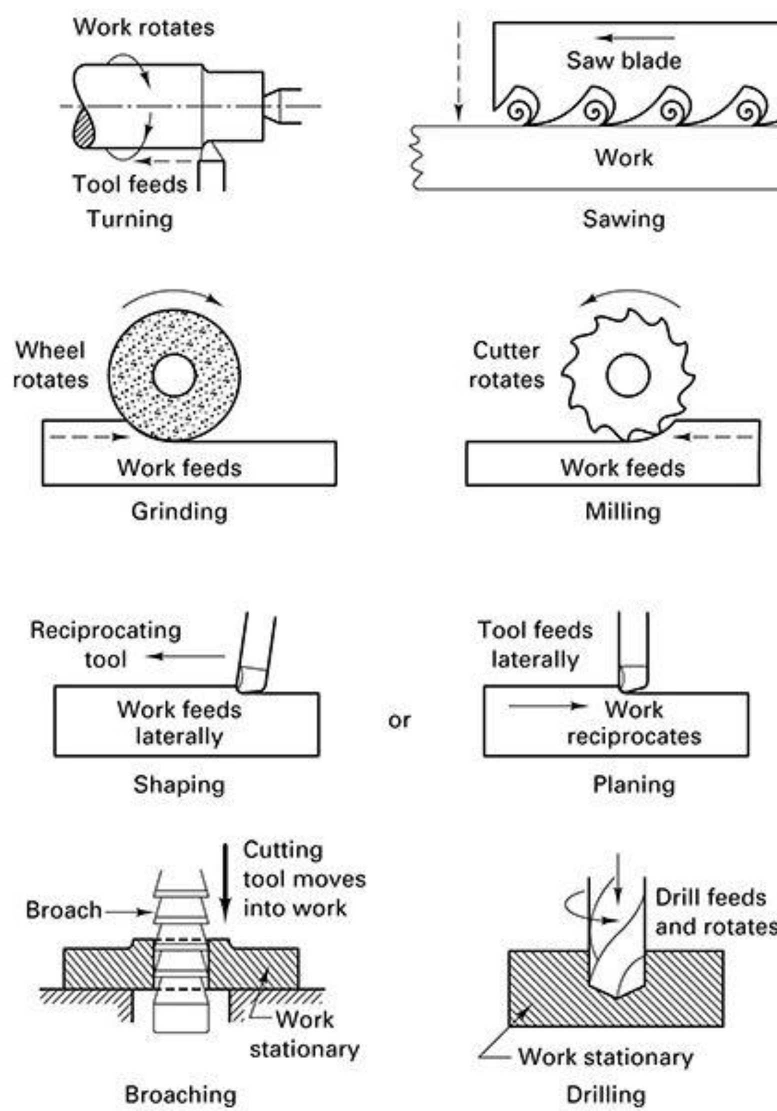
Fundamentals of Chip-Type Machining Processes

Machining

Removing unwanted material in the form of chips:

- Turning
- Sawing
- Grinding
- Milling
- Shaping or planing
- Broaching
- Drilling

Seven Basic Machining Processes

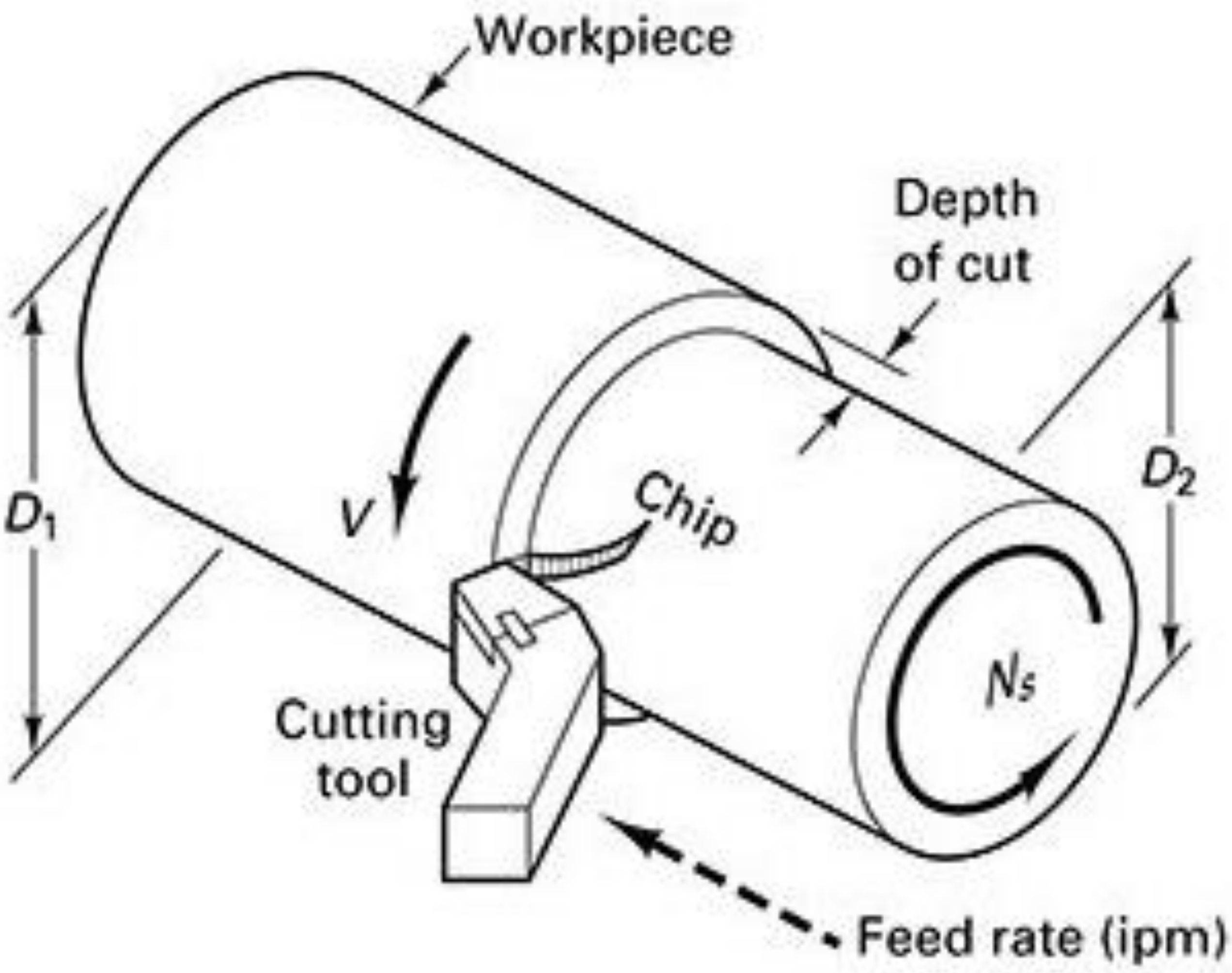


Machining Process

Affected by:

- Machine tool (the machine itself)
- Cutting tool (geometry and material)
- Workpiece (properties and material)
- Cutting tool parameters
  - ❖Speed
  - ❖Feed
  - ❖Depth of cut
- Workpiece holding devices

Cutting Parameters



Four Cutting Tool Parameters

- 1. Speed
- 2. Depth of Cut (DOC)
- 3. Feed Rate (f_r)
- 4. Material Removal Rate (MRR)

Speed

Speed – velocity of workpiece relative to cutting tool; the <u>**primary cutting motion**</u>

- $V = \pi D_1 N_s / 12$, in ft/min
- $D_1 =$ original diameter, inches
- $N_s =$ angular velocity of workpiece, RPM
- $N_s \cong 3.8V/D_1$

Depth of Cut

Depth of Cut (DOC) – distance tool plunged into workpiece

- $d = (D_1 - D_2)/2$, inches

Feed Rate

Feed Rate (f_r) – amount of material removed per revolution (inches/rev)

Material Removal Rate

Material Removal Rate

MRR = (volume removed)/(cutting time), in^3/min

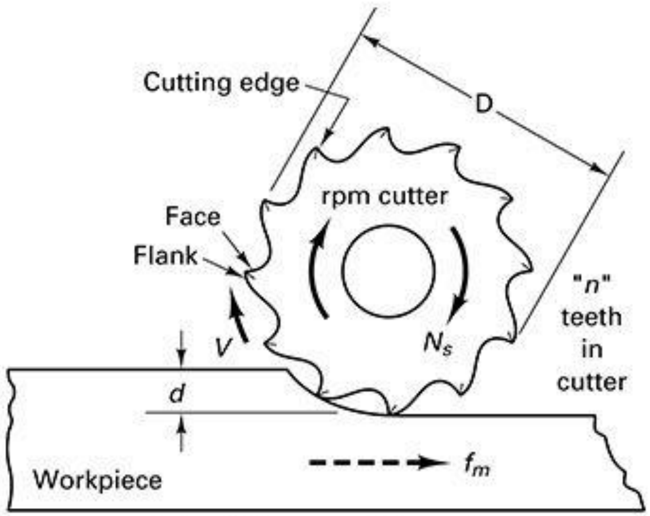
- $MRR \cong 12Vf_rd$, in^3/min
- $MRR \cong \pi D_1 N_s f_r d$, in^3/min
- $d =$ depth of cut

Milling Material Removal Rate

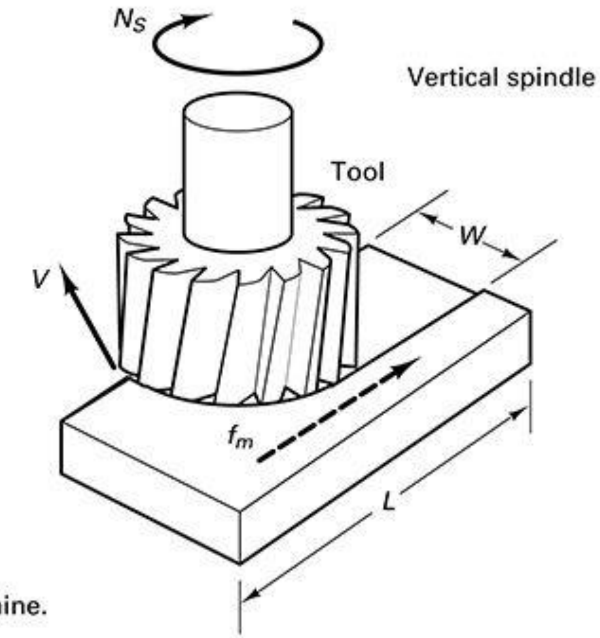
Multiple-tooth cutter is used

- Table feed: $f_m = f_t n N_s$
- $f_t =$ feed per tooth pass, inches/rev
- $n =$ number of teeth
- $N_s =$ angular velocity, RPM
- $MRR = Wdf_m$, in^3/min

Slab/Face Milling Basics



Slab milling – multiple tooth



Face milling
Multiple-tooth cutting

Slab milling is usually performed on a horizontal milling machine. Equations for T_m and MRR derived in Chapter 25.

The tool rotates at rpm N_s. The workpiece translates past the cutter at feed rate f_m, the table feed. The length of cut, L, is the length of workpiece plus allowance, L_A,

$$L_A = \sqrt{\frac{D^2}{4} - \left(\frac{D}{2} - d\right)^2} = \sqrt{d(D-d)} \text{ inches}$$

$T_m = (L + L_A)/f_m$

The MRR $= Wdf_m$ where W = width of the cut and d = depth of cut.

Given a selected cutting speed V and a feed per tooth f_t, the rpm of the cutter is $N_s = 12V/\pi D$ for a cutting of diameter D. The table feed rate is $f_m = f_t n N_s$ for a cutter with n teeth.

The cutting time, $T_m = (L + L_A + L_o)/f_m$

where $L_o = L_A = \sqrt{W(D-W)}$ for $W < D/2$

or $L_o = L_A = D/2$ for $W \geqslant D/2$.

The MRR $= Wdf_m$ where d = depth of cut.

Shop Formulas for Various Processes

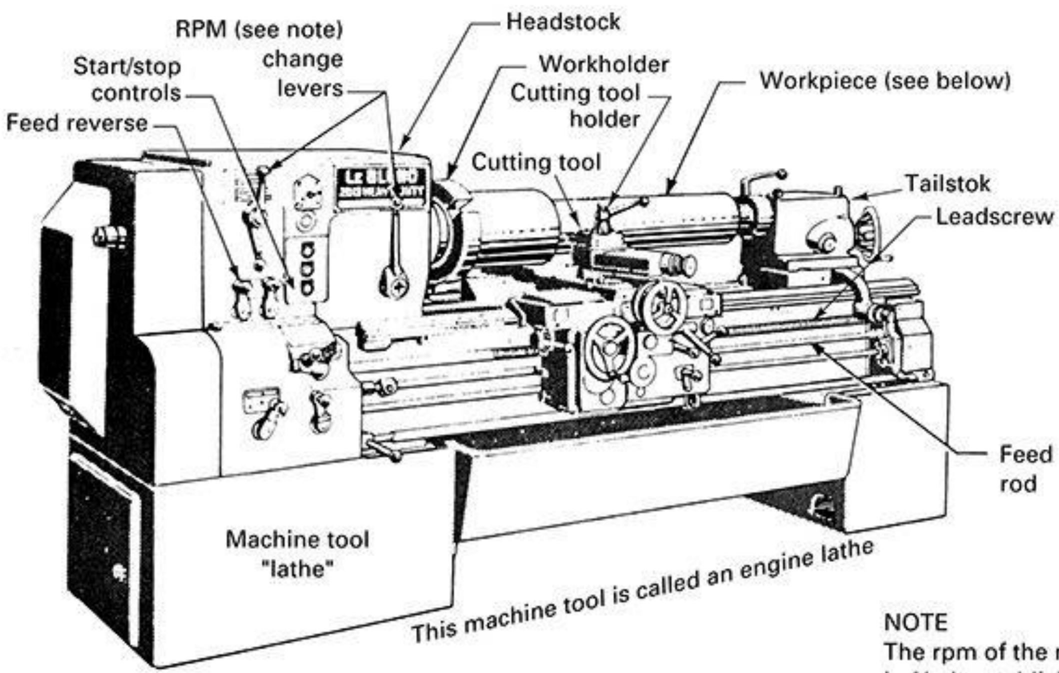
Shop Formulas for Turning, Milling, Drilling, and Broaching (English Units)				
Parameter	Turning	Milling	Drilling	Broaching
Cutting speed, fpm	$V = 0.262 \times D_t \times$ rpm	$V = 0.262 \times D_m \times$ rpm	$V = 0.262 \times D_d \times$ rpm	V
Revolutions per minute, N_s	rpm $= 3.82 \times V_c/D_t$	rpm $= 3.82 \times V_c/D_m$	rpm $= 3.82 \times V_c/D_d$	—
Feed rate, in./min	$f_m = f_r \times$ rpm	$f_m = f_r \times$ rpm	$f_m = f_r \times$ rpm	—
Feed per rev tooth pass, in./rev	f_r	f_t	f_r	—
Cutting time, min, T_m	$T_m = L/f_m$	$T_m = L/f_m$	$T_m = L/f_m$	$T_m = L/12V$
Rate of metal removal, in.^{3}/min	MRR $= 12 \times d \times f_r \times V_c$	MRR $= w \times d \times f_m$	MRR $= \pi D^2 d/4 \times f_m$	MRR $= 12 \times w \times d \times V$
Horsepower required at spindle	hp = MRR × HP_s	hp = MRR × HP_s	hp = MRR × HP_s	—
Horsepower required at motor	hp_m = MRR × HP_s/E	hp_m = MRR × HP_s/E	hp_m = MRR × HP_s/E	hp_m = MRR × HP_s/E
Torque at spindle	$t_s = 63{,}030$ hp/rpm	$t_s = 63{,}030$ hp/rpm	$t_s = 63{,}030$ hp/rpm	—

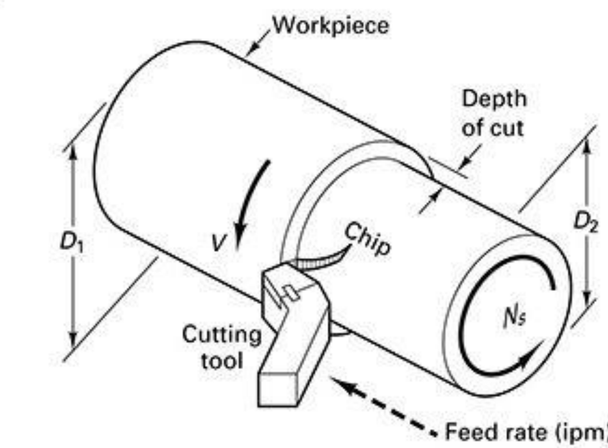
Symbols

D_t = Diameter of workpiece in turning, inches
D_m = Diameter of milling cutter, inches
D_d = Diameter of drill, inches
d = Depth of cut, inches
E = Efficiency of spindle drive
f_m = Feed rate, inches per minute
f_r = Feed, inches per revolution
f_t = Feed, inches per tooth
hp_m = Horsepower at motor
MRR = Metal removal rate, in.^{3}/min

hp = horsepower at spindle
L = Length of cut, inches
n = Number of teeth in cutter
HP_s = Unit power, horsepower per cubic inch per minute, specific horsepower
N_s = Revolution per minute of work or cutter
t_s = Torque at spindle, inch-pound
T_m = Cutting time, minutes
V = Cutting speed, feet per minute
w = Width of cut, inches

Lathe Turning



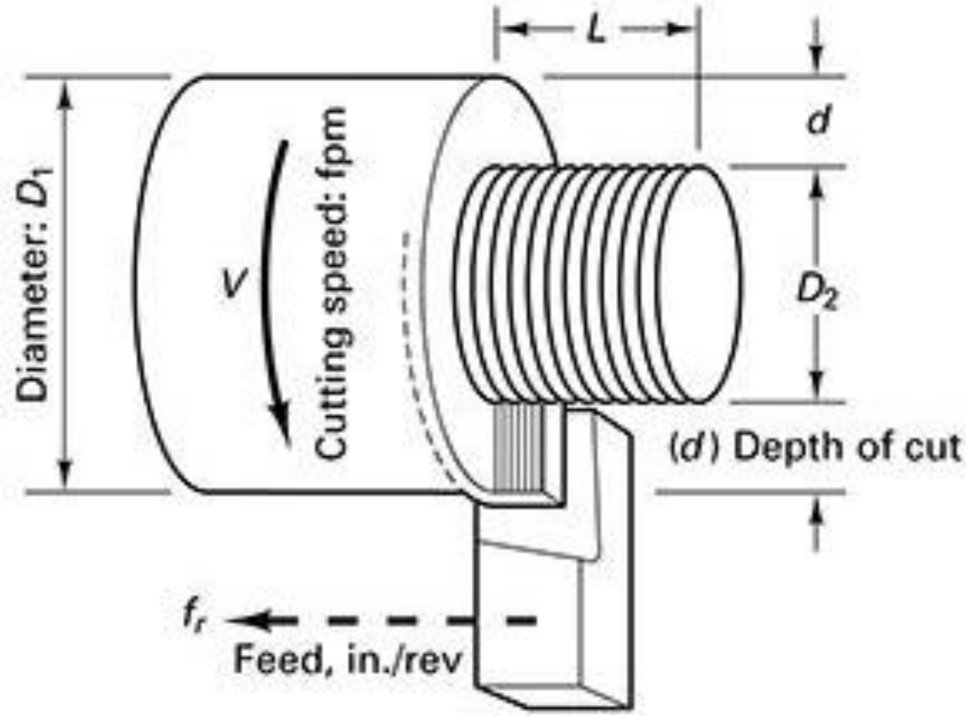


NOTE
The rpm of the rotating workpiece is N_s. It establishes the cutting speed V, at the tool, according to $N_s = 12V/\pi D$.

The depth of cut, d, is equal to $(D_1 - D_2)/2$.
The length of cut is the distance the tool travels parallel to the axis, L.

[Watch Video Here]

Lathe Turning



Turning

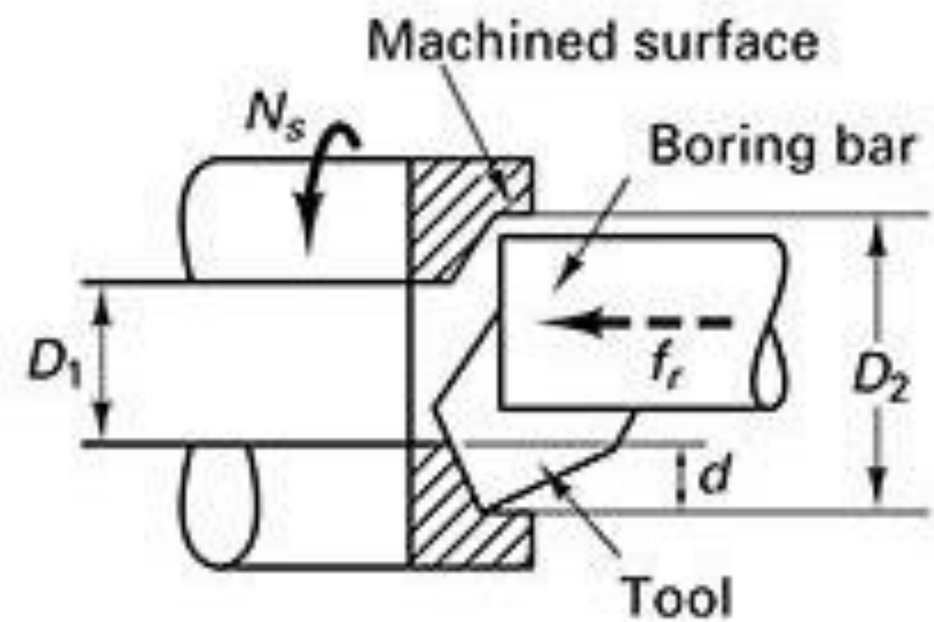
Speed, stated in surface feet per minute (sfpm), is the peripheral speed at the cutting edge. Feed per revolution in turning is a linear motion of the tool parallel to the rotating axis of the workpiece. The depth of cut reflects the third dimension.

L = length of cut

$$T_m = \frac{L + A}{f_r N_s}$$

T_m = cutting time, minutes

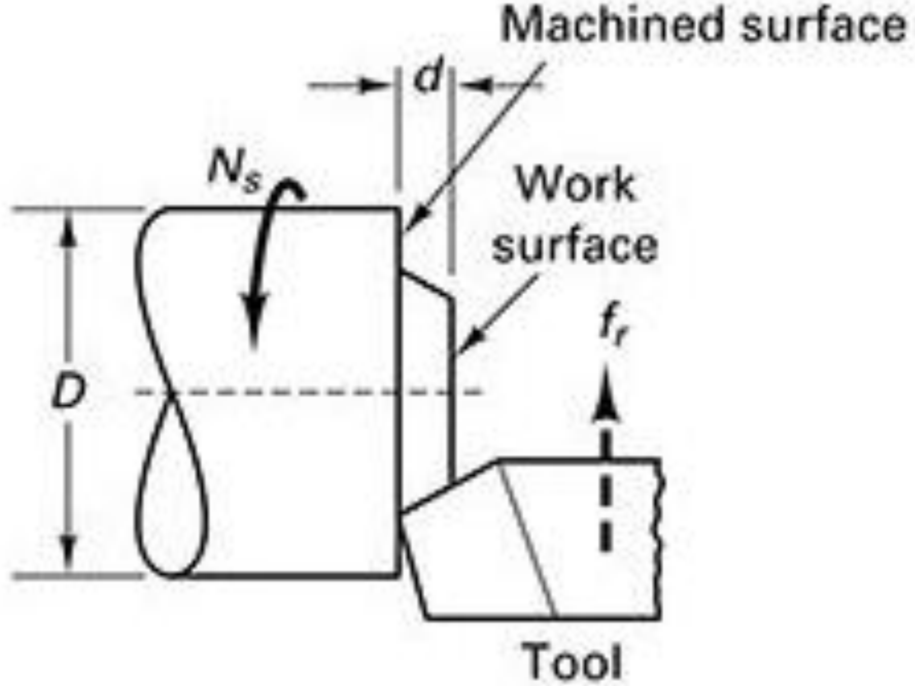
Boring Basics



Boring

Enlarging hole of diameter D_1 to diameter D_2. Boring can be done with multiple cutting tools. Feed in inches per revolution, f_r

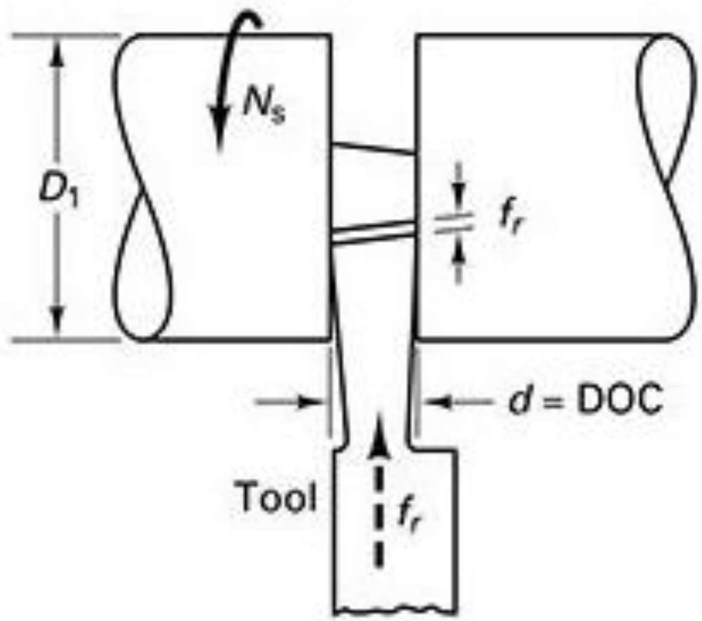
Facing Basics



Facing

Tool feeds to center of workpiece so $L = D/2$. The cutting speed is decreasing as the tool approaches the center of the workpiece.

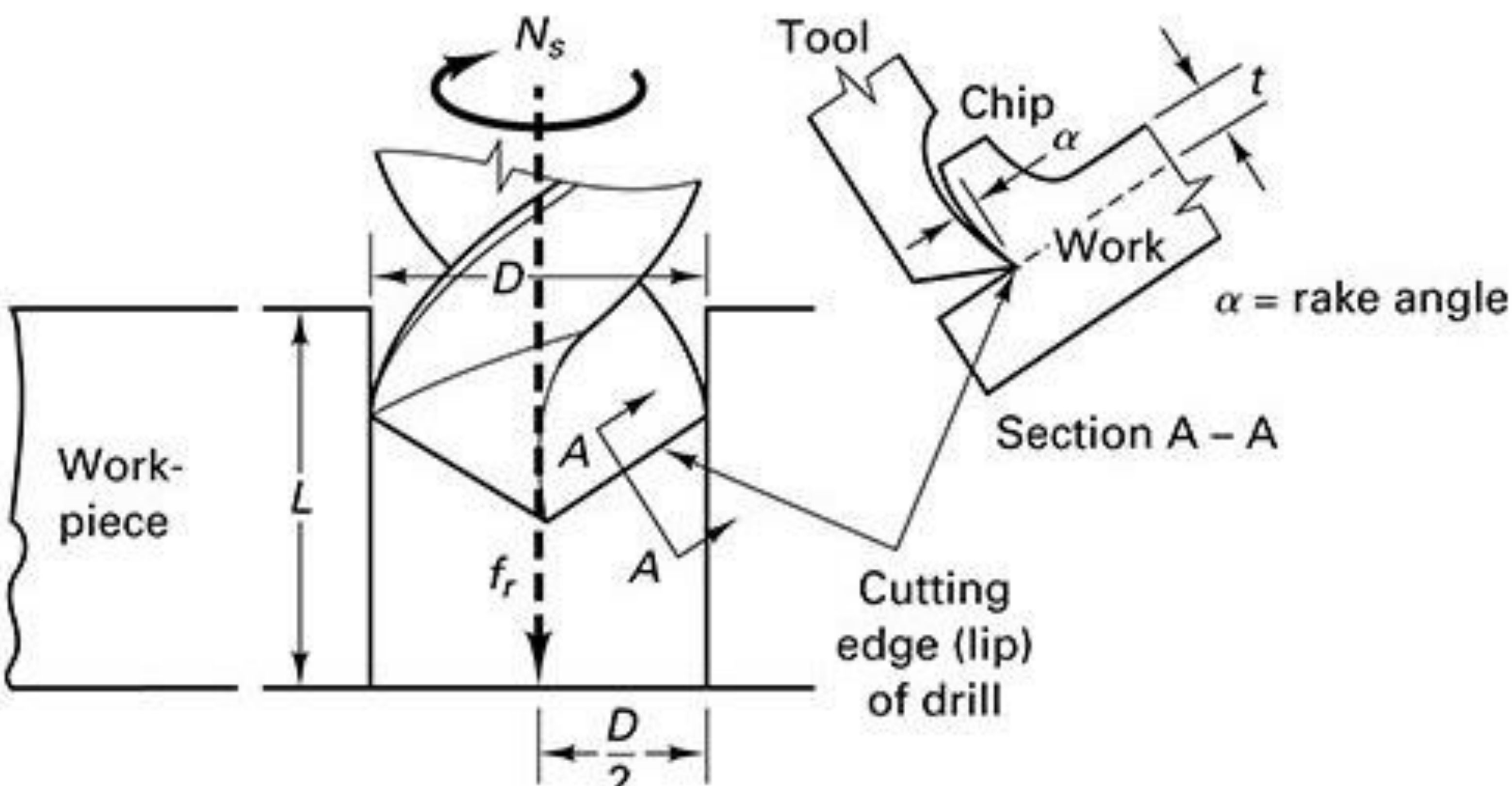
Grooving, Parting, or Cut-off



Grooving, parting, or cutoff

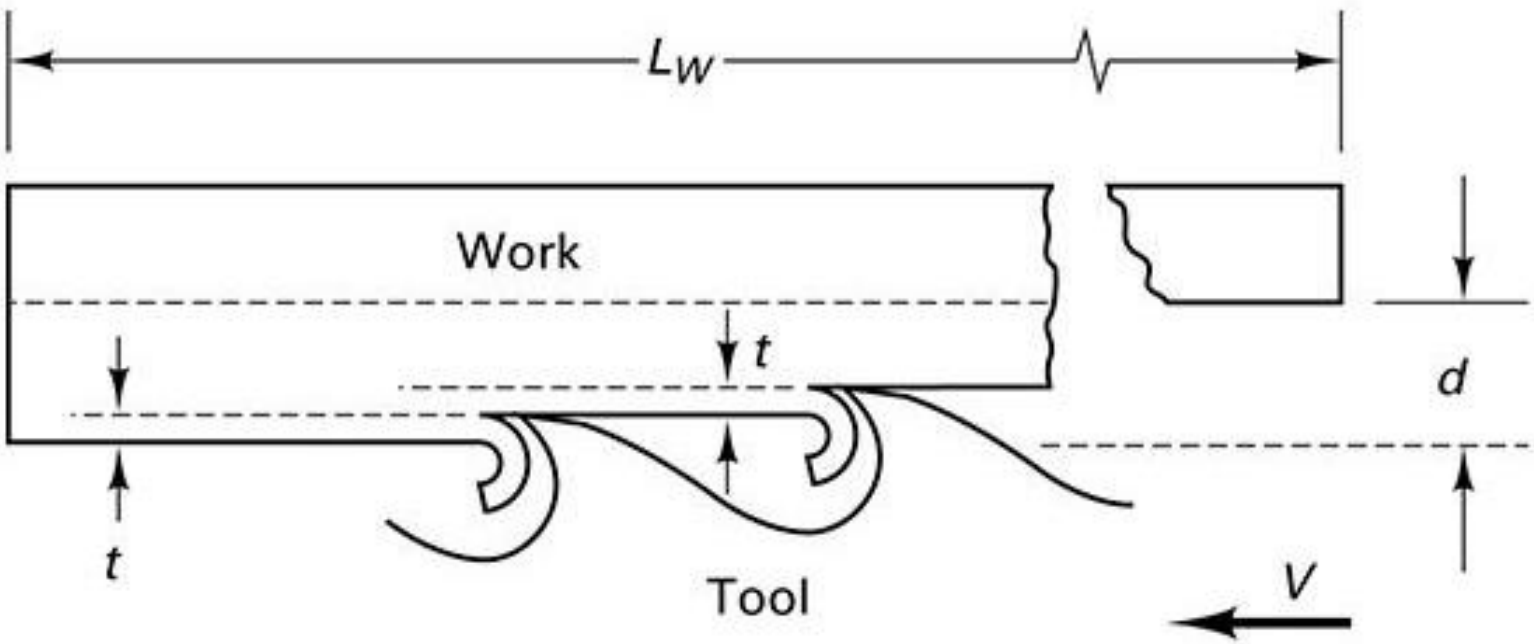
Tool feed perpendicular to the axis of rotation. The width of the tool produces the depth of cut (DOC).

Drilling Basics

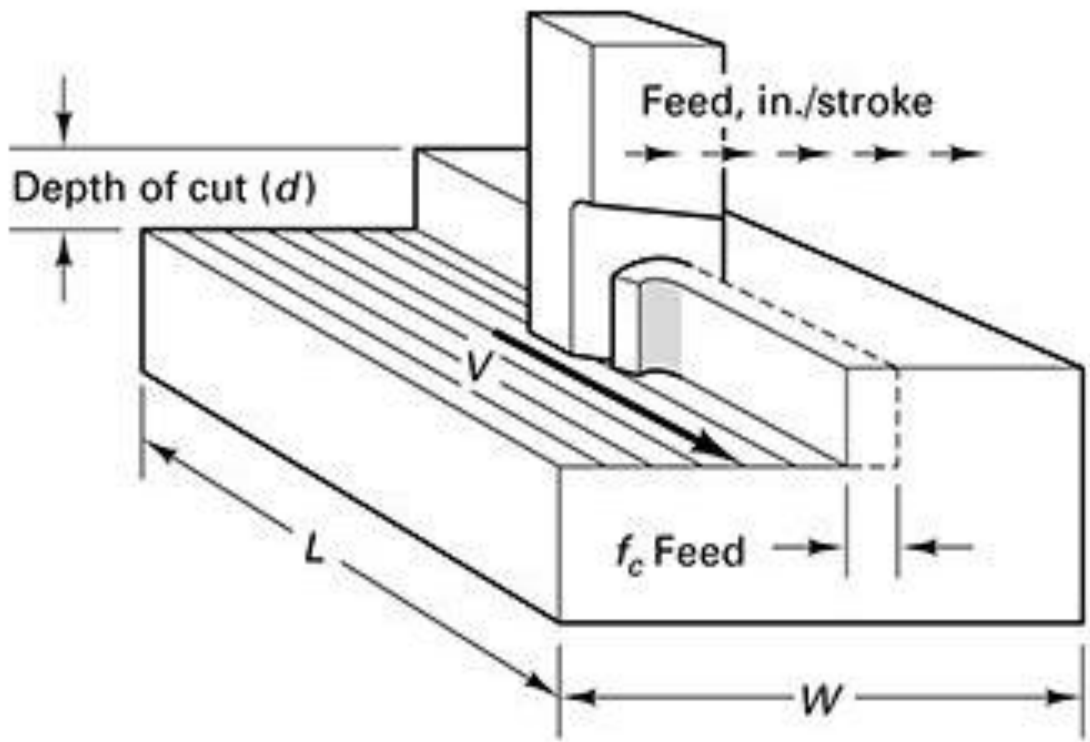


Drilling multiple-edge tool

Broaching Basics

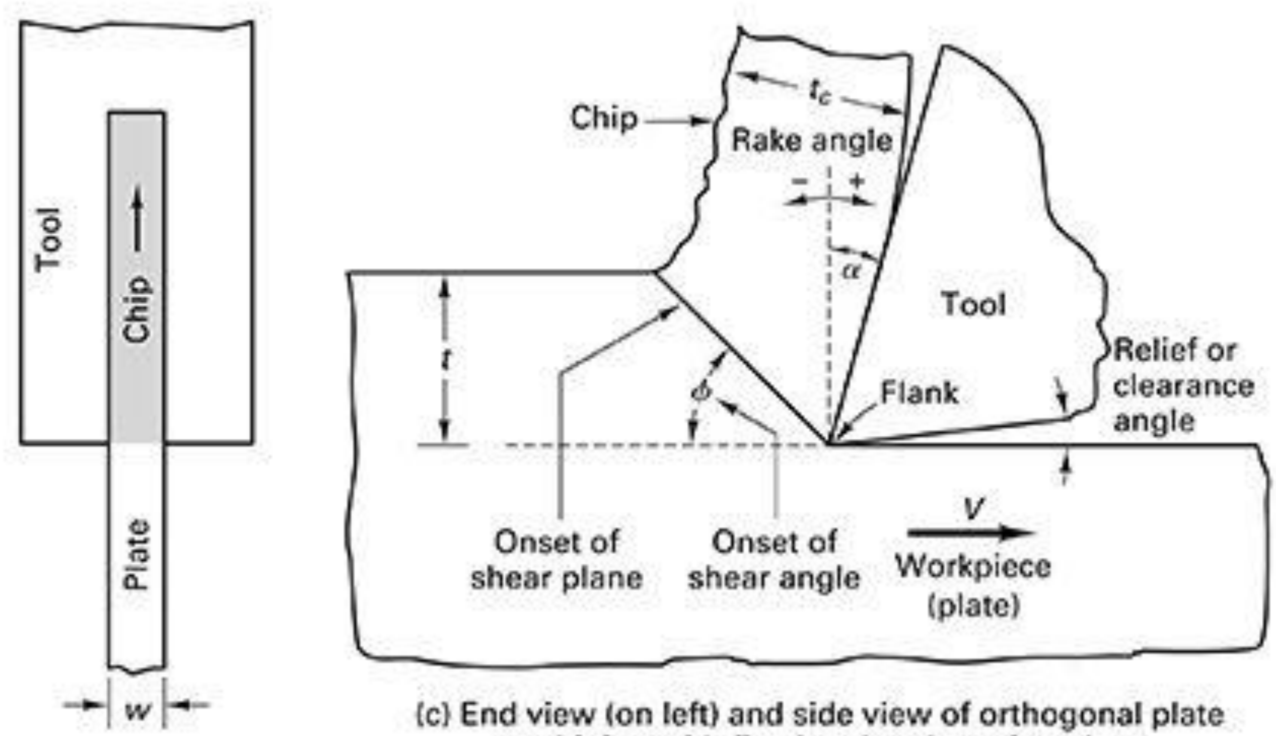


Shaping/Planing Basics



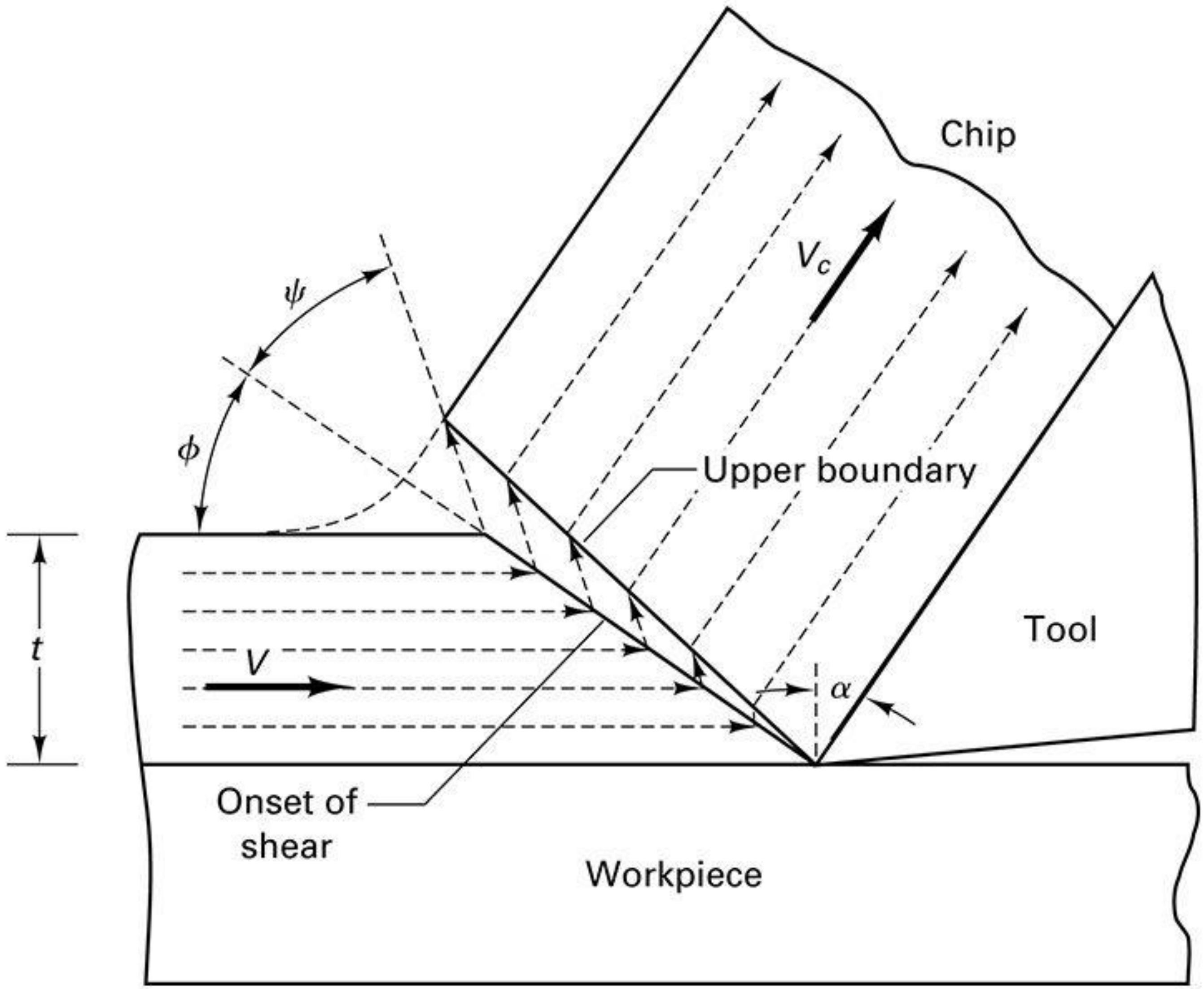
(a)

Understanding Chip Formation

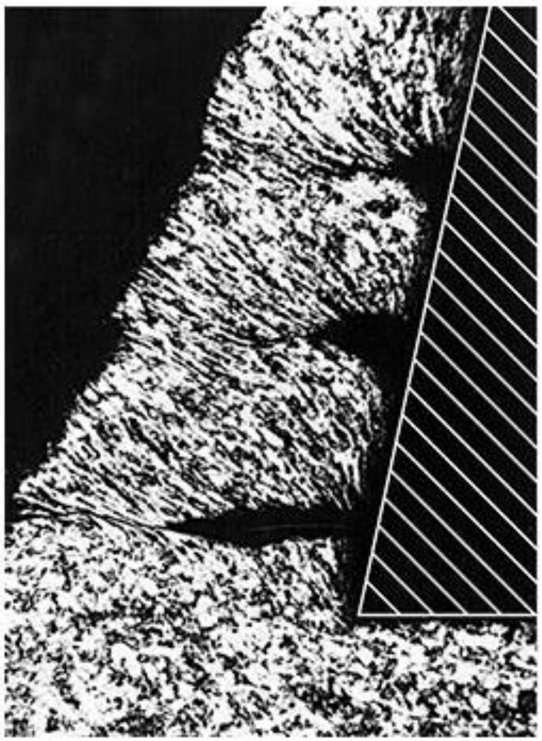


(c) End view (on left) and side view of orthogonal plate machining with fixed tool and moving plate.

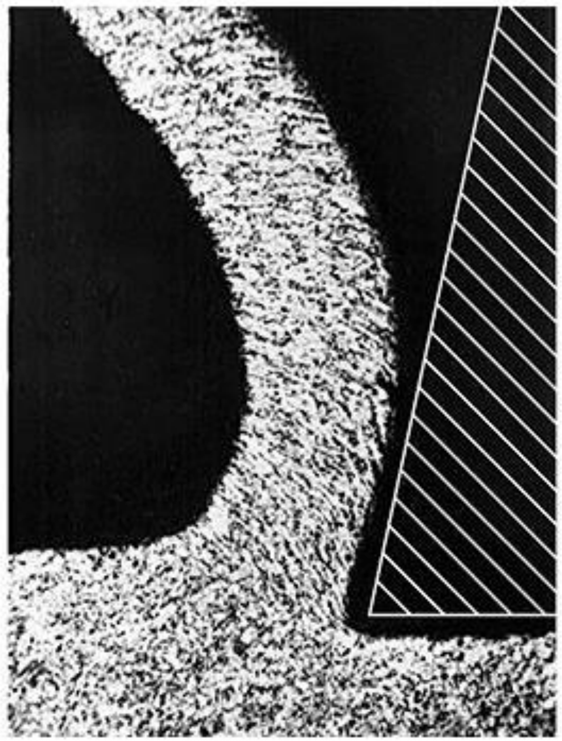
Removing a Chip



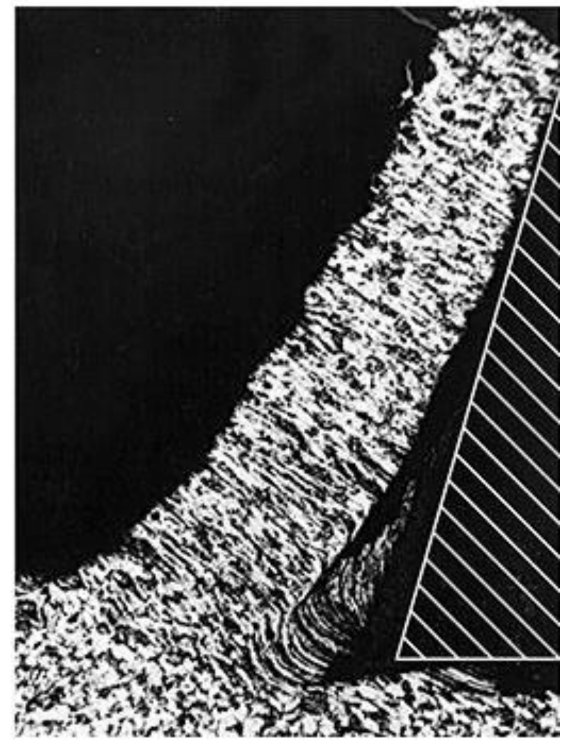
Effect of Workpiece Material Properties



Discontinuous



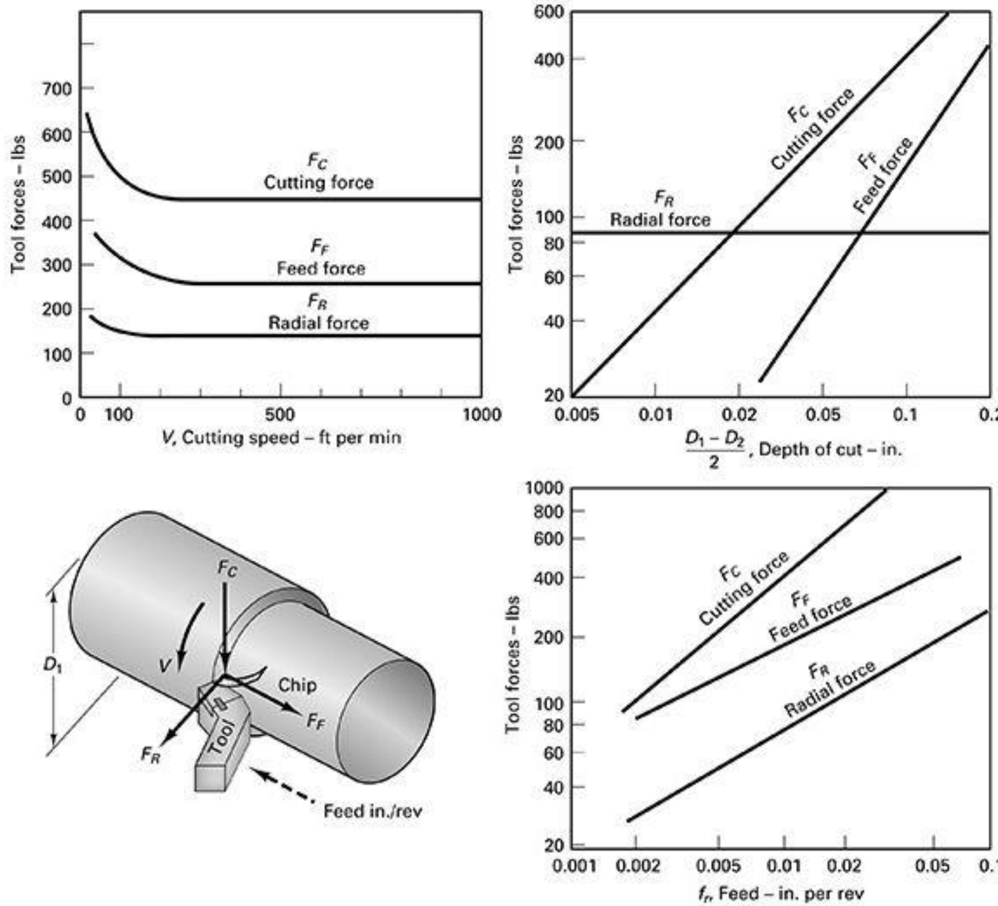
Continuous



Continuous
with built-up edge

[Watch Video Here]

Energy and Power in Machining



3 Force

F_C = Cutting force (vertical)

F_R = Radial force (thrust)

F_F = Feed force

Power

- $Power = F_c V$, ft-lbs/min

  V, ft/min

  F_c, lbs
- $HP = F_c V / 33000$, horsepower
- Specific horsepower $HP_s = HP / MRR$, ft-lbs/in^3

TOOL FAILURE MODES

Watch Video Here