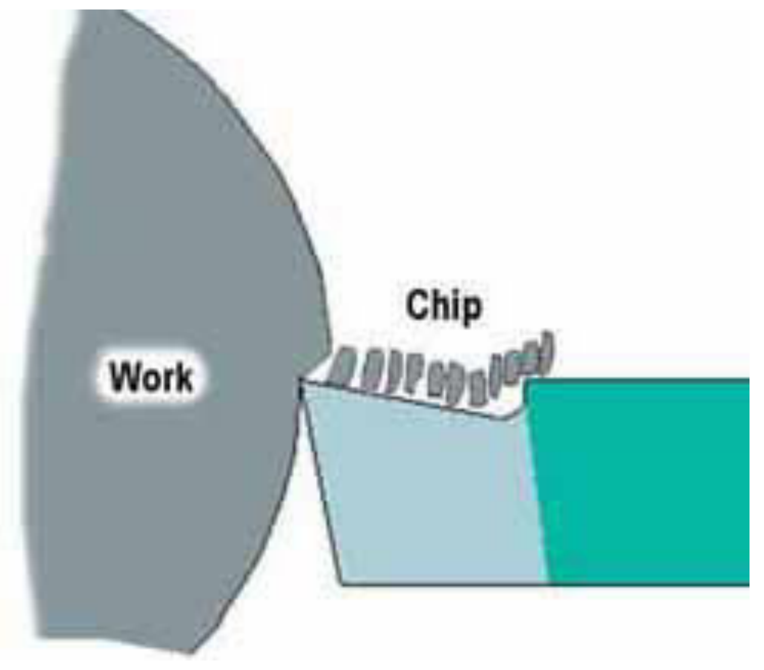
Continuous Chip

This leaves the tool as a long ribbon and is common when cutting most ductile materials such as mild steel, copper and Aluminium. It is associated with good tool angles, correct speeds and feeds, and the use of cutting fluid.



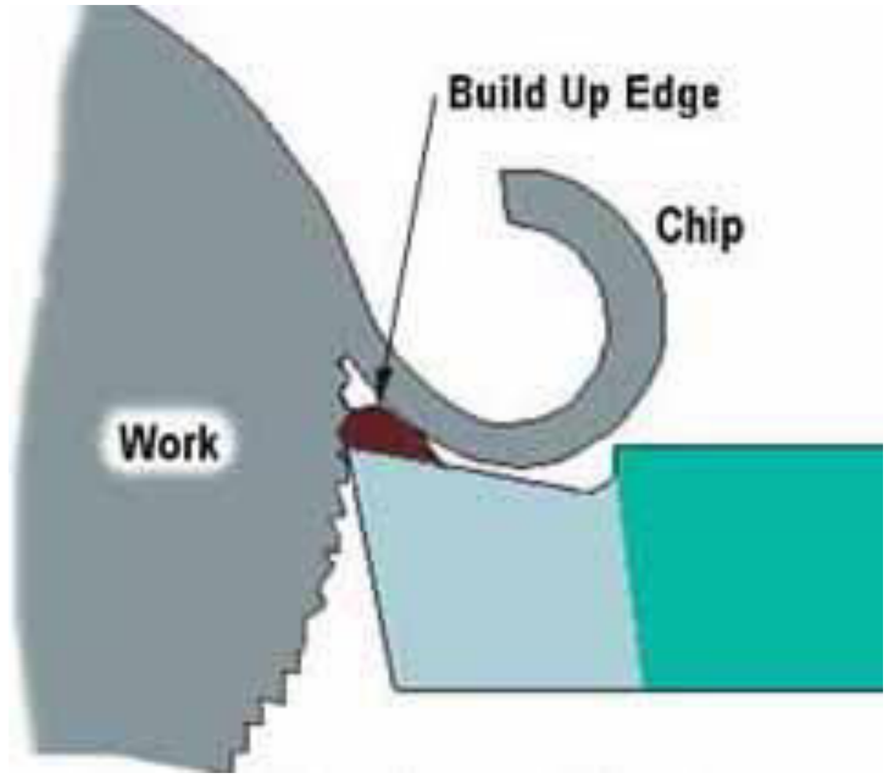
Discontinuous Chip

The chip leaves the tool as small segments of metal resulted from cutting brittle metals such as cast iron and cast brass with tools having small rake angles. There is nothing wrong with this type of chip in these circumstances.



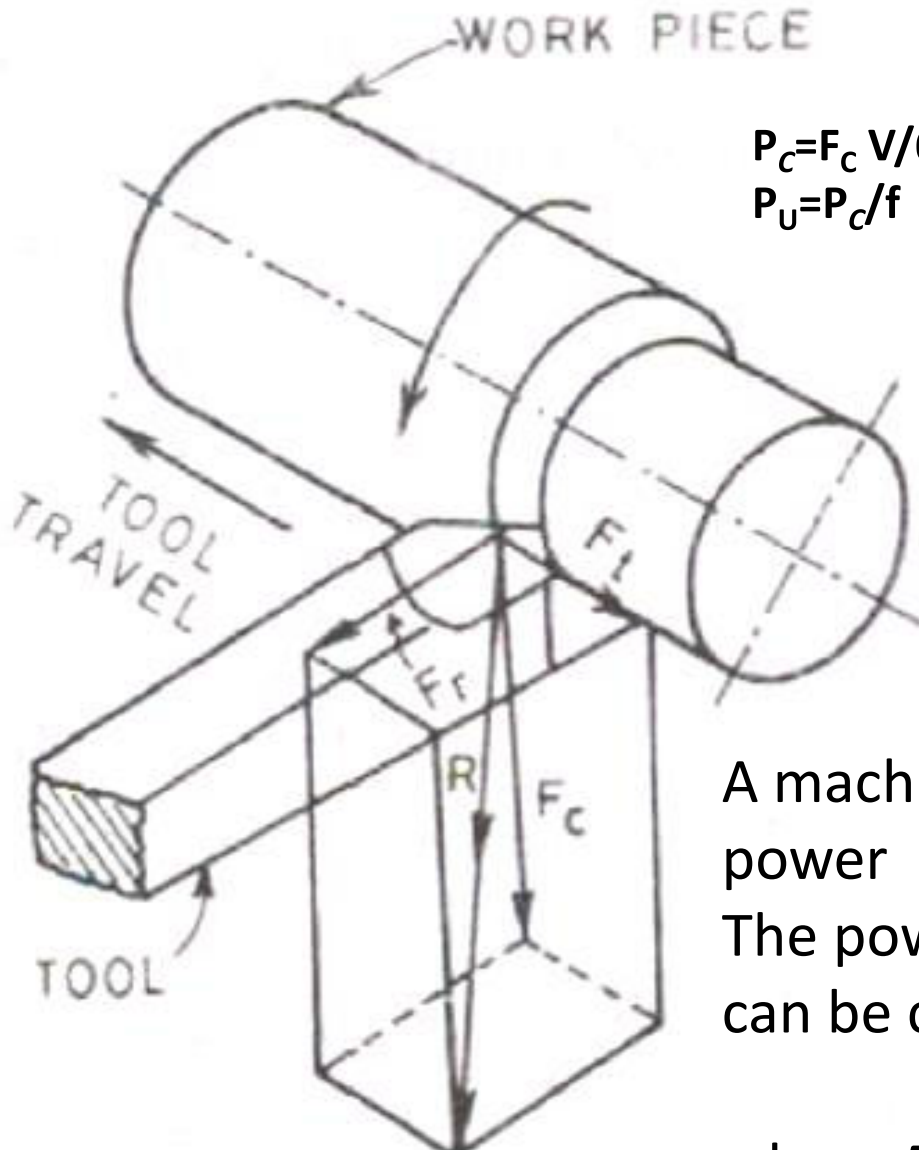
Continuous Chip with Builtup Edge

This is a chip to be avoided and is caused by small particles from the workpiece becoming welded to the tool face under high pressure and heat. The phenomenon results in a poor finish and damage to the tool. It can be minimised or prevented by using light cuts at higher speeds with an appropriate cutting lubricant.



$P_C = F_C V / 60000$ [kW]

$P_U = P_C / f$ [Pa] – material remove rate

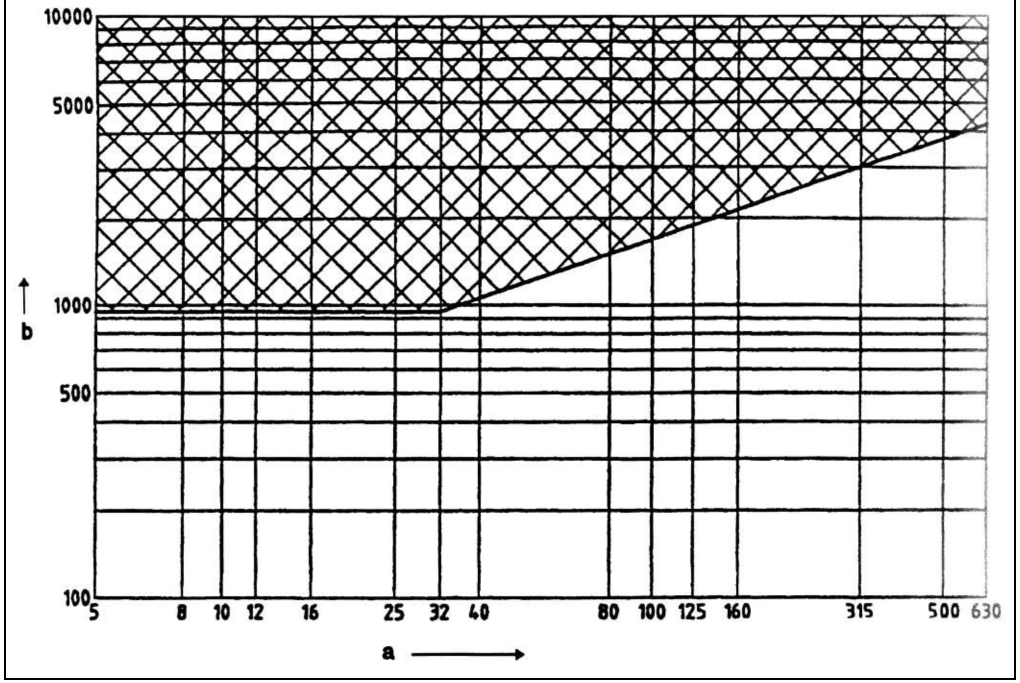


A machining operation requires power

The power to perform machining can be computed from:

$$P_c = F_c v$$

where P_c = cutting power; F_c = cutting force; and v = cutting speed



HSM[C]

High Speed Machining [Cutting]