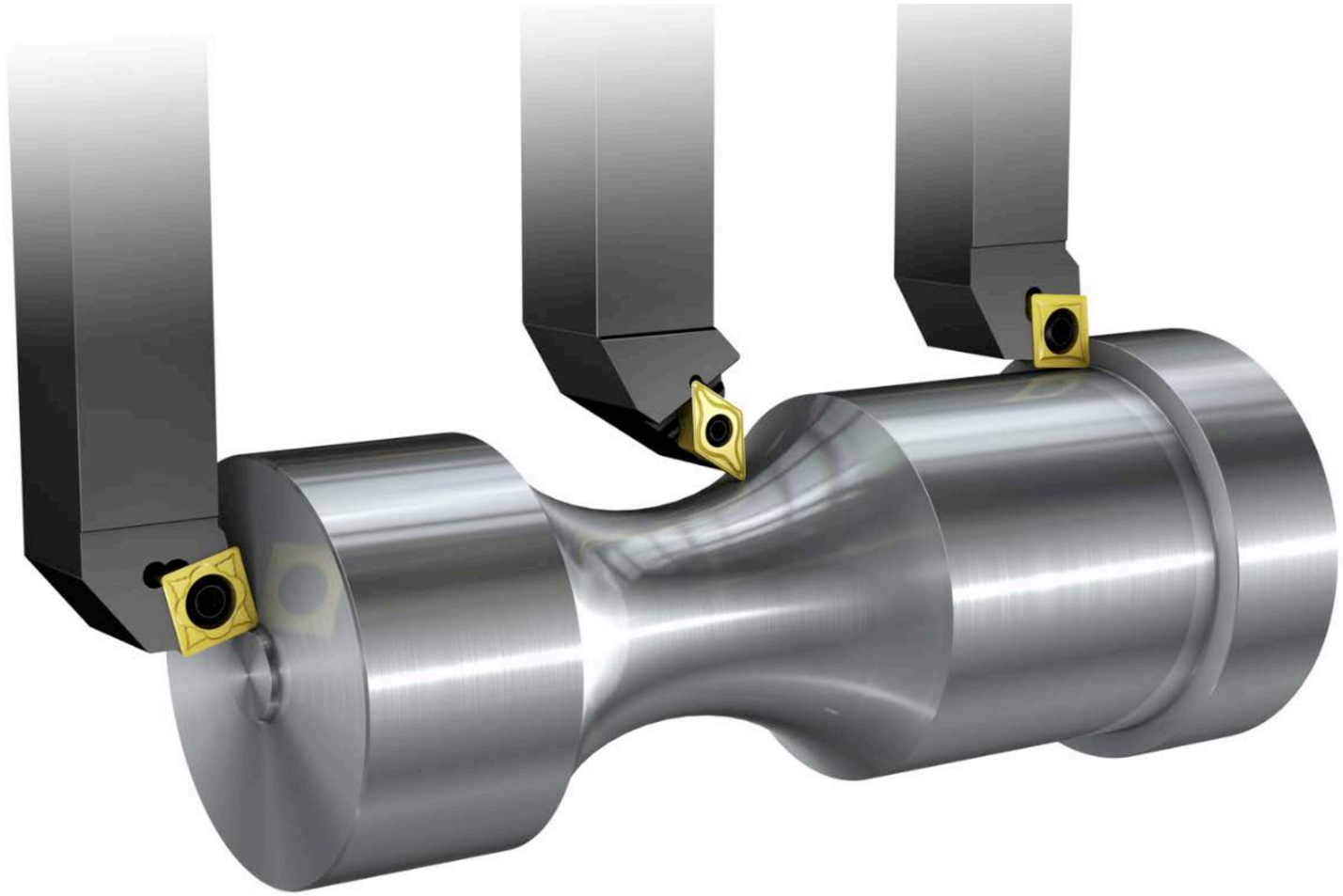
Machining #2

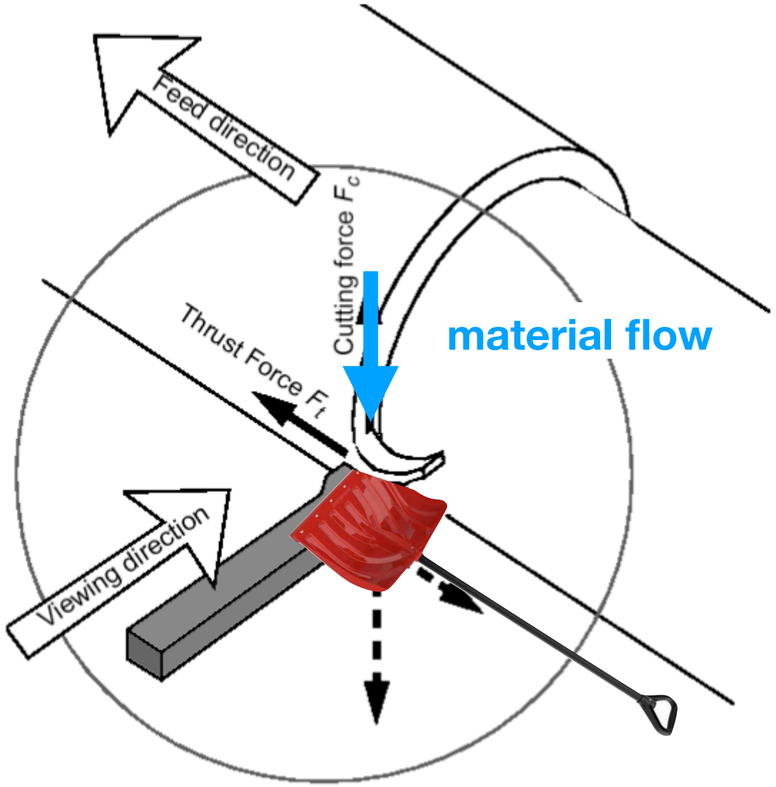
Forces and Power Demos

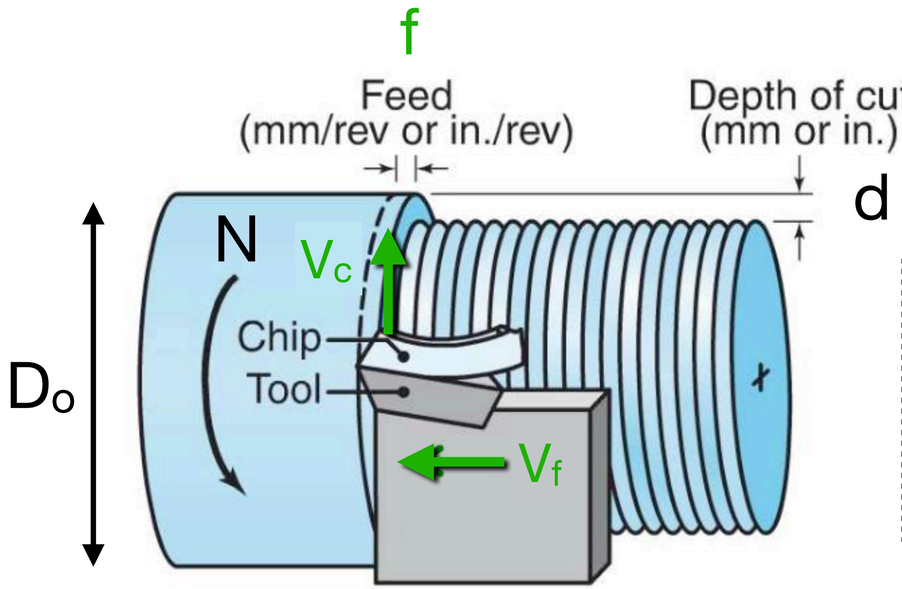


Machining #2

Forces and Power Demos

Lathe Parameters





d: depth of cut [in]

f or t_0: feed [in/rev]

N: spindle speed [rev/min]

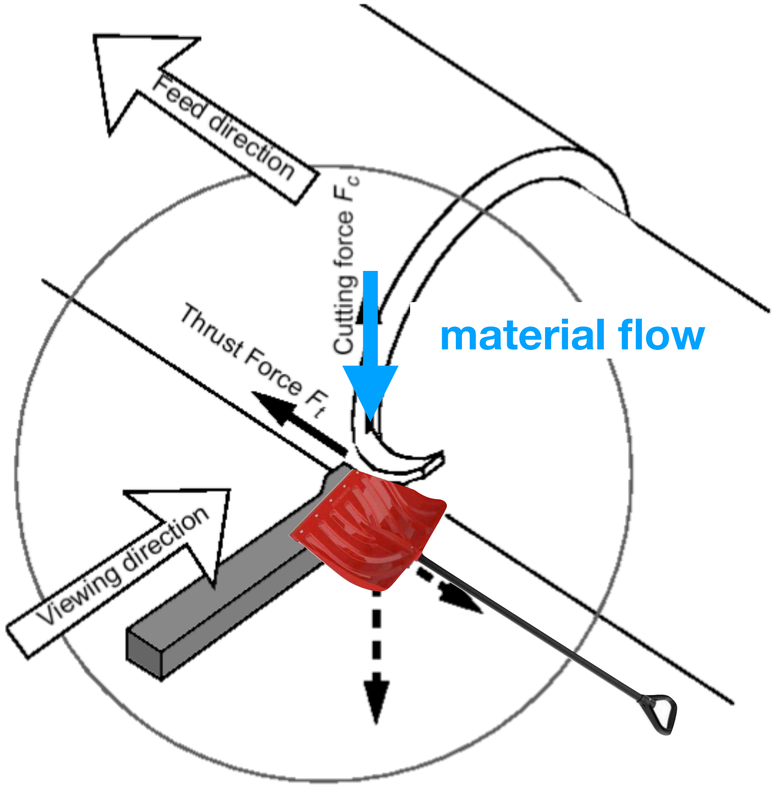
Do: original diameter [in]

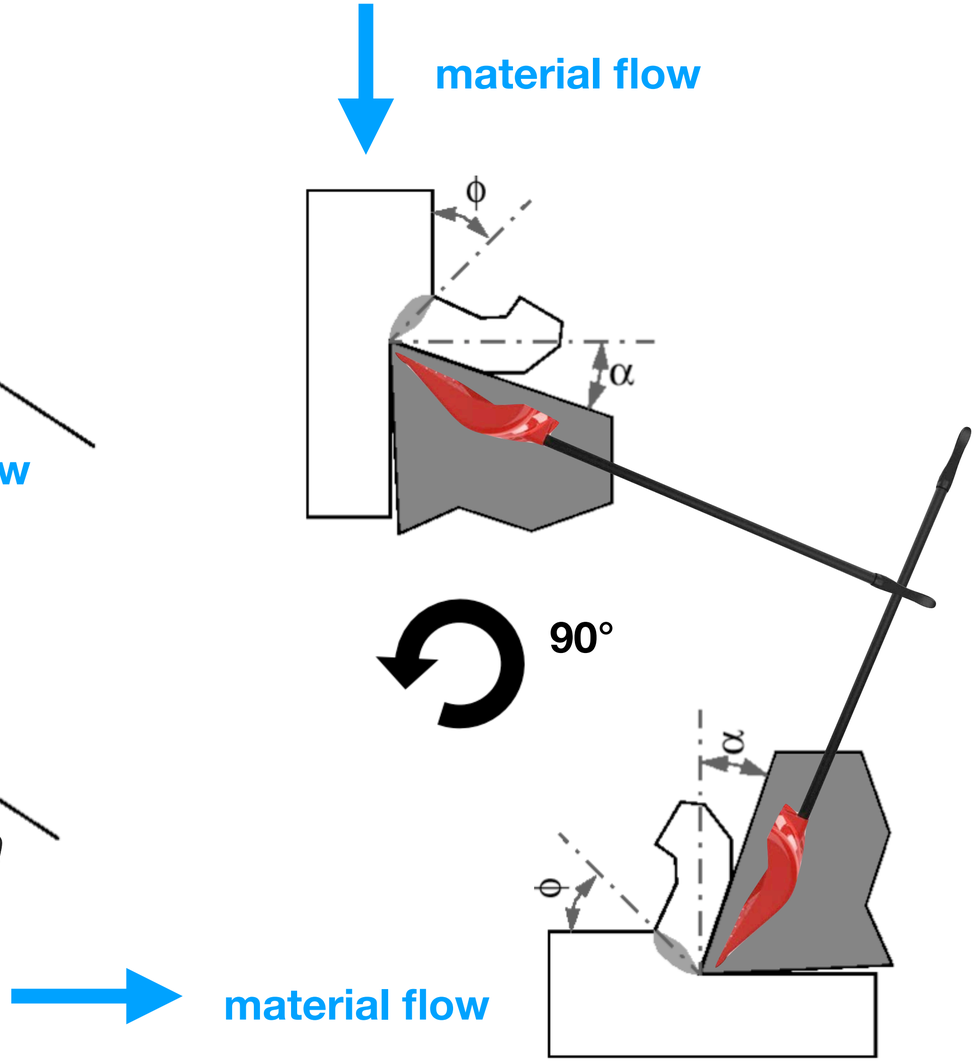
V_f: feed rate = f*N [in/min]

V_c: cutting velocity = π*D*N [in/min]

~~Cutting Theory~~ on a Lathe

Shovel Theory

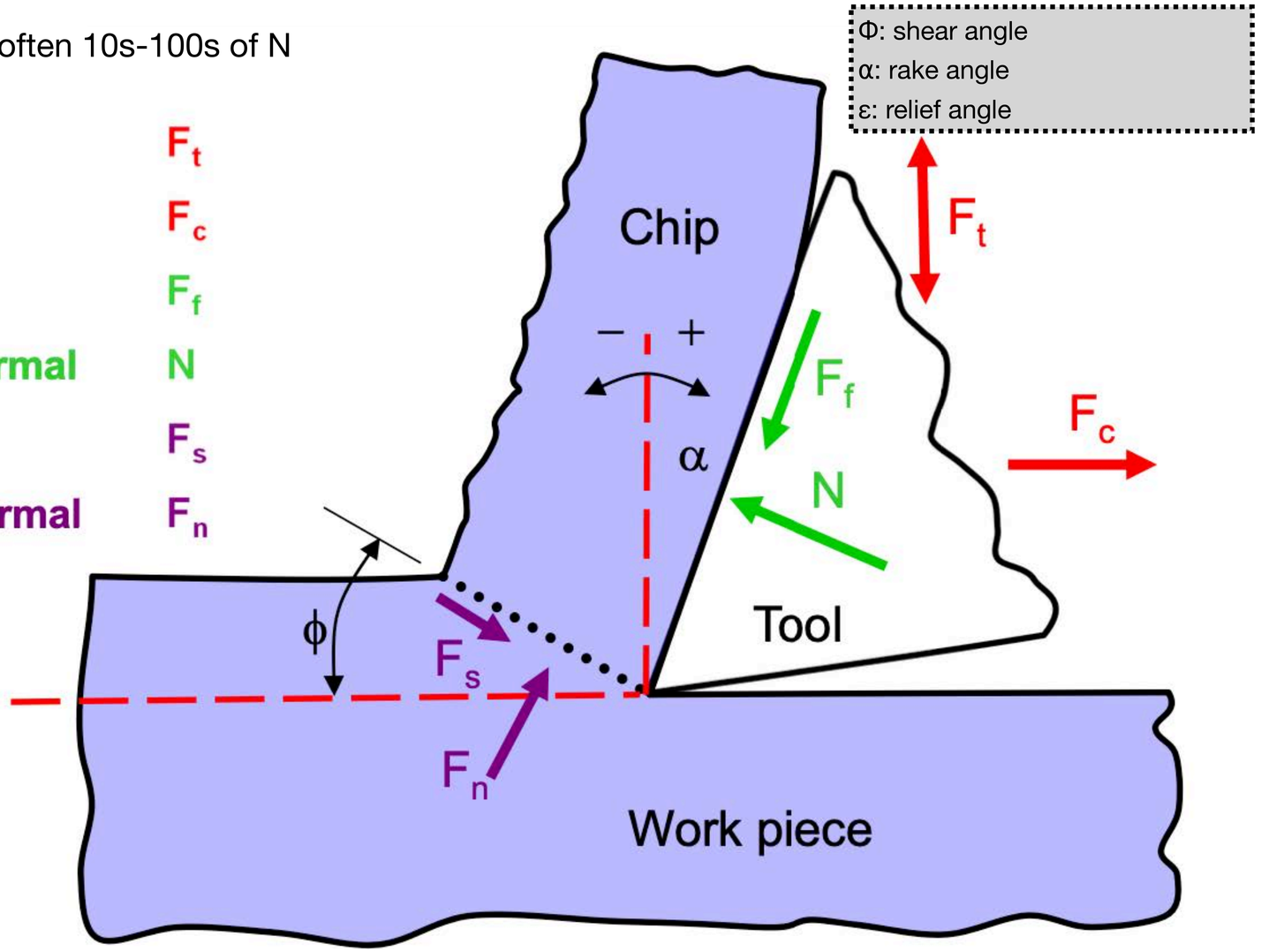




Forces in Cutting

cutting forces: often 10s-100s of N

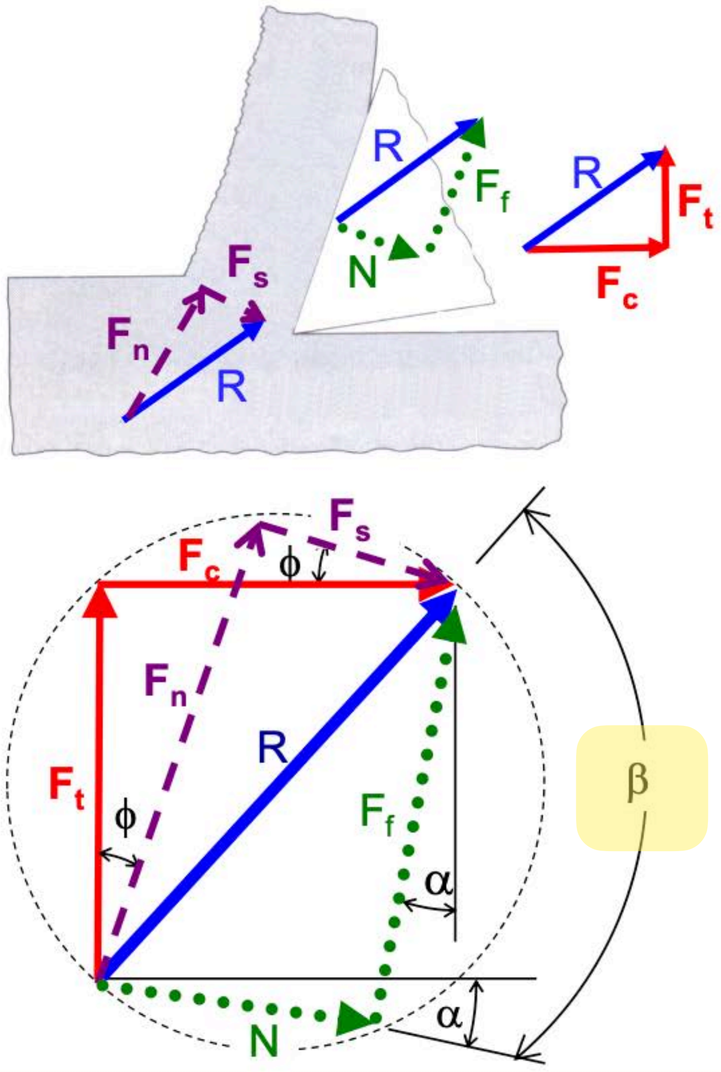
Thrust	F_t
Cutting	F_c
Friction	F_f
Tool normal	N
Shear	F_s
Chip normal	F_n



Machining #2

Forces and Power Demos

Merchant's Diagram



Shear plane forces:

$$F_s = F_c \cdot \cos(\phi) - F_t \cdot \sin(\phi)$$

$$F_n = F_c \cdot \sin(\phi) + F_t \cdot \cos(\phi)$$

Tool-chip forces:

$$F_f = F_c \cdot \sin(\alpha) + F_t \cdot \cos(\alpha)$$

$$N = F_c \cdot \cos(\alpha) - F_t \cdot \sin(\alpha)$$

$$\mu = \frac{F_f}{N} = \tan(\beta)$$

$$Typcially: 0.5 < \mu < 2$$

Machining #2

Forces and Power Demos

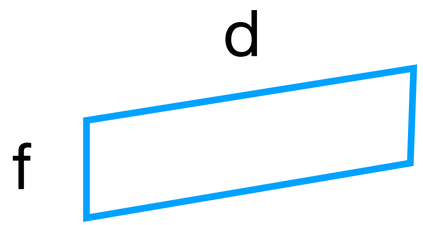
Cutting Force

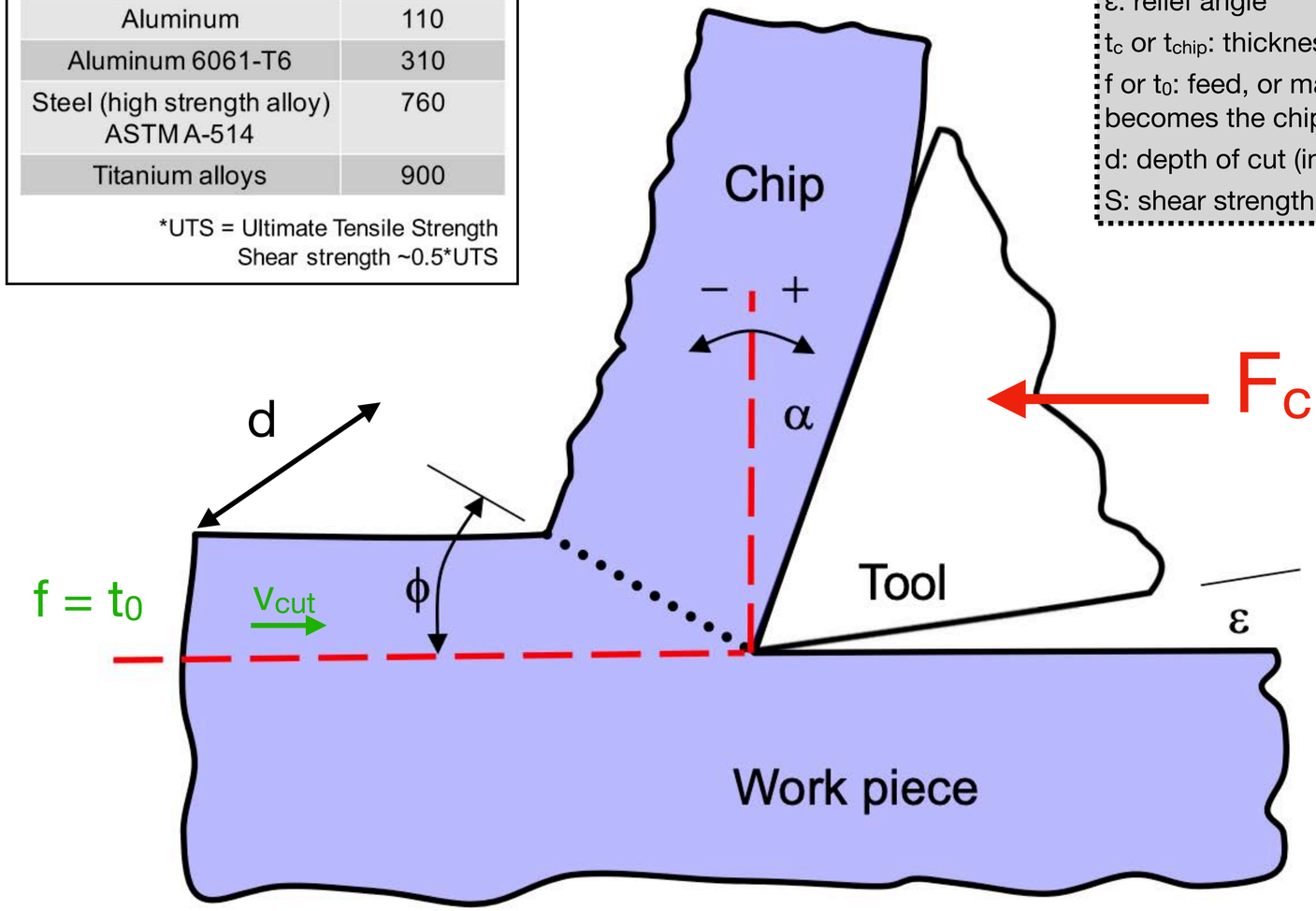
Material	UTS* (MPa)
Wax	0.86
Aluminum	110
Aluminum 6061-T6	310
Steel (high strength alloy) ASTM A-514	760
Titanium alloys	900

*UTS = Ultimate Tensile Strength
Shear strength ~0.5*UTS

Φ: shear angle
α: rake angle
ε: relief angle
t_c or t_{chip}: thickness of the chip
f or t_0: feed, or material that becomes the chip
d: depth of cut (into the page)
S: shear strength

$$F_c \sim d*f*S$$

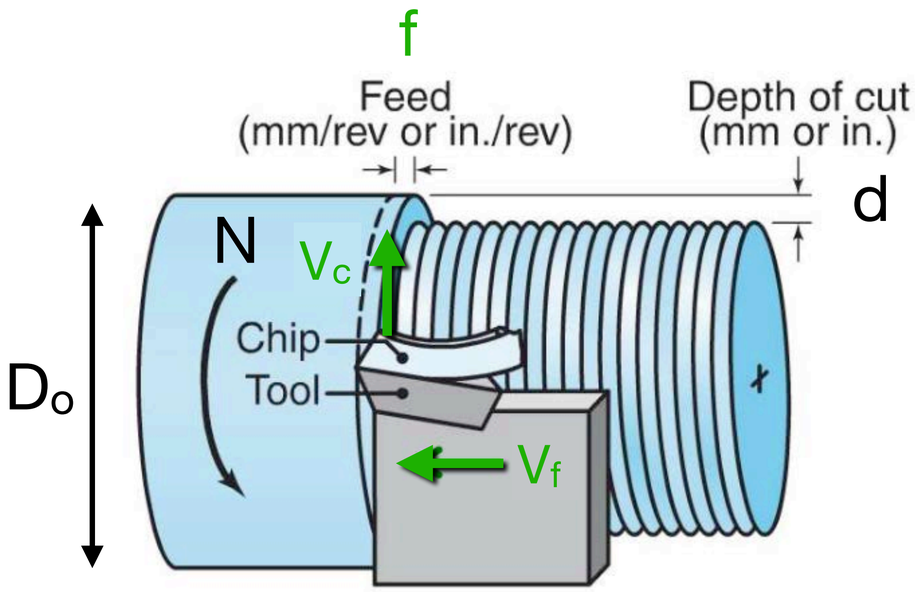


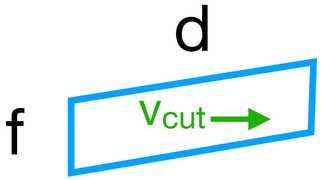


*assumes all the cutting force goes directly into shearing the plane

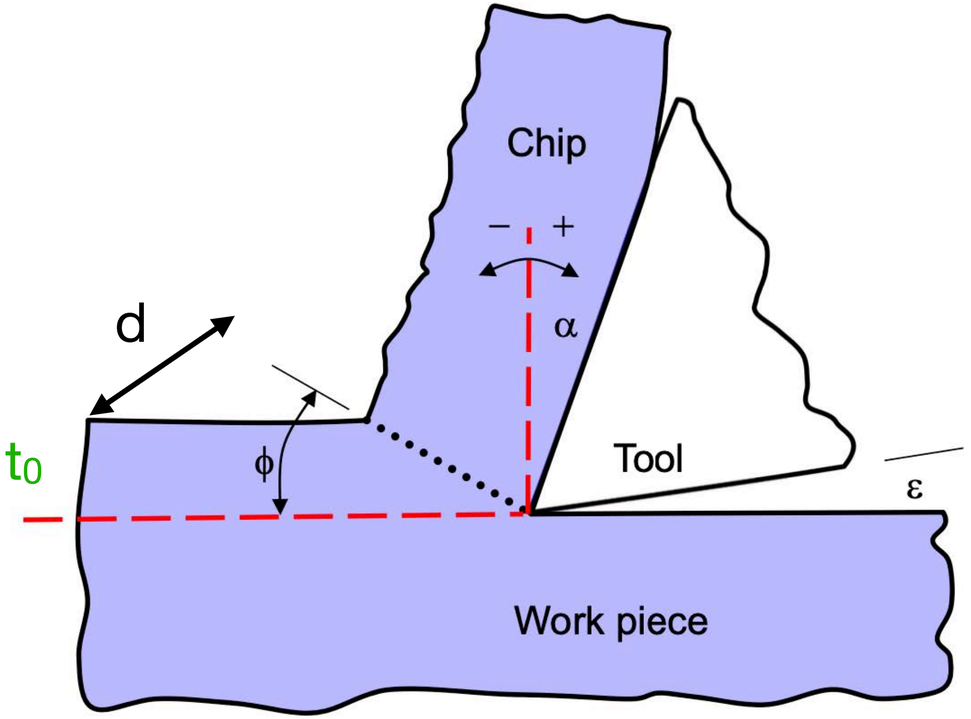
underestimate: lower bound

Material Removal Rate: Lathe





$f = t_0$



d: depth of cut [in]
f or t_0: feed [in/rev]
N: spindle speed [rev/min]
Do: original diameter [in]
u: specific cutting energy [Ws/mm^3]

V_f: feed rate = f*N [in/min]

V_c: cutting velocity = π*D*N [in/min]

$$MRR_{turning} = fdv_{cut} = fd\pi D_{avg}N$$

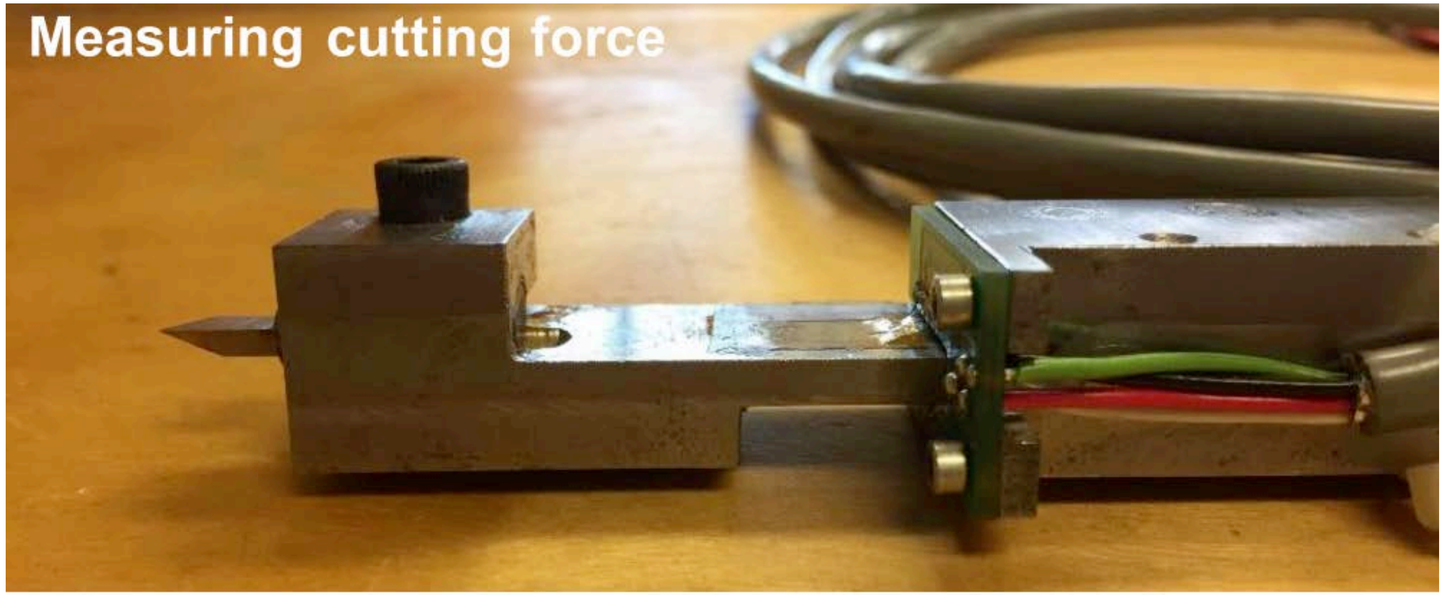
$$P_{turning} = uMRR_{turning}$$

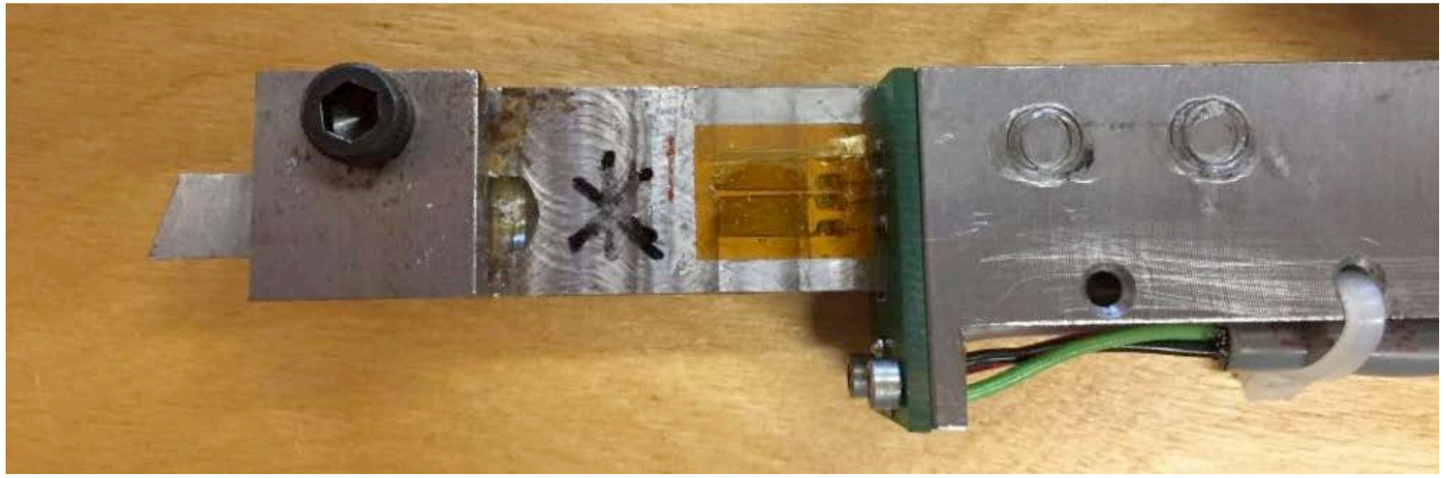
Machining #2

Forces and Power Demos

Cutting Force Demo

Logger Pro + scale calibration





Cutting Force Activity

F ➡ 2F or **F/2** or **⬆F** or **⬇F**

Rake angle (deg)	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	Change in Force Hypothesis	Voltage (mV)	Fc exp (lbf)	Fc the (lbf)	Notes
60	140	2	0.030	0.0042	**F**				
60	140	2	0.030	0.0147					
0	140	2	0.030	0.0147					
0	330	2	0.030	0.0147					
0	330	2	0.060	0.0147					
0	330	1	0.060	0.0147					

Cutting Force Activity

F ➡ 2F or **F/2** or **⬆F** or **⬇F**

Rake angle (deg)	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	Change in Force Hypothesis	Voltage (mV)	Fc exp (lbf)	Fc the (lbf)	Notes
60	140	2	0.030	0.0042	**F**				
60	140	2	0.030	0.0147					
0	140	2	0.030	0.0147					
0	330	2	0.030	0.0147					
0	330	2	0.060	0.0147					
0	330	1	0.060	0.0147					

Cutting Force Activity

F ➡ 2F or **F/2** or **⬆F** or **⬇F**

Rake angle (deg)	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	Change in Force Hypothesis	Voltage (mV)	Fc exp (lbf)	Fc the (lbf)	Notes
60	140	2	0.030	0.0042	**F**				
60	140	2	0.030	0.0147					
0	140	2	0.030	0.0147					
0	330	2	0.030	0.0147					
0	330	2	0.060	0.0147					
0	330	1	0.060	0.0147					

Cutting Force Activity

F ➡ 2F or **F/2** or **⬆F** or **⬇F**

Rake angle (deg)	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	Change in Force Hypothesis	Voltage (mV)	Fc exp (lbf)	Fc the (lbf)	Notes
60	140	2	0.030	0.0042	**F**				
60	140	2	0.030	0.0147					
0	140	2	0.030	0.0147					
0	330	2	0.030	0.0147					
0	330	2	0.060	0.0147					
0	330	1	0.060	0.0147					

Cutting Force Activity

F ➡ 2F or **F/2** or **⬆F** or **⬇F**

Rake angle (deg)	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	Change in Force Hypothesis	Voltage (mV)	Fc exp (lbf)	Fc the (lbf)	Notes
60	140	2	0.030	0.0042	**F**				
60	140	2	0.030	0.0147					
0	140	2	0.030	0.0147					
0	330	2	0.030	0.0147					
0	330	2	0.060	0.0147					
0	330	1	0.060	0.0147					

Cutting Force Activity

F ➡ 2F or **F/2** or **⬆F** or **⬇F**

Rake angle (deg)	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	Change in Force Hypothesis	Voltage (mV)	Fc exp (lbf)	Fc the (lbf)	Notes
60	140	2	0.030	0.0042	**F**				
60	140	2	0.030	0.0147					
0	140	2	0.030	0.0147					
0	330	2	0.030	0.0147					
0	330	2	0.060	0.0147					
0	330	1	0.060	0.0147					

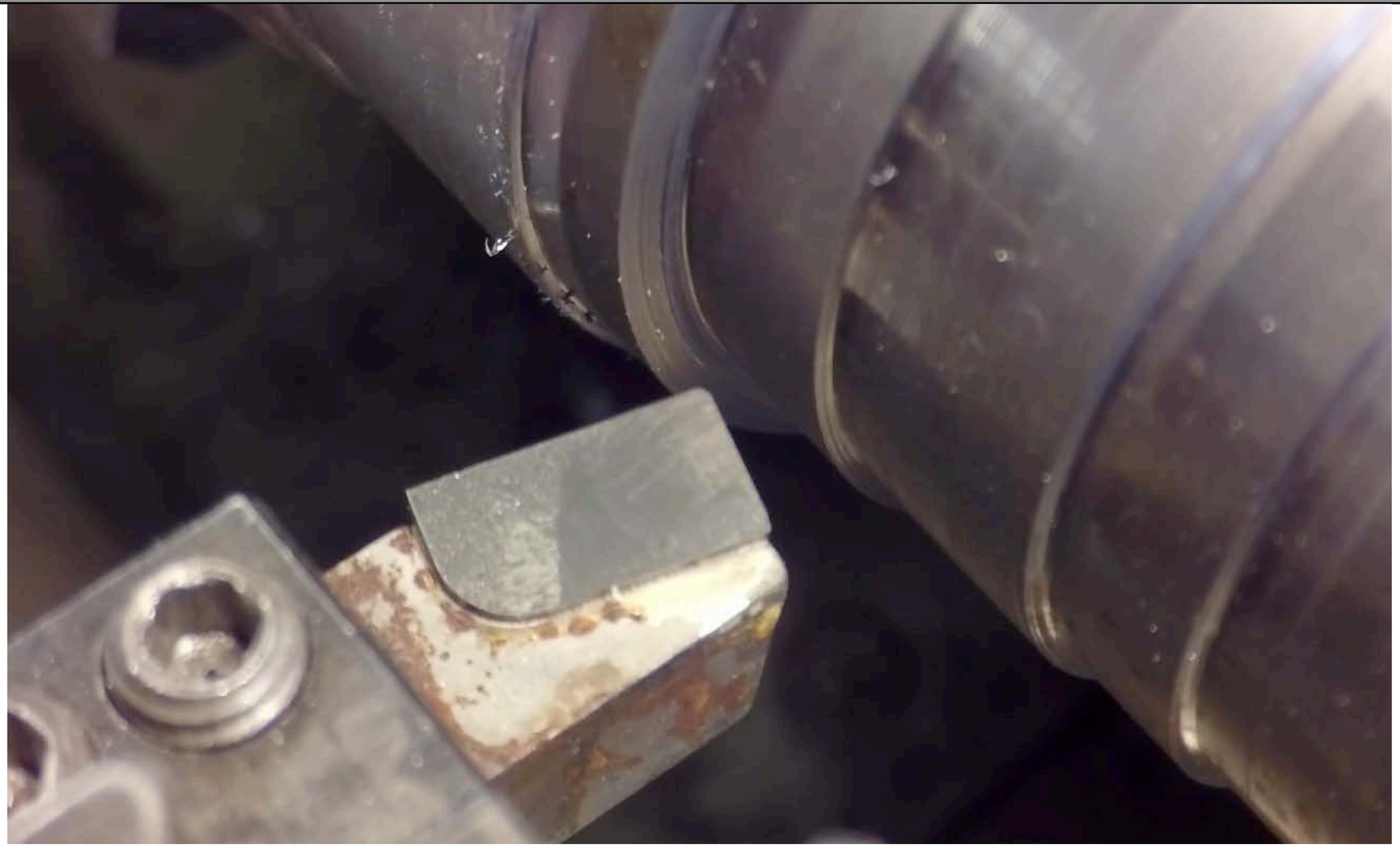
Cutting Force Activity

Rake angle (deg)	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	Change in Force Hypothesis	Voltage (mV)	Fc exp (lbf)	Fc the (lbf)	Notes
60	140	2	0.030	0.0042	**F**				
60	140	2	0.030	0.0147					
0	140	2	0.030	0.0147					
0	330	2	0.030	0.0147					
0	330	2	0.060	0.0147					
0	330	1	0.060	0.0147					

Machining #2

Forces and Power Demos

Cutting Power Demo



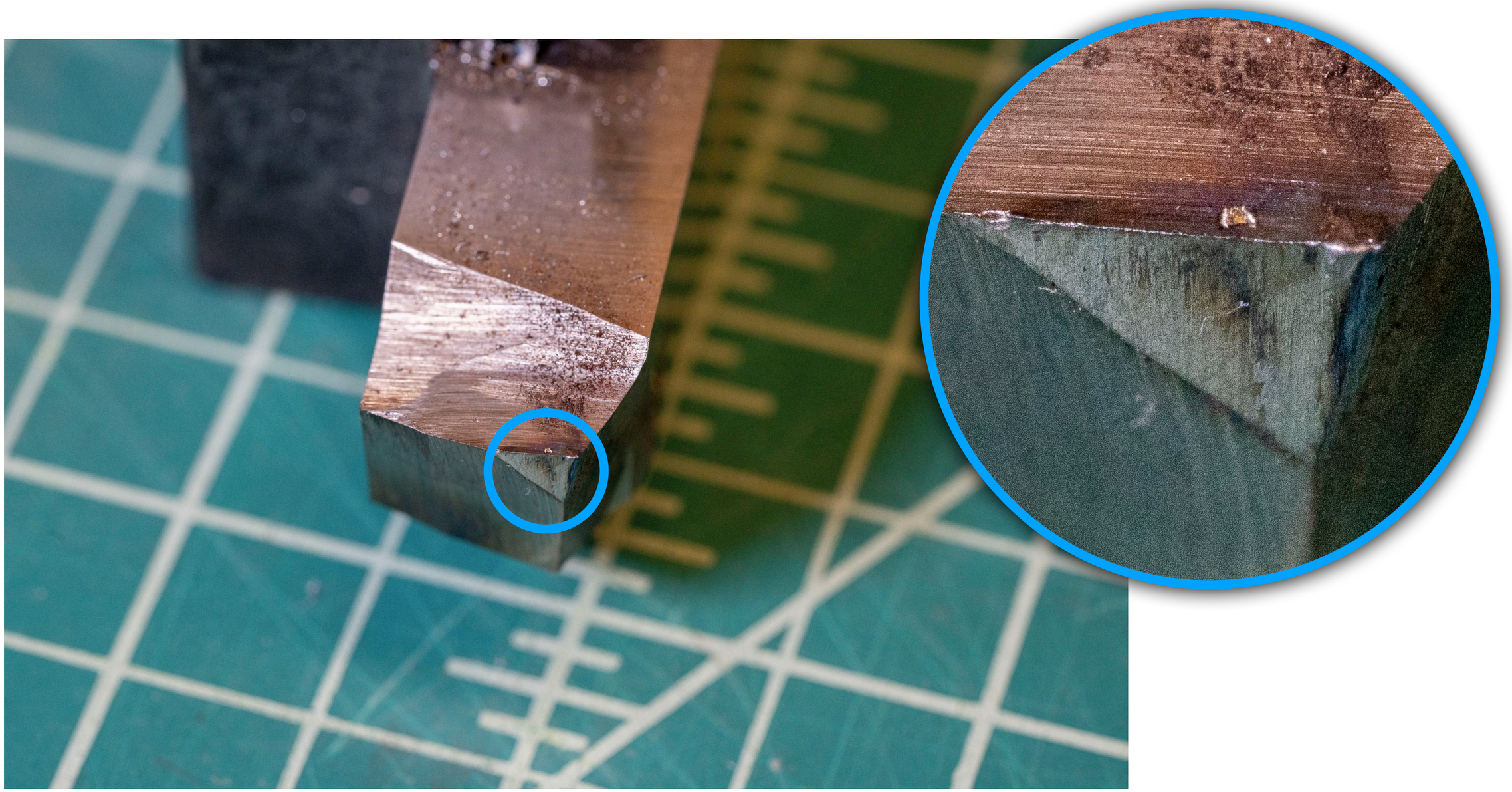
Cutting Power Demo

Rake angle (deg)	Tool	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	MRR (in^3/ min)	Power (hp)	Observations (chips, sounds, etc.)
7	HSS	90	3.87	0.050	0.0073			
7	HSS	140	3.87	0.050	0.0073			
7	HSS	330	3.87	0.050	0.0073			
7	Carbide	330	3.87	0.050	0.0147			
7	Carbide	385	3.87	0.050	0.0147			
7	Carbide	585	3.87	0.050	0.0147			

Cutting Power Demo

Rake angle (deg)	Tool	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	MRR (in^3/ min)	Power (hp)	Observations (chips, sounds, etc.)
7	HSS	90	3.87	0.050	0.0073			
7	HSS	140	3.87	0.050	0.0073			
7	HSS	330	3.87	0.050	0.0073			
7	Carbide	330	3.87	0.050	0.0147			
7	Carbide	385	3.87	0.050	0.0147			
7	Carbide	585	3.87	0.050	0.0147			

Cutting Power Demo: Discussion



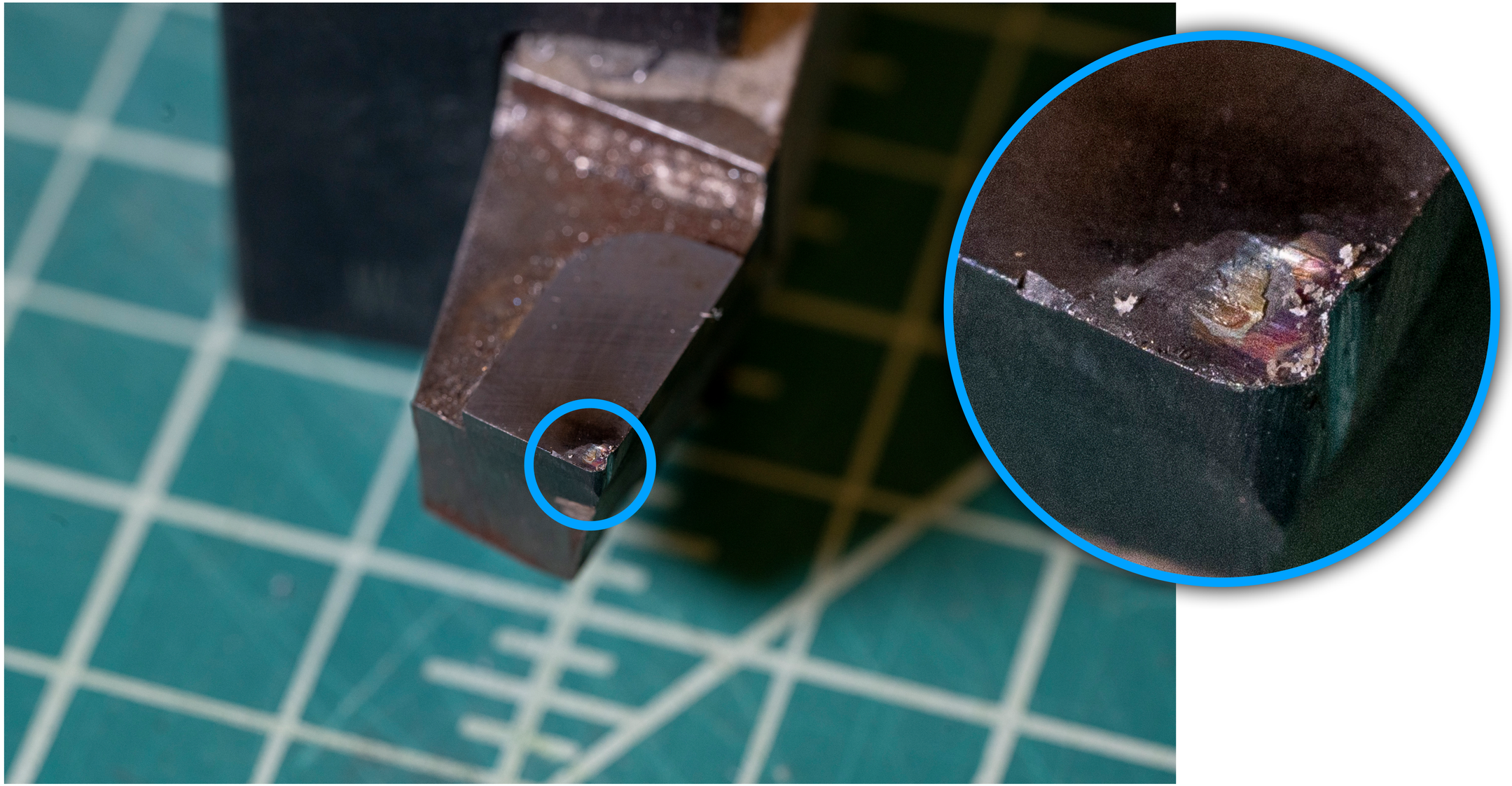
Cutting Power Demo

Rake angle (deg)	Tool	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	MRR (in^3/ min)	Power (hp)	Observations (chips, sounds, etc.)
7	HSS	90	3.87	0.050	0.0073			
7	HSS	140	3.87	0.050	0.0073			
7	HSS	330	3.87	0.050	0.0073			
7	Carbide	330	3.87	0.050	0.0147			
7	Carbide	385	3.87	0.050	0.0147			
7	Carbide	585	3.87	0.050	0.0147			

Cutting Power Demo

Rake angle (deg)	Tool	Spindle speed (RPM)	Diameter (in)	DOC (in)	Feed (in/ rev)	MRR (in^3/ min)	Power (hp)	Observations (chips, sounds, etc.)
7	HSS	90	3.87	0.050	0.0073			
7	HSS	140	3.87	0.050	0.0073			
7	HSS	330	3.87	0.050	0.0073			
7	**Carbide**	330	3.87	0.050	**0.0142**			
7	Carbide	385	3.87	0.050	0.0142			
7	Carbide	585	3.87	0.050	0.0142			

Cutting Power Demo: Discussion



2.008 Design and Manufacturing II

Spring 2025