Fundamentals of Chip-Type Machining Processes

Machining

Removing unwanted material in the form of chips:

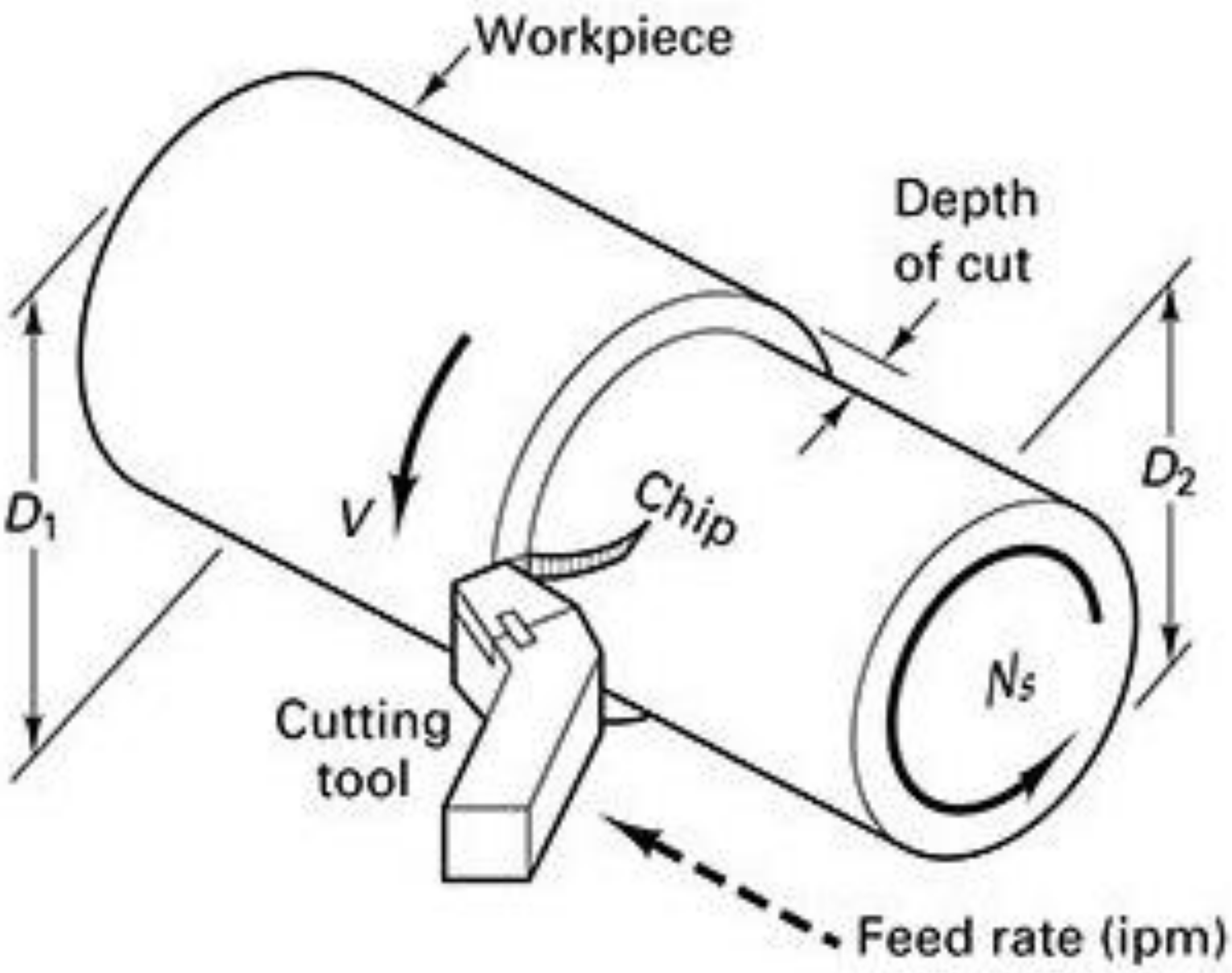
- Drilling
- Sawing
- Milling
- Turning
- Filing

Machining Process

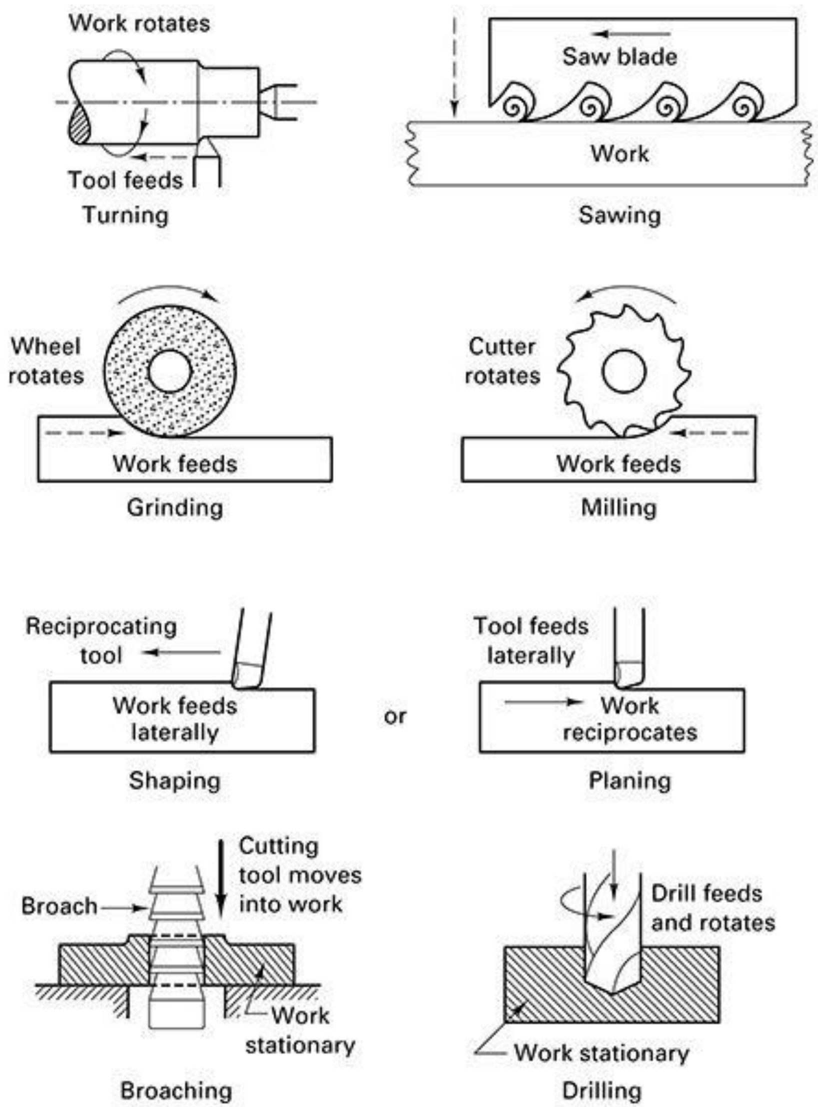
Affected by:

- 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



Seven Basic Machining Processes



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 **primary cutting motion**

- $V = \pi D_1 N_s / 12$ ft/min
- D_1 = original diameter, inches
- N_s = RPM
- RPM $\approx 3.8 V / D_1$

Depth of Cut

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

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

Feed Rate

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

Material Removal Rate

Material Removal Rate (MRR) = (volume removed)/(cutting time) – (in^3/min)

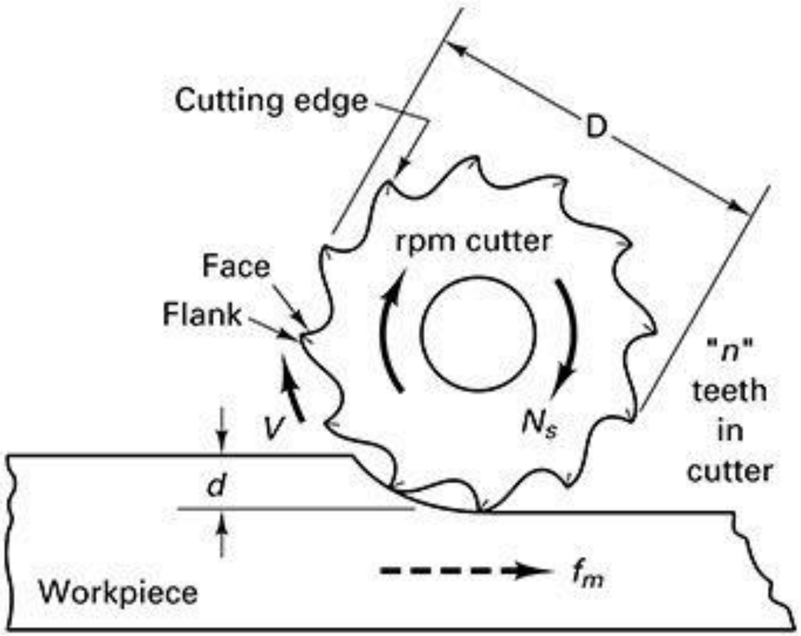
- MRR ≈ $12Vf_rd$, in^3/min
- ≈ $\pi D_1 N_s f_r d$, in^3/min
- d = depth of cut

Milling Material Removal Rate

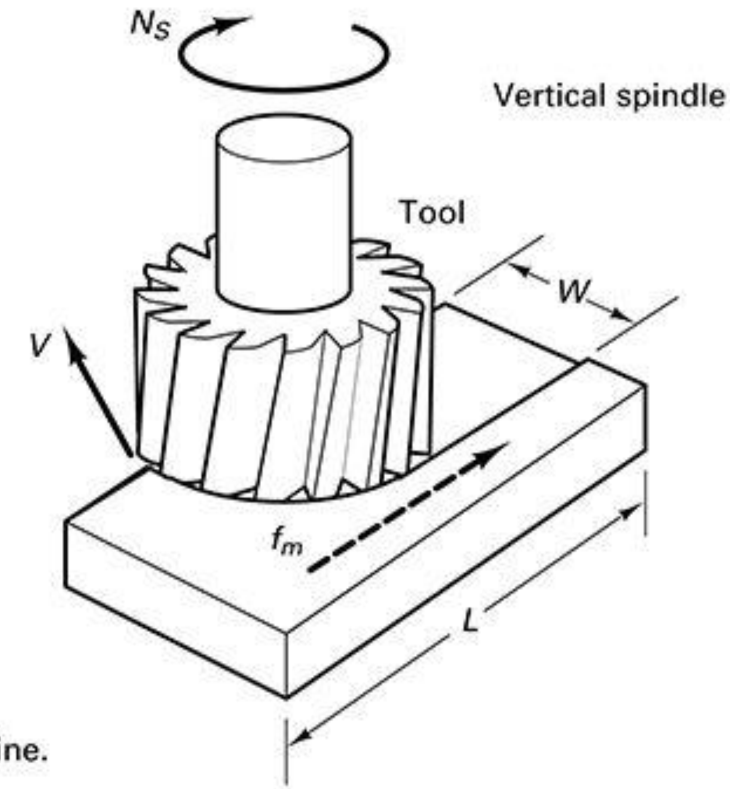
Multiple-tooth cutter is used

- Table feed: $f_m = f_t n N_s$
- f_t = feed per tooth
- n = number of teeth
- N_s = RPM
- $MRR = Wd\, f_m$

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

Shop Formulas for Varioius Materials

Shop Formulas for Turning, Milling, Drilling, and Broaching (English Units)

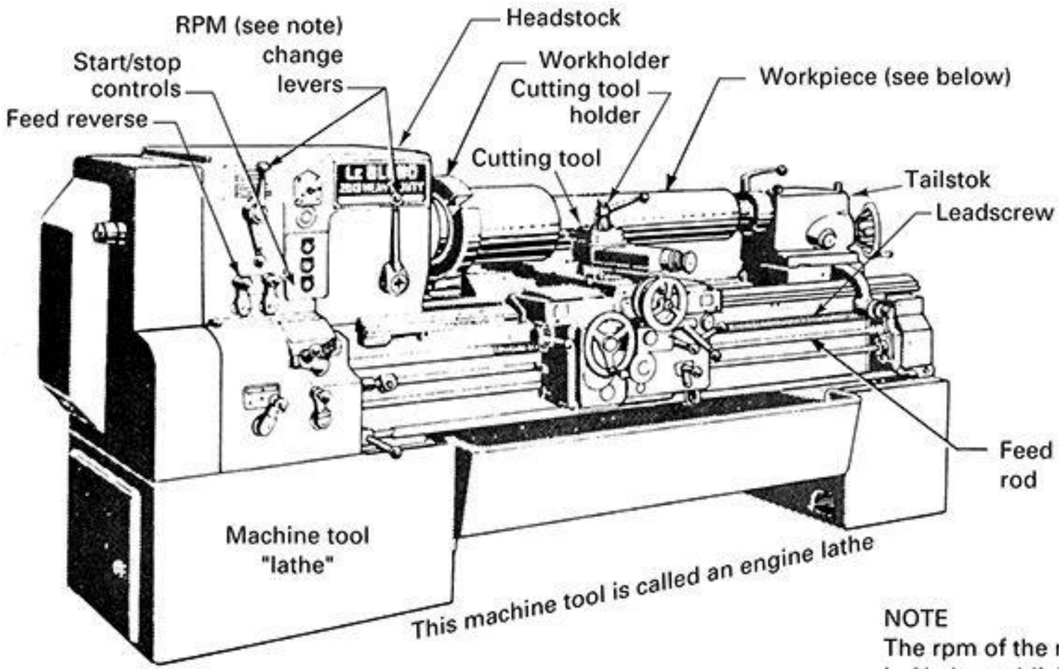
Parameter	Turning	Milling	Drilling	Broaching
Cutting speed, fpm	$V = 0.262 \times D_l \times$ rpm	$V = 0.262 \times D_m \times$ rpm	$V = 0.262 \times D_d \times$ rpm	V
Revolutions per minute, N_s	rpm $= 3.82 \times V_c/D_l$	rpm $= 3.82 \times V_c/D_m$	rpm $= 3.82 \times V_c/D_d$	—
Feed rate, in./min	$f_m = f_r \times$ 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 $\times$ HP$_s$	hp = MRR $\times$ HP$_s$	hp = MRR $\times$ HP$_s$	—
Horsepower required at motor	hp$_m$ = MRR $\times$ HP$_s/E$	hp$_m$ = MRR $\times$ HP$_s/E$	hp$_m$ = MRR $\times$ HP$_s/E$	hp$_m$ = MRR $\times$ HP$_s/E$
Torque at spindle	$t_s = 63{,}030$ hp/rpm	$t_s = 63{,}030$ hp/rpm	$t_s = 63{,}030$ hp/rpm	—

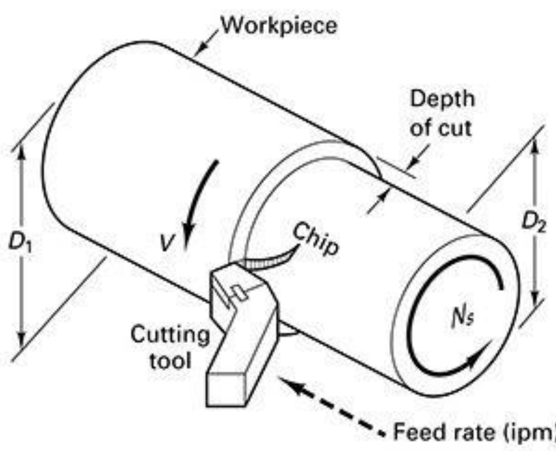
Symbols

D_l = 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



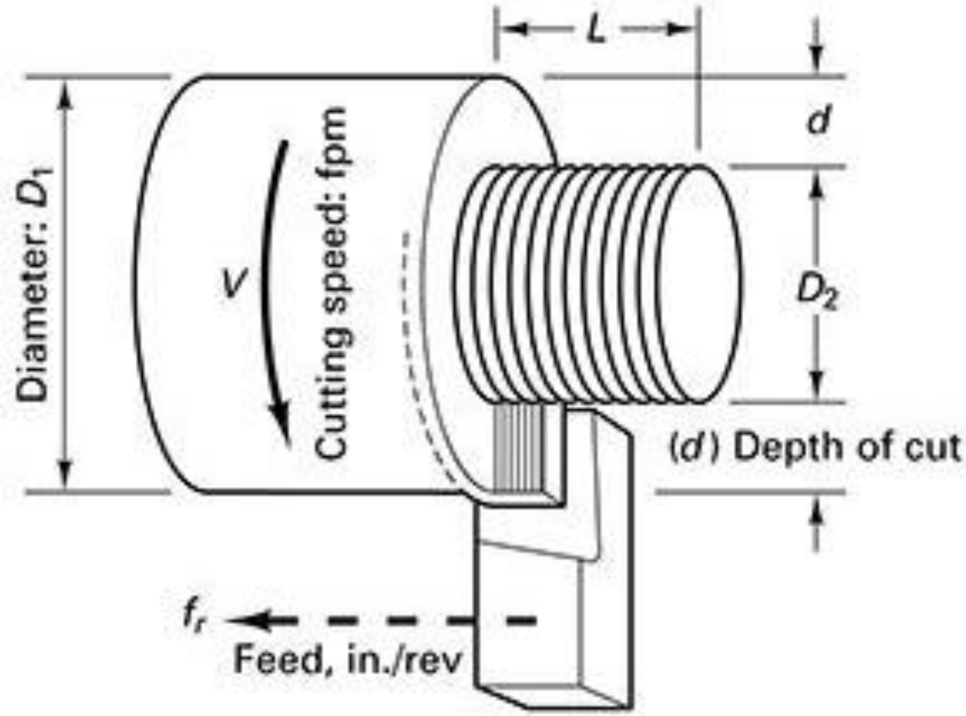


NOTE
The rpm of the rotating workpiece is N_s. It establishes the cutting speed V, at the tool, according to $N_s = 12V/\pi D$.

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



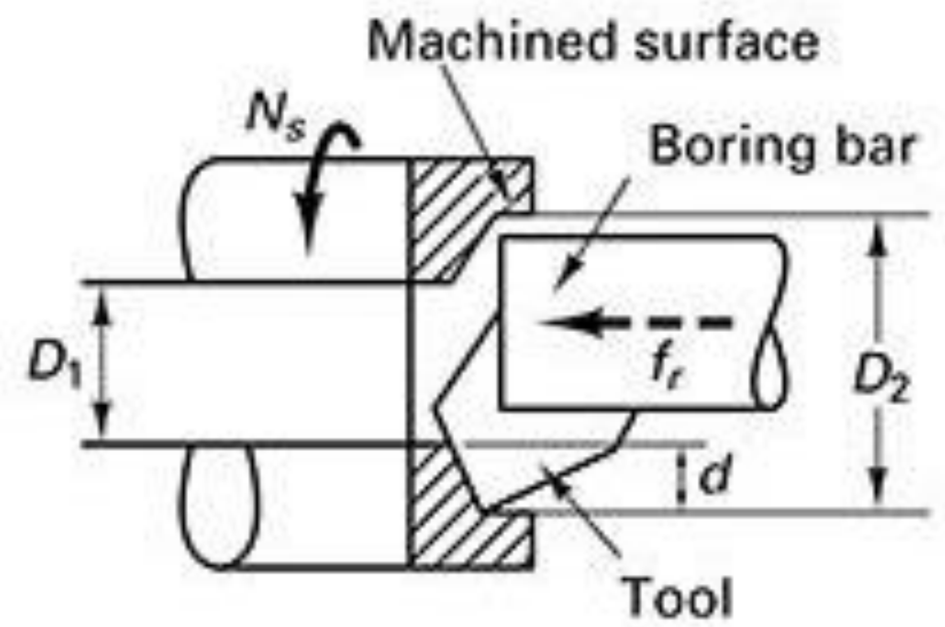
Turning

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

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

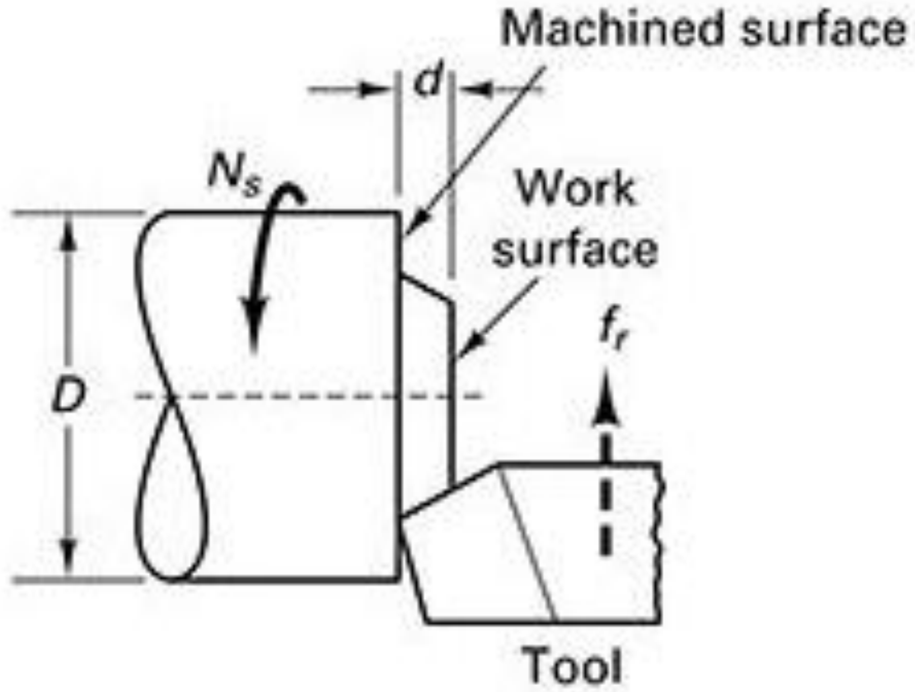
Boring Basics



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

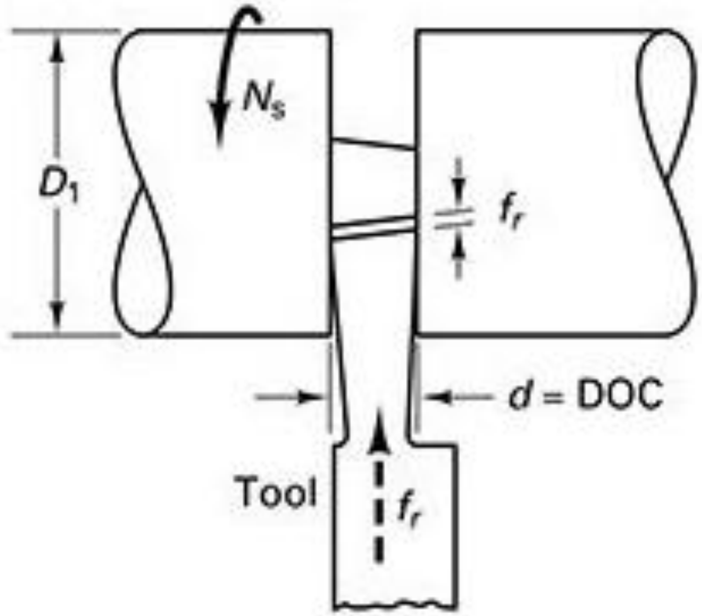
Facing Basics



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.

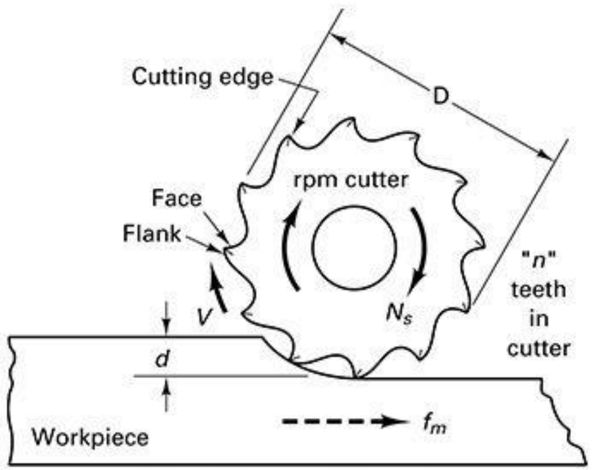
Grooving, Parting or Cut-off



Grooving, parting, or cutoff

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

Slab/Face Milling Basics



Slab milling – multiple tooth

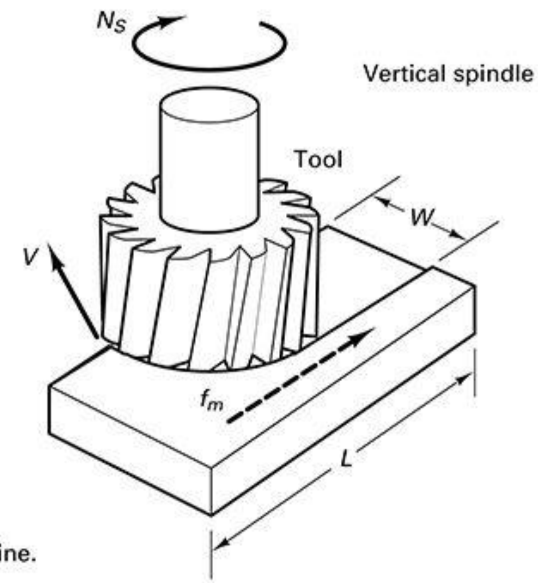
Slab milling is usually performed on a horizontal milling machine. Equations for T_m and MRR derived in Chapter 25.

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.



Face milling
Multiple-tooth cutting

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 $f_m = f_t nN_s$ for a cutter with n teeth.

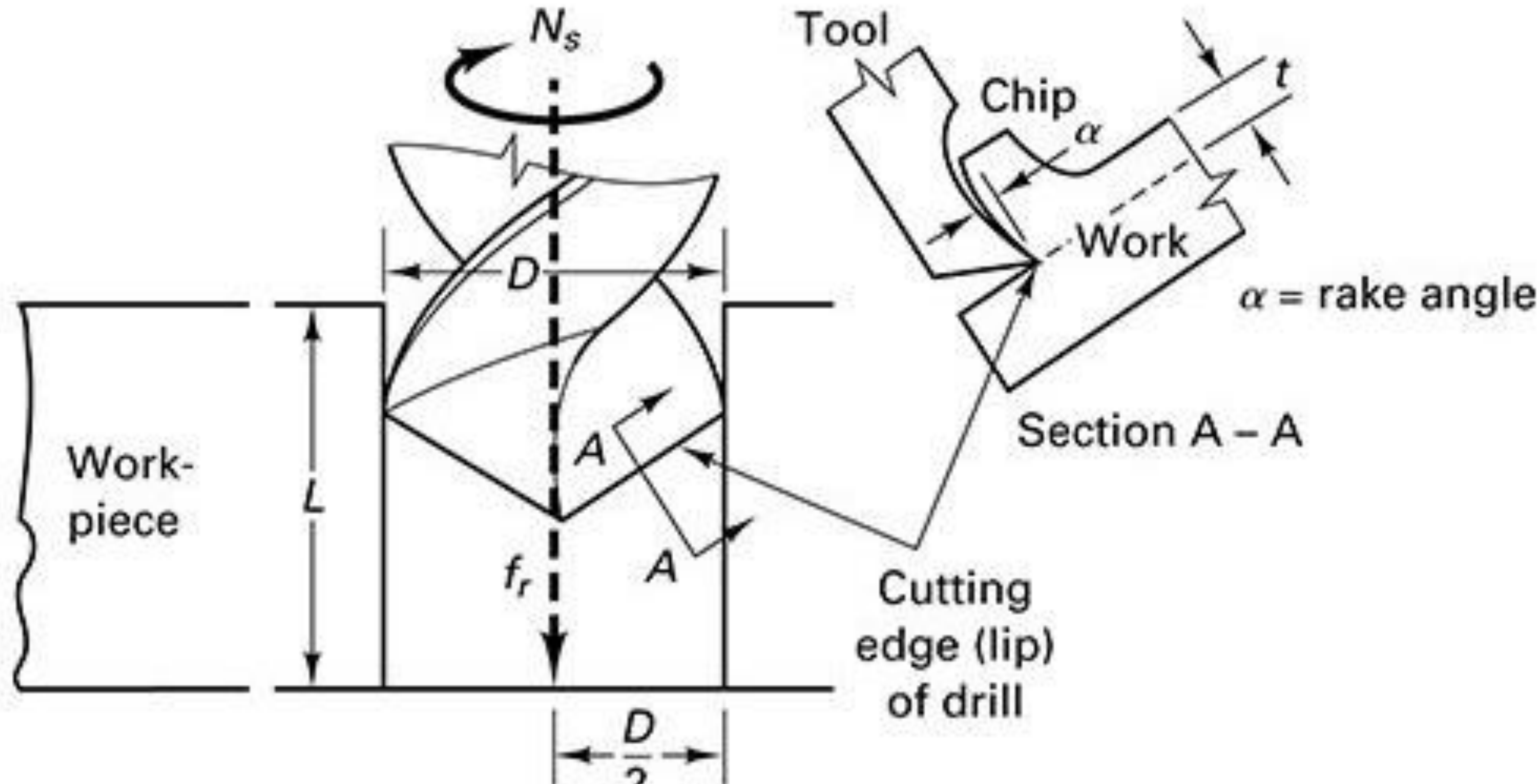
The cutting time, $T_m = (L + L_A + L_o)/f_m$

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

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

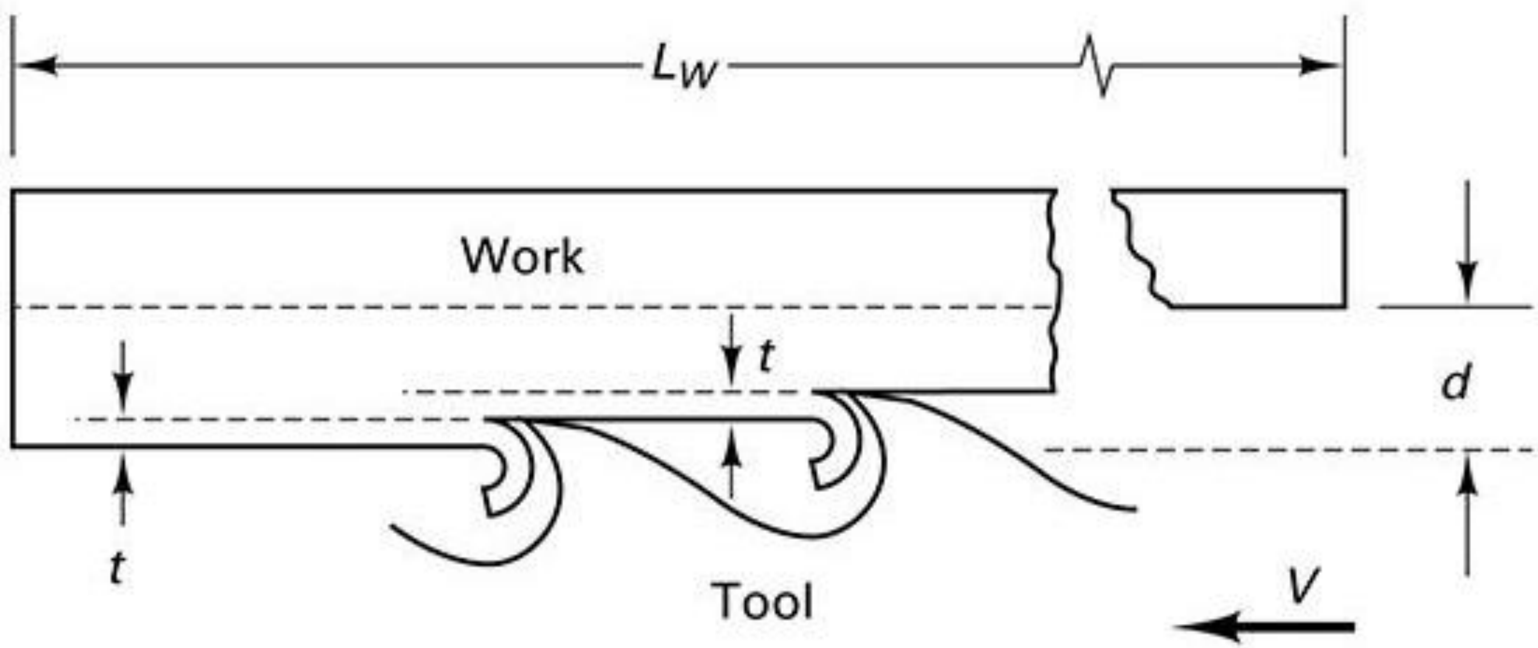
The MRR $= Wdf_m$ where d = depth of cut.

Drilling Basics

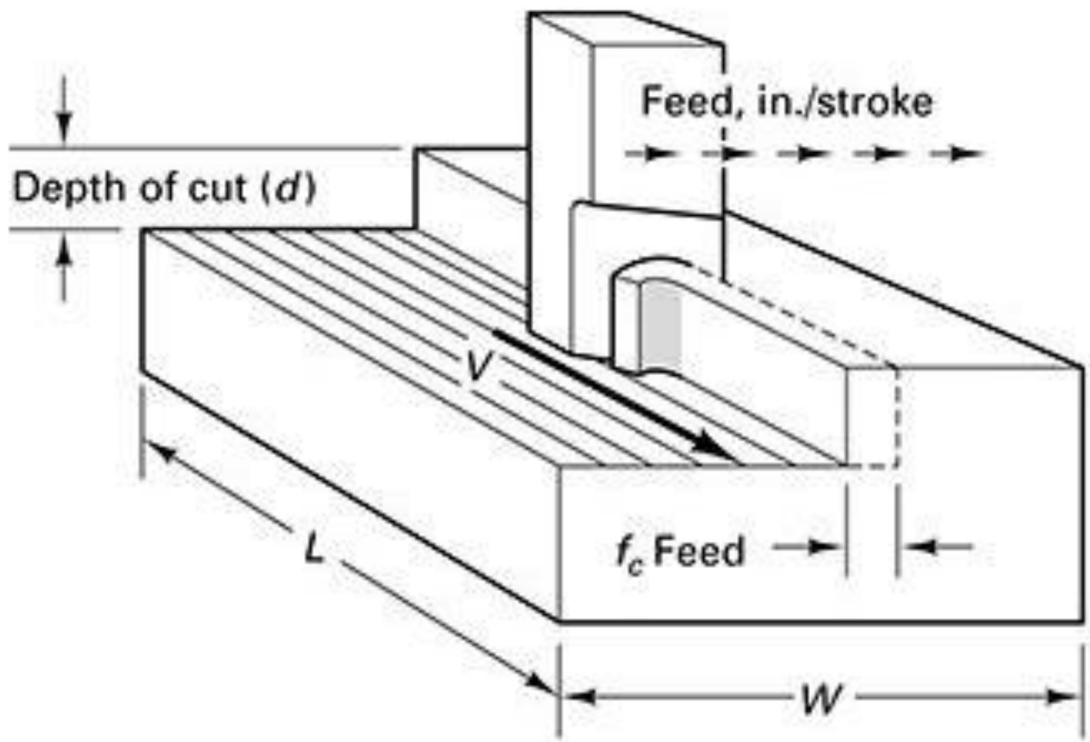


Drilling multiple-edge tool

Broaching Basics

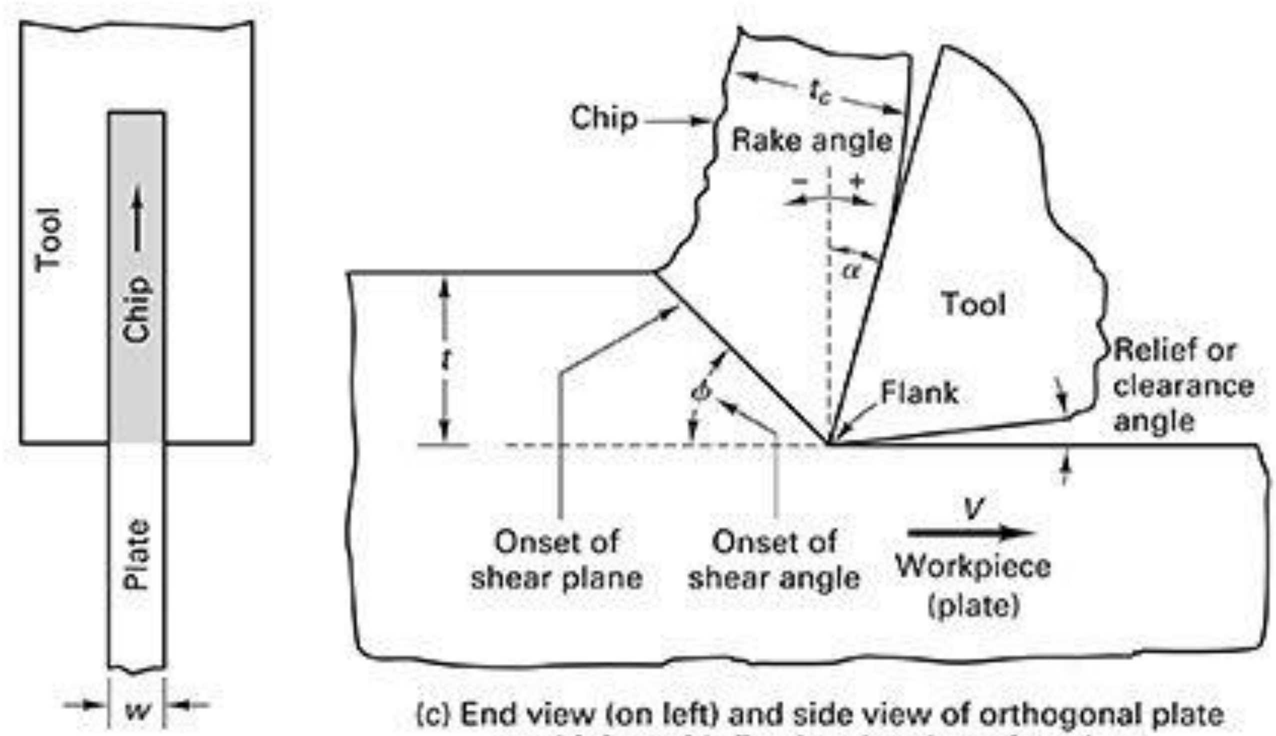


Shaping/Planing Basics



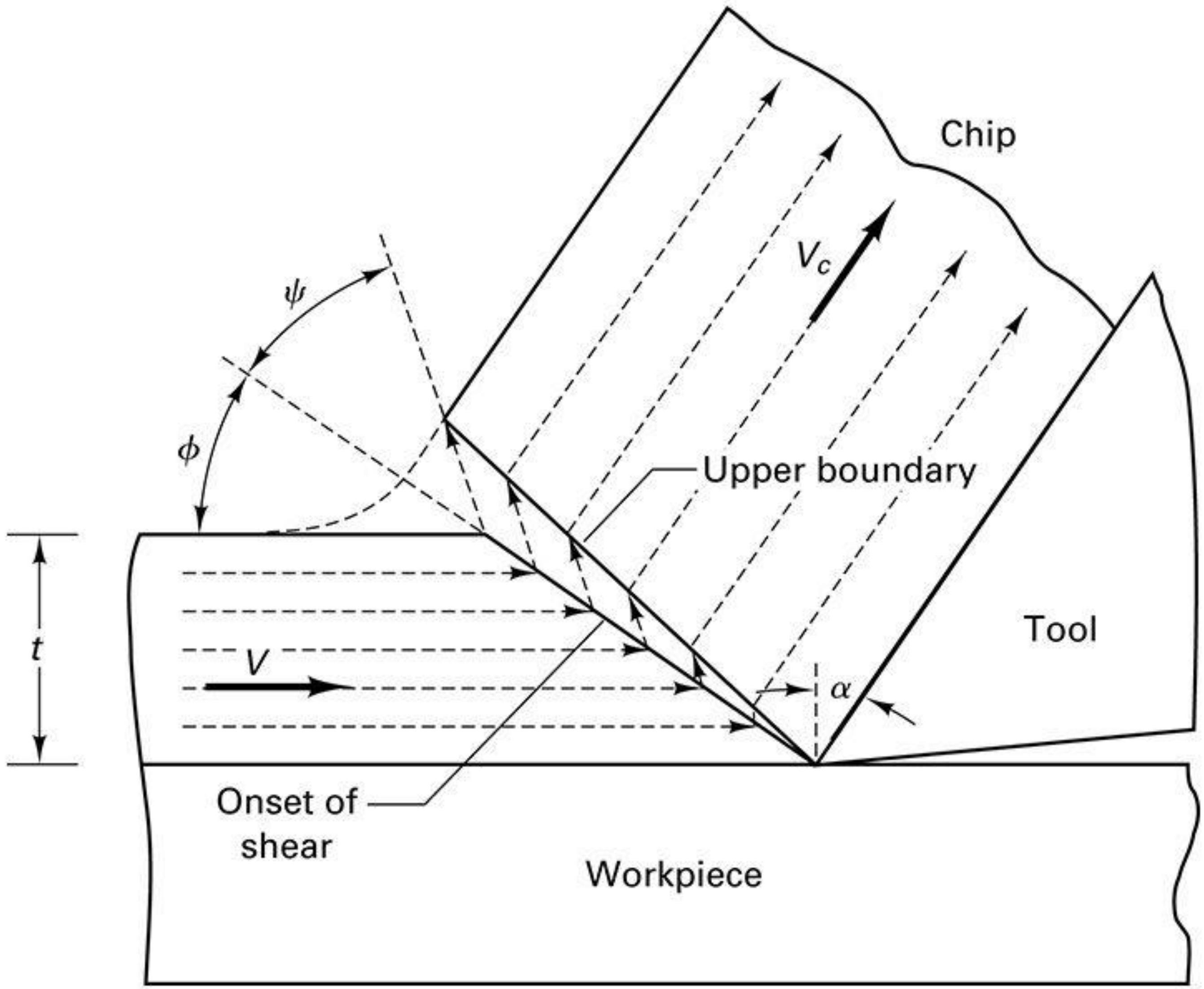
(a)

Understanding Chip Formation

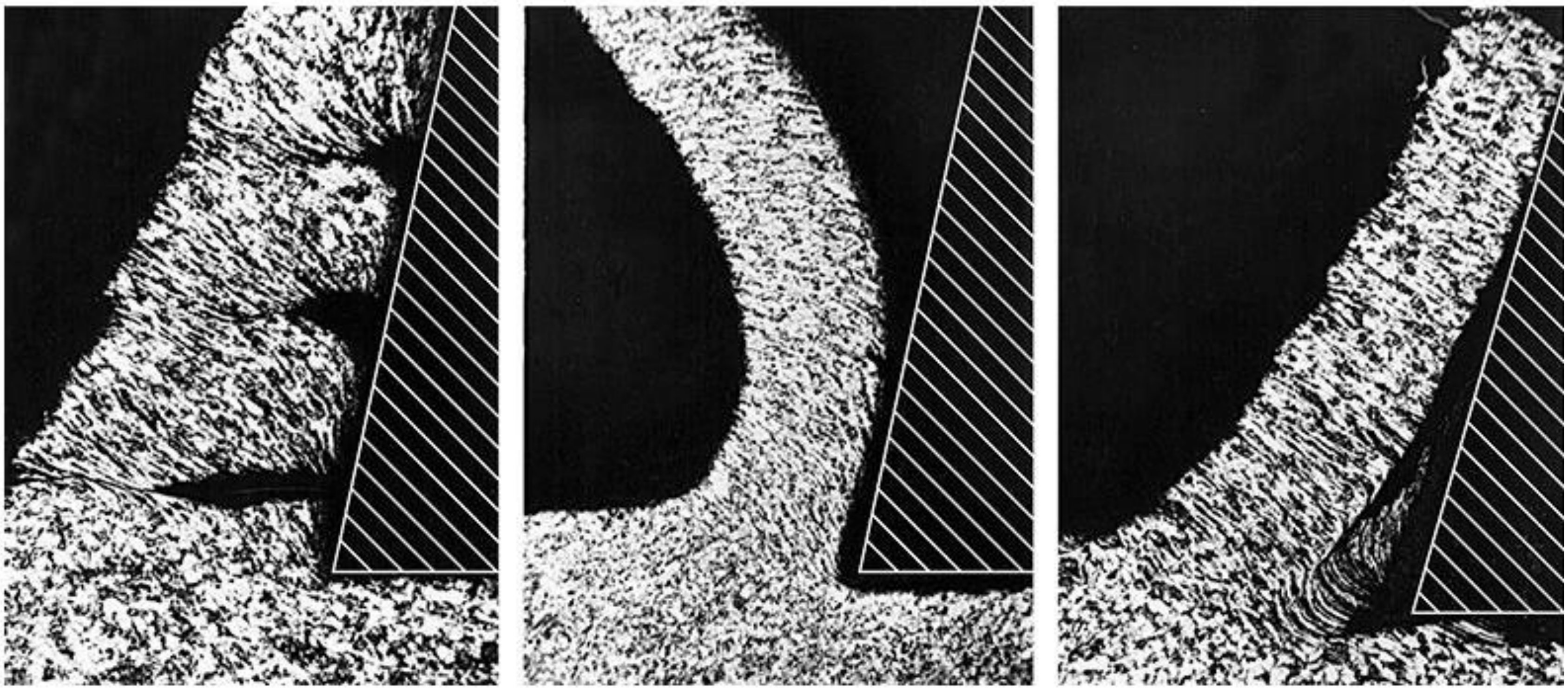


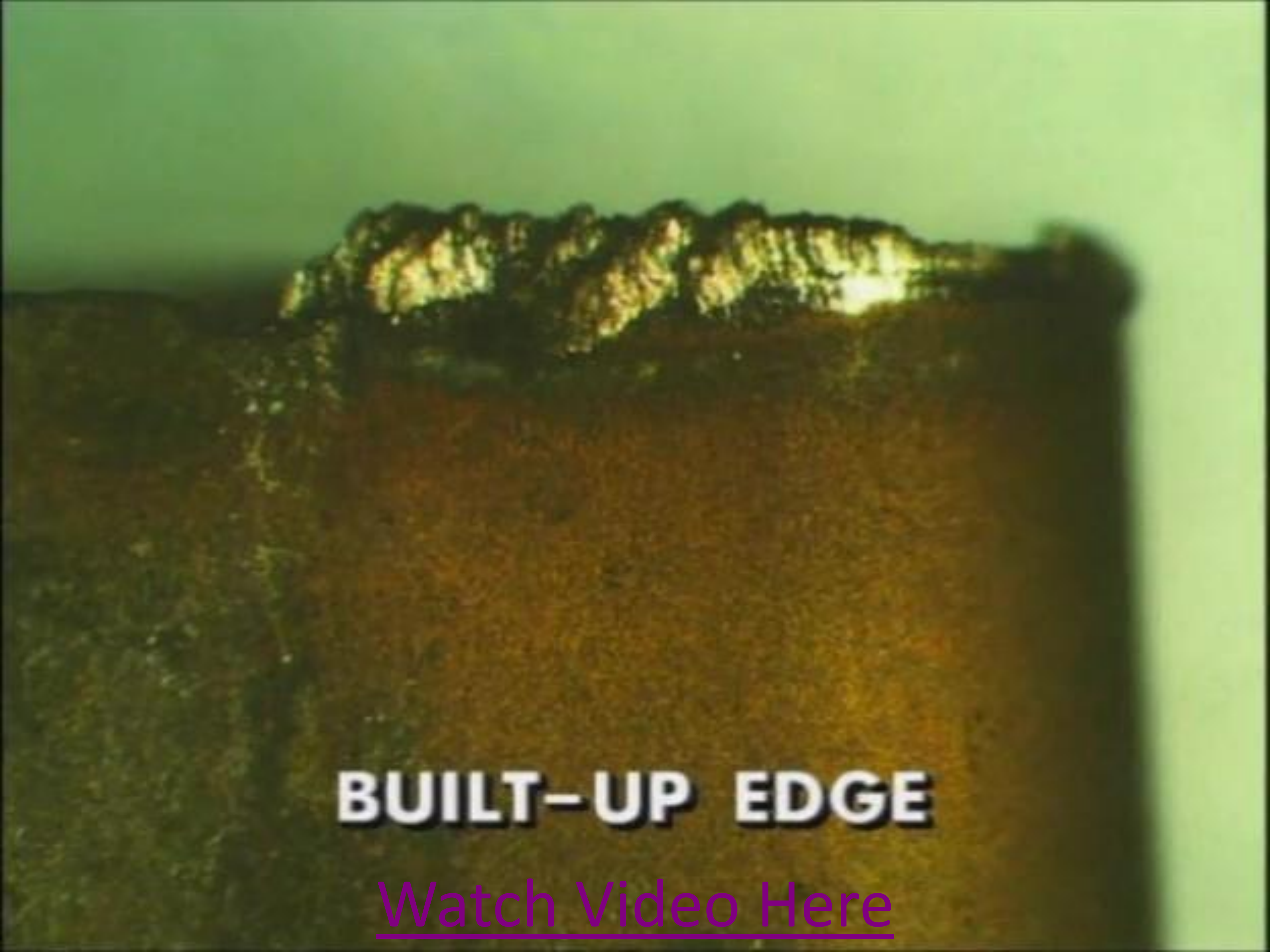
(c) End view (on left) and side view of orthogonal plate machining with fixed tool and moving plate.

Removing a Chip



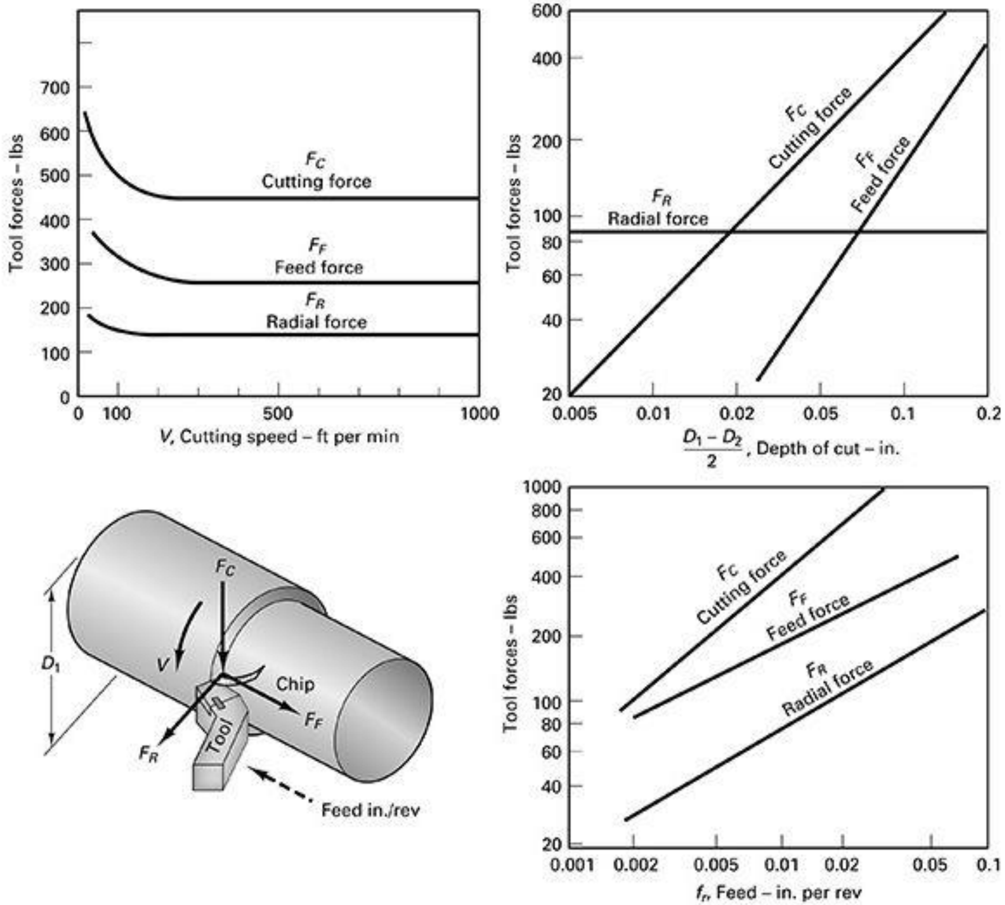
Effect of Workpiece Material Properties





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 = fpm

  F_c = lbs
- HP = $F_c V/33{,}000$
- HP_s = specific hp = HP/MRR energy/unit vol

TOOL FAILURE MODES

Watch Video Here