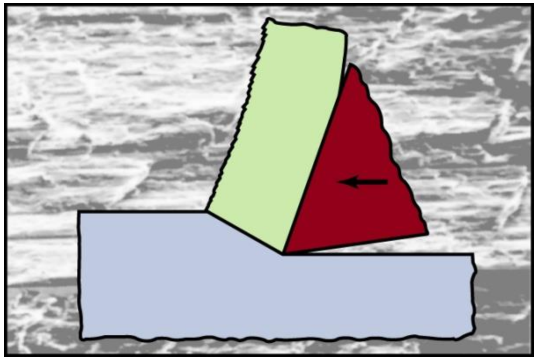
Chapter 7 : Machining

Reference: Kalpakjian, chap. 21 - 24



Dr. Nafisa Bano

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7. Machining

7.1. Generals to material removing processes

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7. Machining
7.1. Generals to material removing processes

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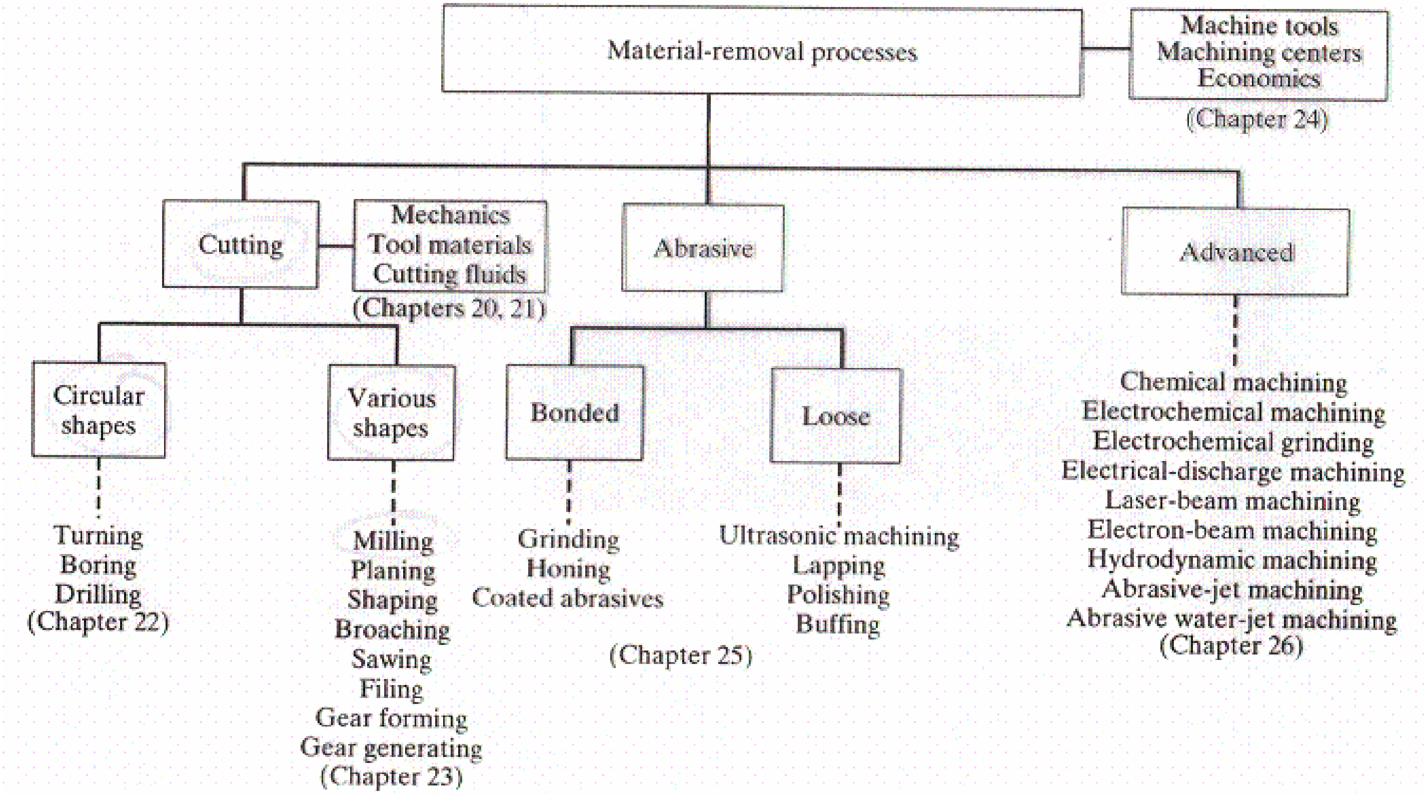


FIGURE IV.4 Outline of the material-removal processes described in Part IV.

7. Machining

7.1. Generals to material removing processes

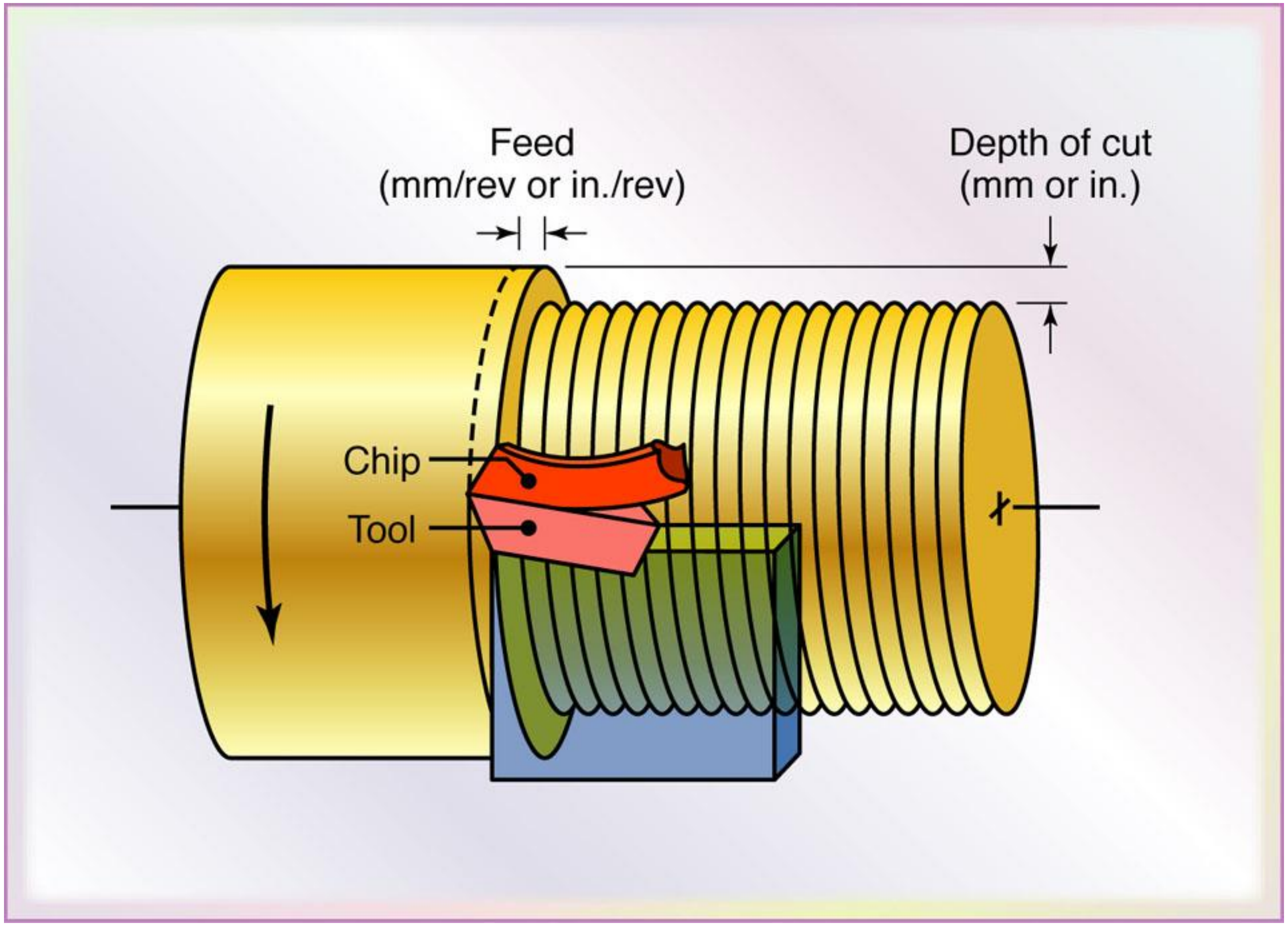


Figure 21.2 Schematic illustration of the turning operation showing various features.

7. Machining

7.2. Mechanics of cutting and cutting forces

❑Cutting force and power

7.2. Mechanics of cutting and cutting forces

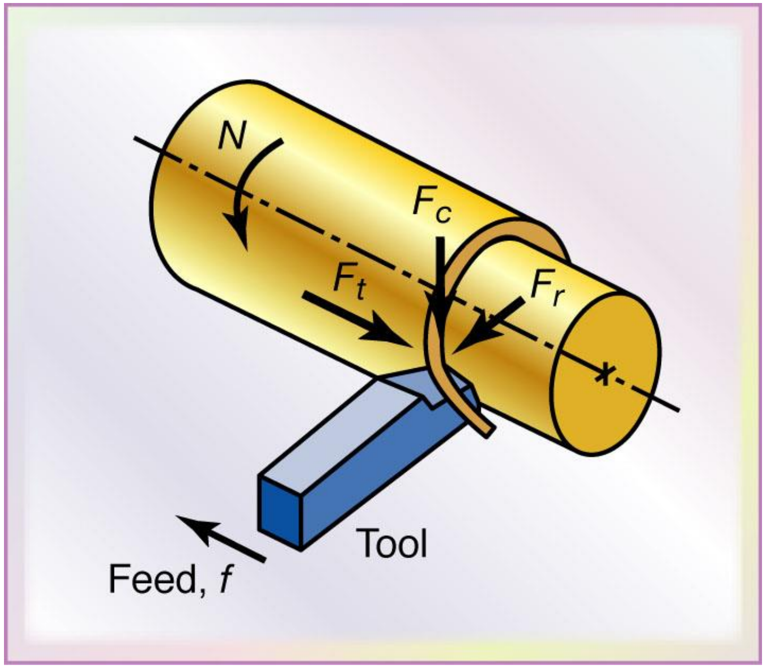


Figure 23.5 Forces acting on a cutting tool in turning, F_c is the cutting force, F_t is the thrust of feed force (in the direction of feed), and F_r is the radial force that tends to push the tool away from the workpiece being machined.

7. Machining

7.2. Mechanics of cutting and cutting forces

- Cutting tools can be measured using strain-gauged tool holders
- Although tool and tool holder are generally sufficiently strong, it is important to know cutting forces and ensure that machining set-up has sufficient stiffness and does not deflect above the specified allowable value.
- Power Requirement: Power = F_cV
- More accurate estimate of the power requirement is achieved by using experimental measurement as:

Power = Power consumed / volume removed / time

7. Machining

7.2. Mechanics of cutting and cutting forces

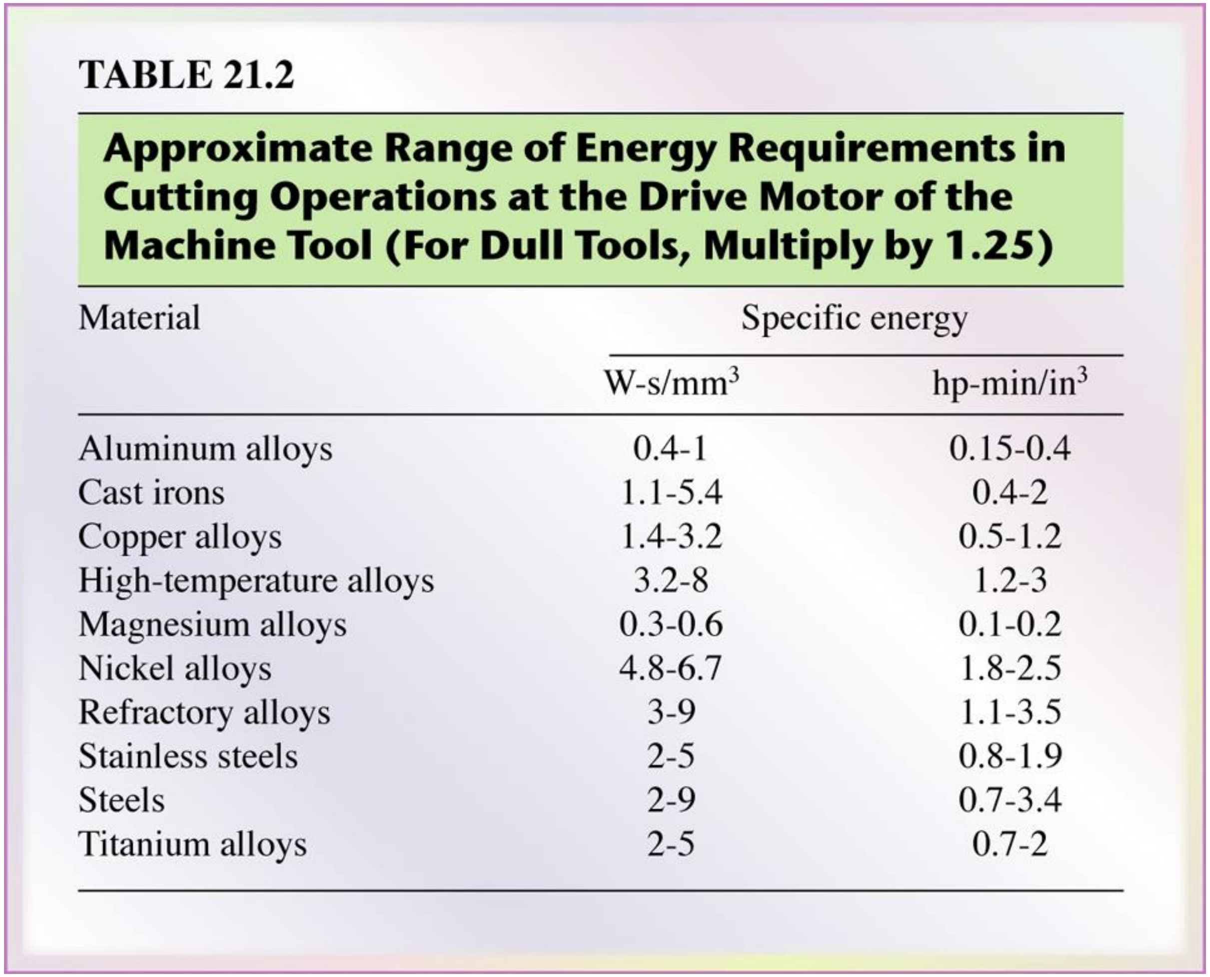


TABLE 21.2

Approximate Range of Energy Requirements in Cutting Operations at the Drive Motor of the Machine Tool (For Dull Tools, Multiply by 1.25)

Material	Specific energy	
	W-s/mm^3	hp-min/in^3
Aluminum alloys	0.4-1	0.15-0.4
Cast irons	1.1-5.4	0.4-2
Copper alloys	1.4-3.2	0.5-1.2
High-temperature alloys	3.2-8	1.2-3
Magnesium alloys	0.3-0.6	0.1-0.2
Nickel alloys	4.8-6.7	1.8-2.5
Refractory alloys	3-9	1.1-3.5
Stainless steels	2-5	0.8-1.9
Steels	2-9	0.7-3.4
Titanium alloys	2-5	0.7-2

7. Machining

7.2. Mechanics of cutting and cutting forces

☐Cutting temperature

- During machining, tool, workpiece and chip are heated due to:
  - Shearing of workpiece material (deformation energy)
  - Friction at tool-chip interface (tool dimension changes / thermal expansion)
  - Friction at tool-workpiece cutting surface
- Most of the heat is carried away by the chip.

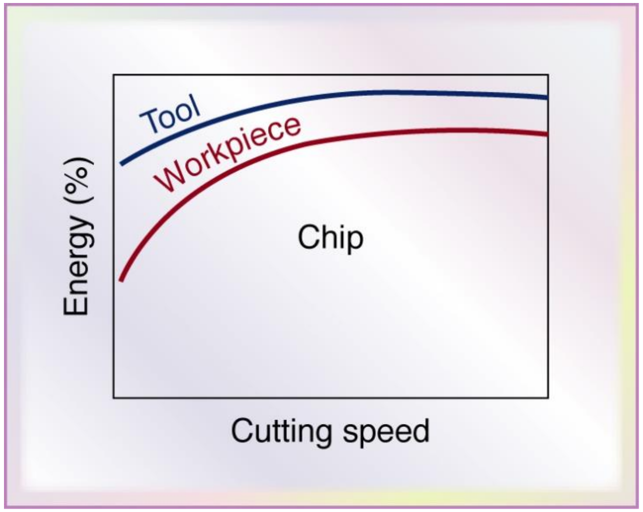


Figure 21.14 Proportion of the heat generated in cutting transferred into the tool, workpiece, and chip as a function of the cutting speed. Note that the chip removes most of the heat.

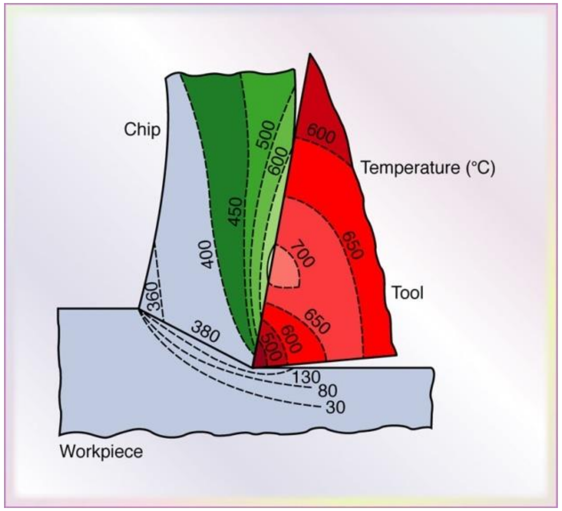


Figure 21.12 Typical temperature distribution in the cutting zone. Note the severe temperature gradients within the tool and the chip, and that the workpiece is relatively cool. *Source*: After G. Vieregge.

7. Machining

7.2. Mechanics of cutting and cutting forces

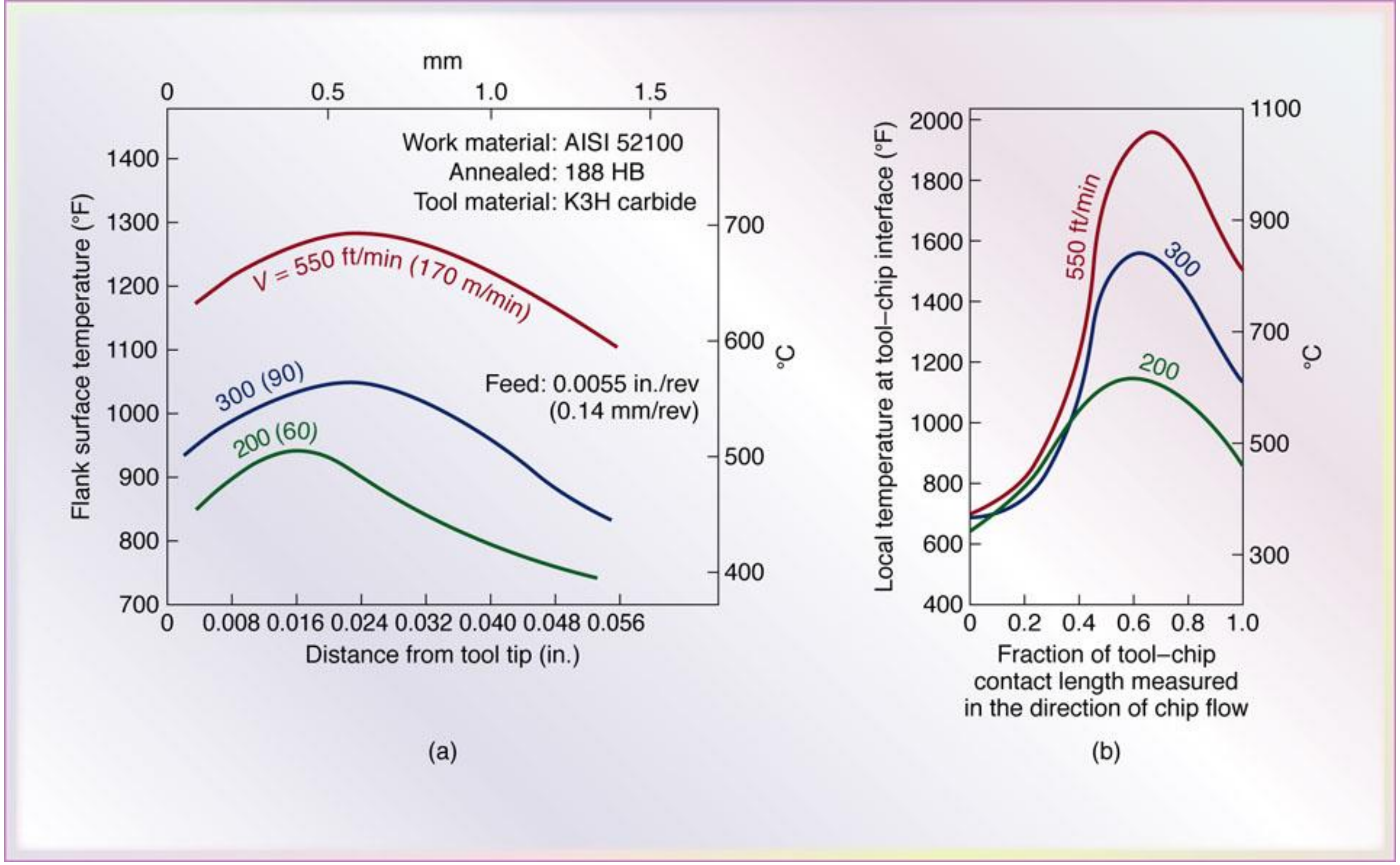
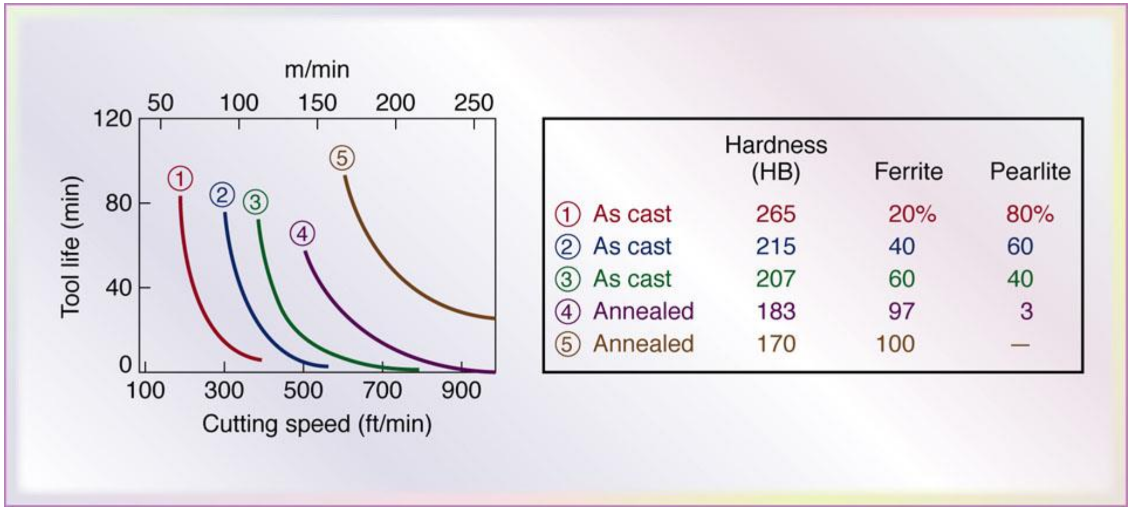


Figure 21.13 Temperatures developed in turning 52100 steel: (a) flank temperature distribution and (b) tool-ship interface temperature distribution. *Source*: After B. T. Chao and K. J. Trigger.

7. Machining

7.2. Mechanics of cutting and cutting forces

- The tool dimensions change due to thermal expansion can lead to increased tolerances.
- Excessive temperatures can cause residual stresses in the workpiece.
- High temperatures can cause accelerated wear of the cutting tool edge.
- Higher cutting speed → Higher production rate → shorter tool life

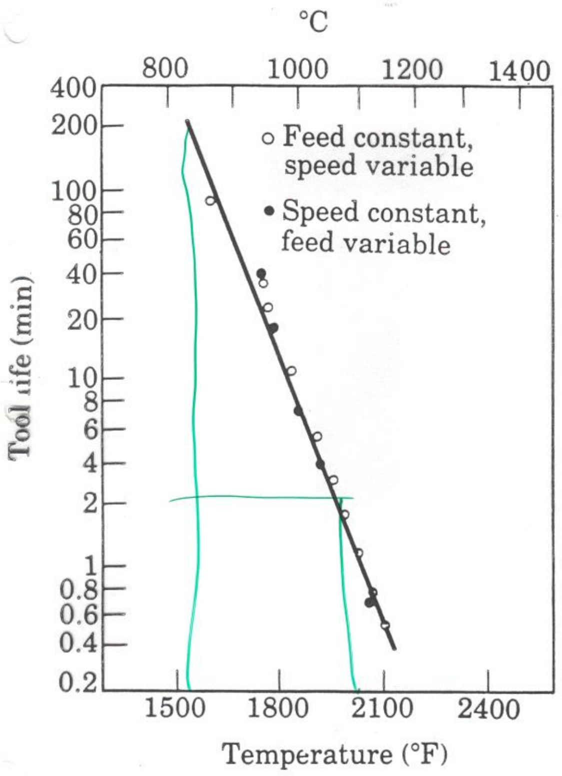


		Hardness (HB)	Ferrite	Pearlite
①	As cast	265	20%	80%
②	As cast	215	40	60
③	As cast	207	60	40
④	Annealed	183	97	3
⑤	Annealed	170	100	—

Figure 21.16 Effect of workpiece hardness and microstructure on tool life in turning ductile cast iron. Note the rapid decrease in tool life (approaching zero) as the cutting speed increases. Tool materials have been developed that resist high temperatures, such as carbides, ceramics, and cubic boron nitride, as will be described in Chapter 22.

7. Machining

7.2. Mechanics of cutting and cutting forces



Work material: Heat-resistant alloy
Tool material: Tungsten carbide
Tool life criterion: 0.024 in. (0.6 mm) flank wear

7. Machining

7.3. Chip formation and effect of machining parameters

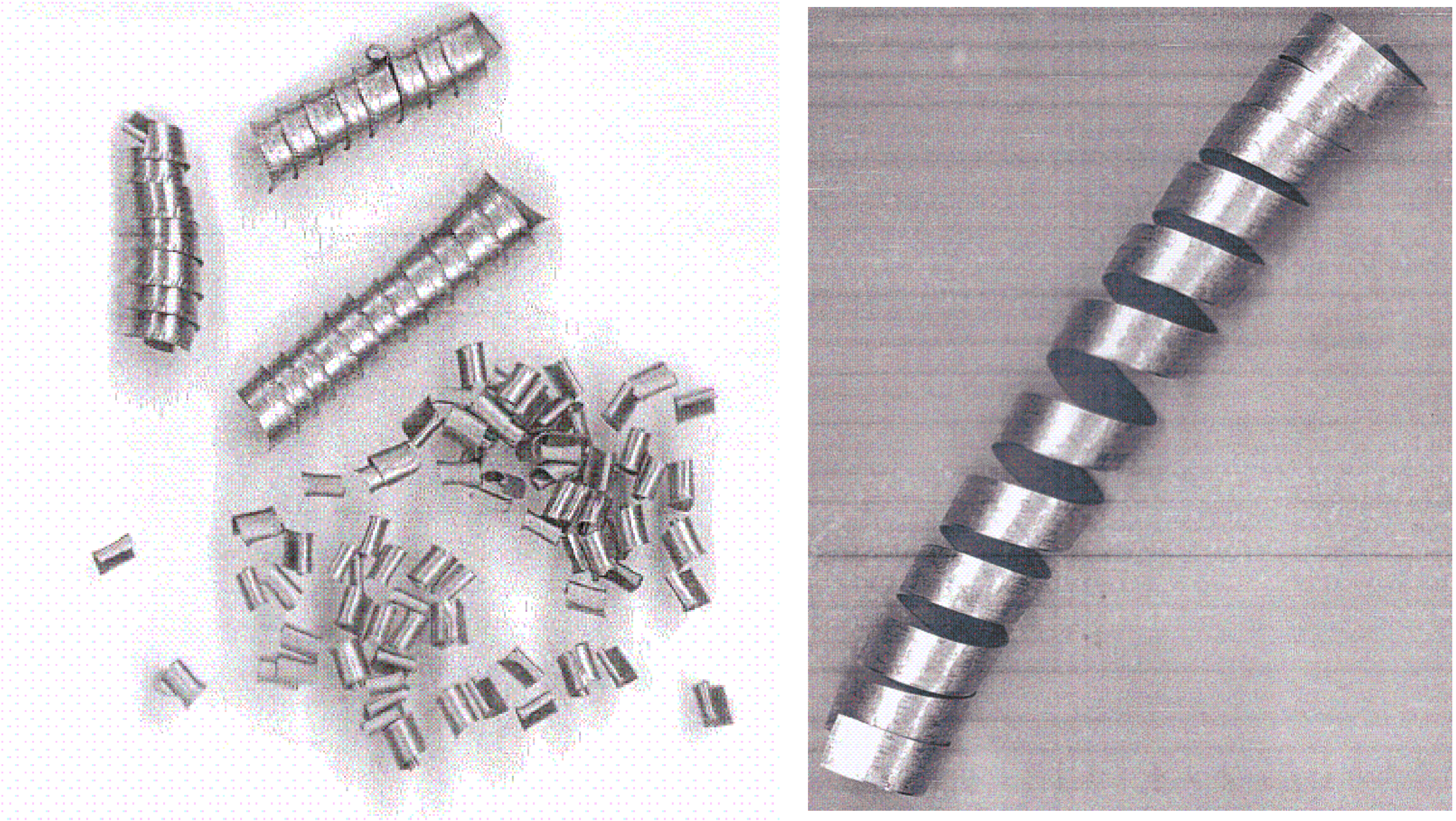
7.3. Chip formation and effect of machining parameters

- Independent parameters:
  - Workpiece material and its condition (cold worked; aged; etc..)
  - Cutting conditions (feed rate, cutting depth)
  - Cutting fluid (yes or no; type)
  - Characteristics of machine tool (stiffness; damping; hardness)

- These independent variables affect the dependent variables:
  - Type of chips (short-good; continuous-bad)
  - Cutting forces and power requirements
  - Machine deflection
  - Wear and failure of tool (temperature rises in chip, tool and workpiece)
  - Surface finish

7. Machining

7.3. Chip formation and effect of machining parameters



7. Machining

7.4. Cutting tools and cutting fluids

7.4. Cutting tools and cutting fluids

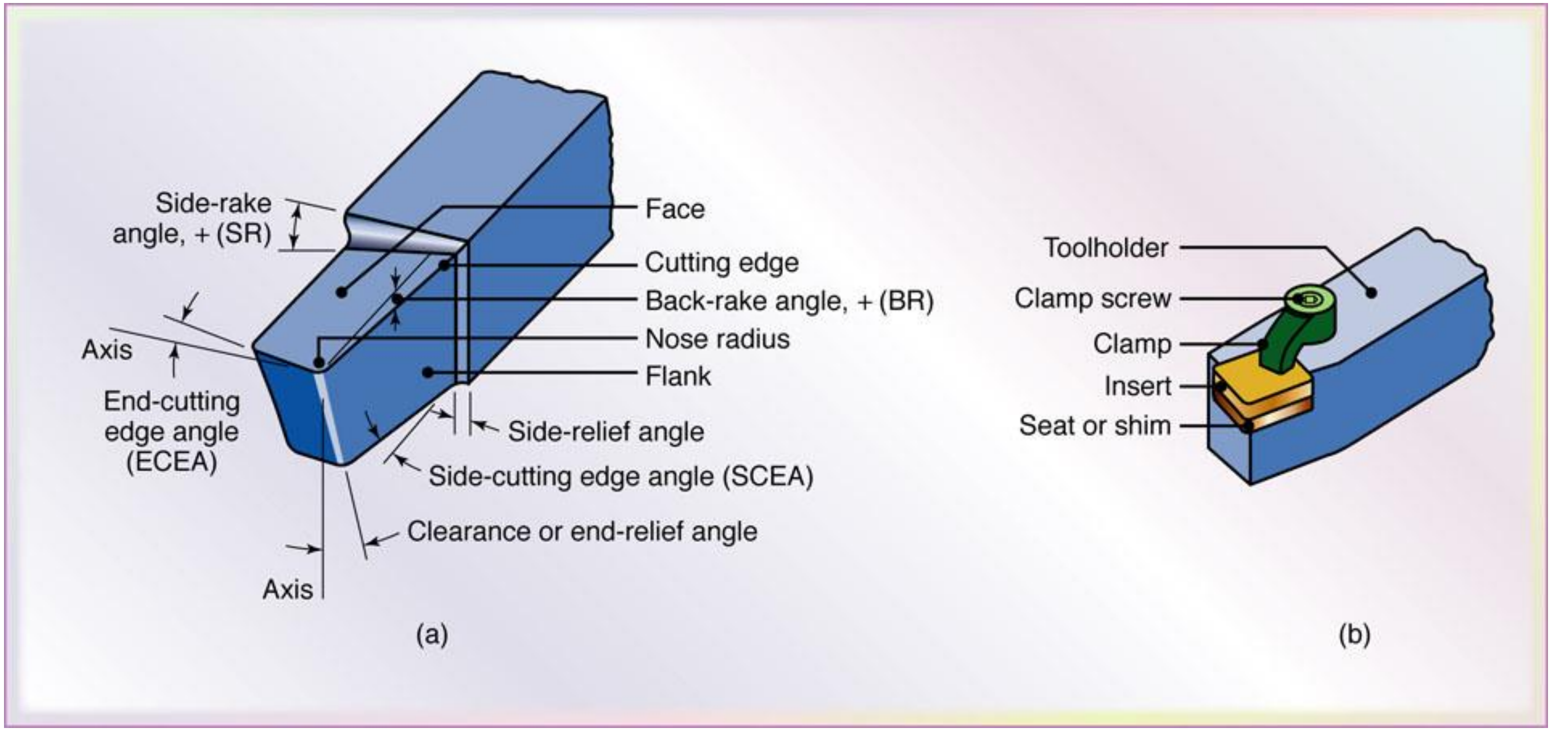


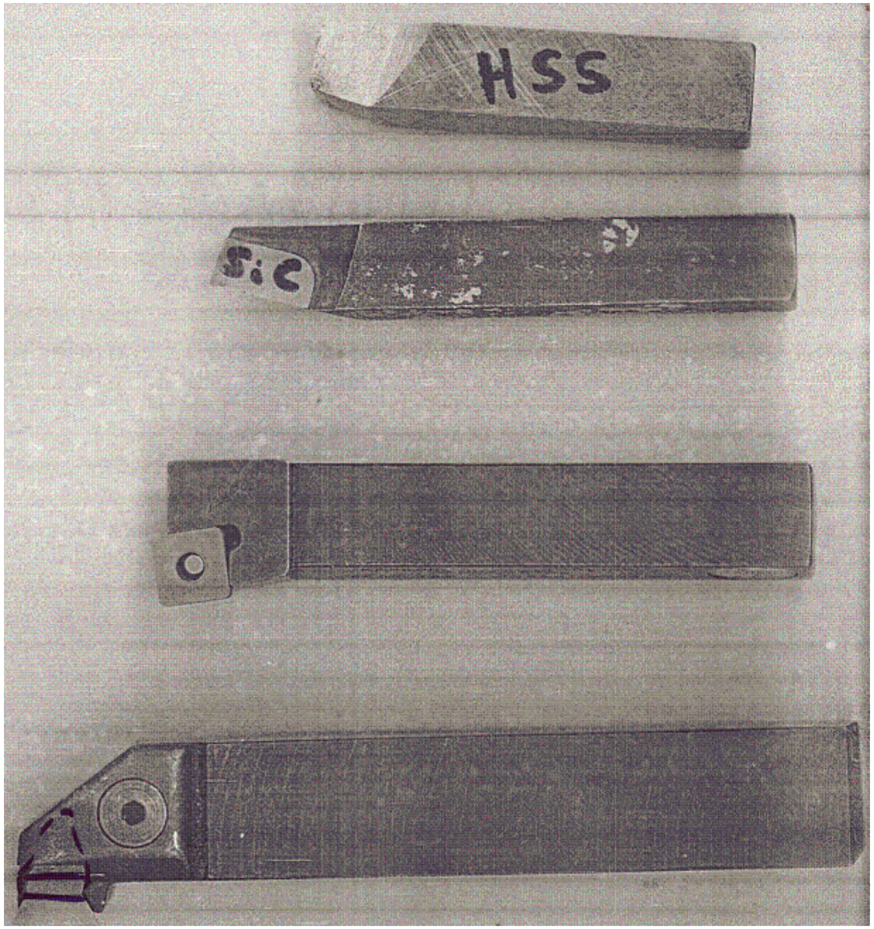
Figure 21.10 (a) Schematic illustration of right-hand cutting tool. The various angles on these tools and their effects on machining are described in Section 23.3.1 Although these tools traditionally have been produced from solid tool-steel bars, they have been replaced largely with (b) inserts made of carbides and other materials of various shapes and sizes.

7. Machining

7.4. Cutting tools and cutting fluids

Typical cutting tool materials:

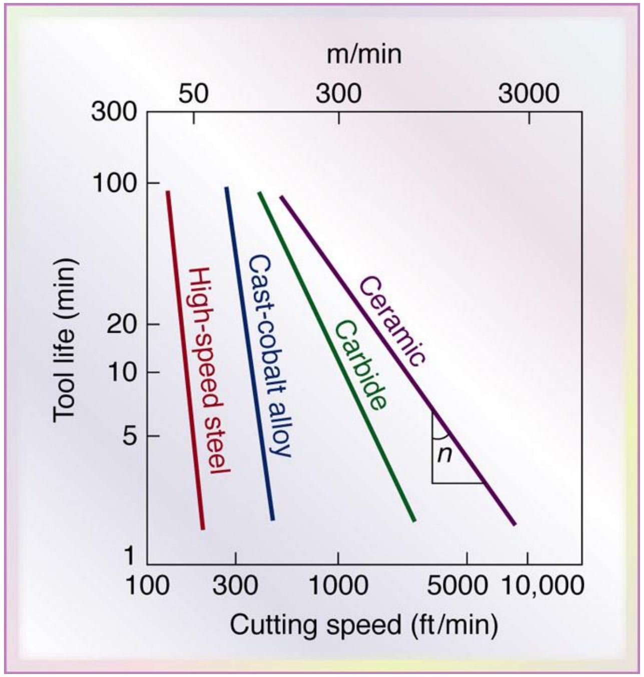
- Single piece tools (usually steels)
- Coated tools (Usually steels with ceramic based coatings)
- Tool inserts (usually ceramics, composites, diamonds)



7. Machining

7.4. Cutting tools and cutting fluids

❑ Estimating cutting tool life



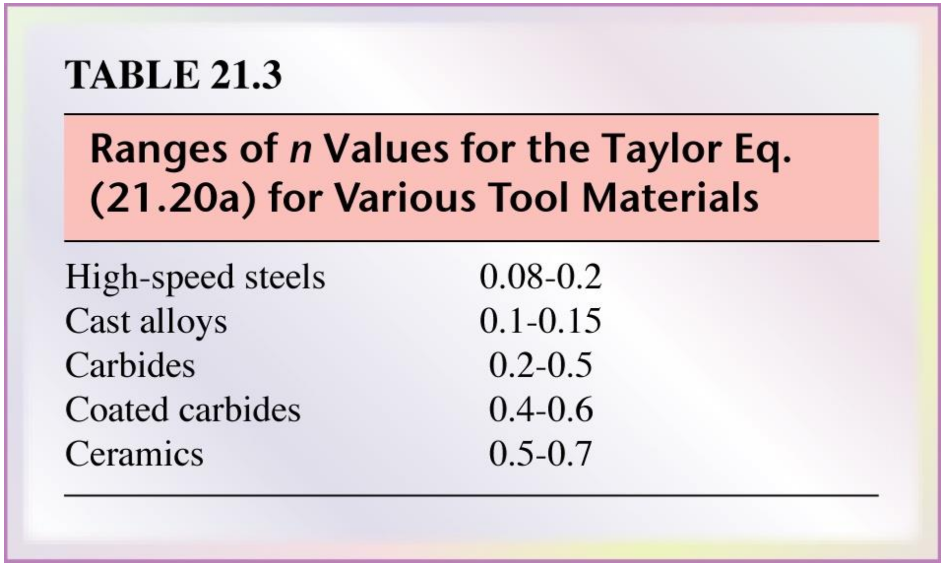


TABLE 21.3

Ranges of *n* Values for the Taylor Eq. (21.20a) for Various Tool Materials

High-speed steels	0.08-0.2
Cast alloys	0.1-0.15
Carbides	0.2-0.5
Coated carbides	0.4-0.6
Ceramics	0.5-0.7

Figure 21.17 Tool-life curves for a variety of cutting-tool materials. The negative inverse of the slope of these curves is the exponent *n* in the Taylor tool-life equation and *C* is the cutting speed at *T* = 1 min, ranging from about 200 to 10,000 ft./min in this figure.

7. Machining

7.4. Cutting tools and cutting fluids

- The basic Taylor's equation: $VT^n = C$

With: V: Surface cutting speed in m/min
T: Tool life in minutes, or time to develop a critical wear land
C: Constant depending primarily upon work piece material
It is defined as the cutting speed when tool life is 1 minute
n: Exponent depending primarily upon cutting tool material
(Table 21.3; Figure 21.17)

- Taylor's revised equation: $V*T^n*d^m*f^p = C$

With: d: Depth of cut in mm (fig. 21.2)
f: Feed rate in mm (per revolution) (fig. 21.2)
m and p: other constants depending on cutting tool and workpiece material as well as on cutting conditions

- The typical values in machining, n = 0.15; m = 0.15 and p = 0.6, show that the most important factor for tool life is cutting speed (V), followed by feed rate (f) and last cutting depth (d).

7. Machining

7.6. Machinability of materials

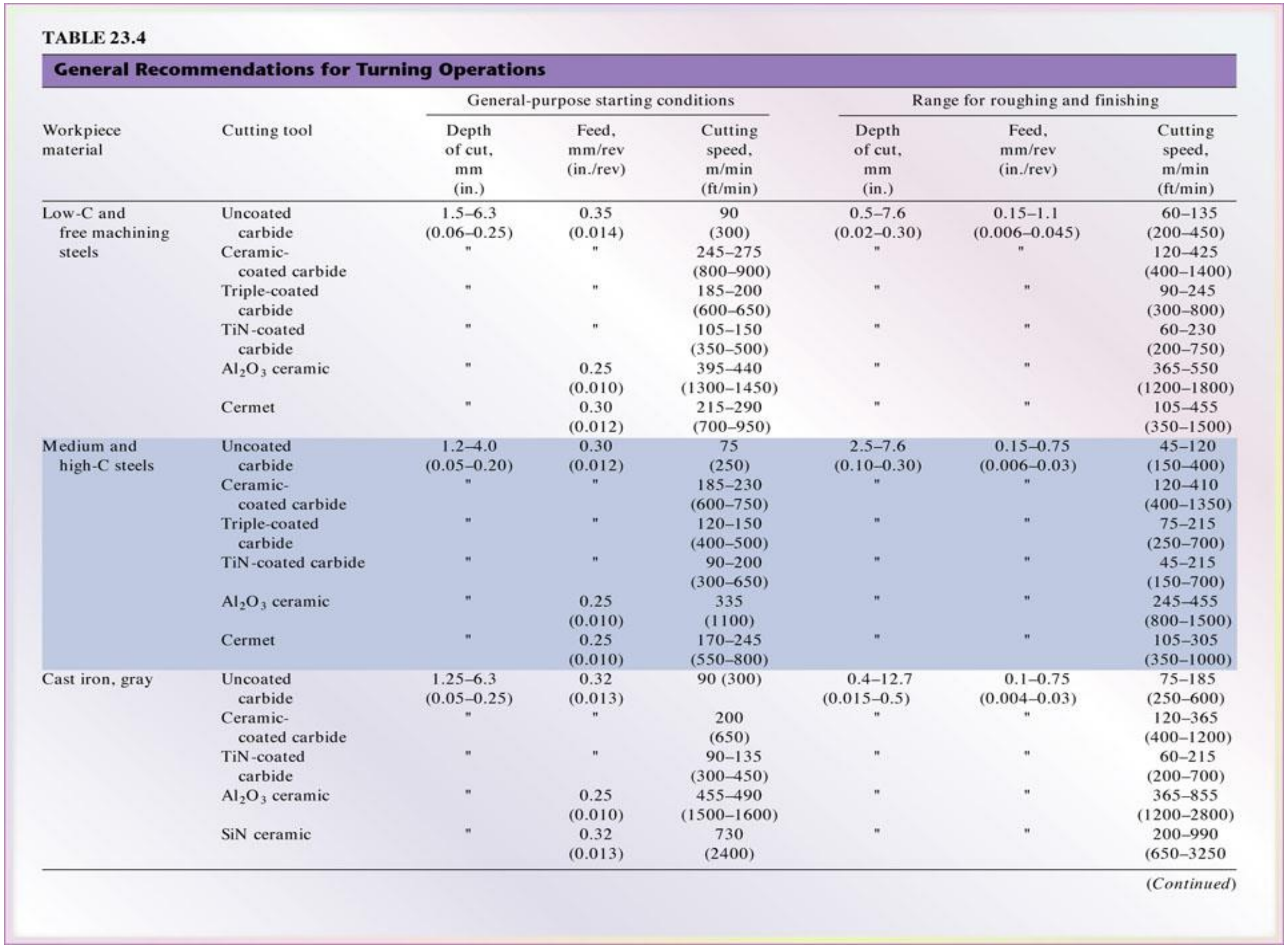


TABLE 23.4

General Recommendations for Turning Operations

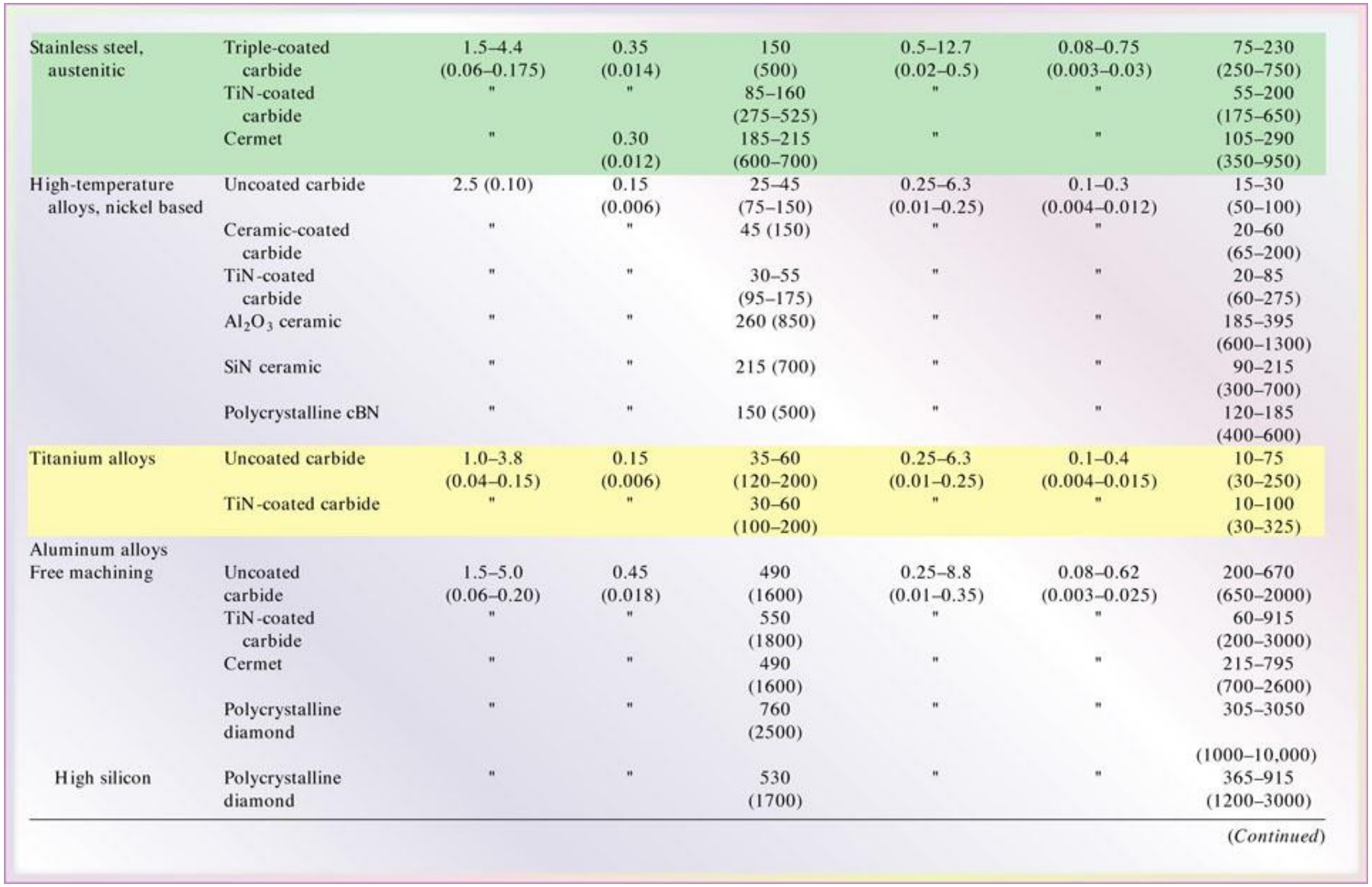
		General-purpose starting conditions			Range for roughing and finishing		
Workpiece material	Cutting tool	Depth of cut, mm (in.)	Feed, mm/rev (in./rev)	Cutting speed, m/min (ft/min)	Depth of cut, mm (in.)	Feed, mm/rev (in./rev)	Cutting speed, m/min (ft/min)
Low-C and free machining steels	Uncoated carbide	1.5–6.3 (0.06–0.25)	0.35 (0.014)	90 (300)	0.5–7.6 (0.02–0.30)	0.15–1.1 (0.006–0.045)	60–135 (200–450)
	Ceramic-coated carbide	"	"	245–275 (800–900)	"	"	120–425 (400–1400)
	Triple-coated carbide	"	"	185–200 (600–650)	"	"	90–245 (300–800)
	TiN-coated carbide	"	"	105–150 (350–500)	"	"	60–230 (200–750)
	Al_2O_3 ceramic	"	0.25 (0.010)	395–440 (1300–1450)	"	"	365–550 (1200–1800)
	Cermet	"	0.30 (0.012)	215–290 (700–950)	"	"	105–455 (350–1500)
Medium and high-C steels	Uncoated carbide	1.2–4.0 (0.05–0.20)	0.30 (0.012)	75 (250)	2.5–7.6 (0.10–0.30)	0.15–0.75 (0.006–0.03)	45–120 (150–400)
	Ceramic-coated carbide	"	"	185–230 (600–750)	"	"	120–410 (400–1350)
	Triple-coated carbide	"	"	120–150 (400–500)	"	"	75–215 (250–700)
	TiN-coated carbide	"	"	90–200 (300–650)	"	"	45–215 (150–700)
	Al_2O_3 ceramic	"	0.25 (0.010)	335 (1100)	"	"	245–455 (800–1500)
	Cermet	"	0.25 (0.010)	170–245 (550–800)	"	"	105–305 (350–1000)
Cast iron, gray	Uncoated carbide	1.25–6.3 (0.05–0.25)	0.32 (0.013)	90 (300)	0.4–12.7 (0.015–0.5)	0.1–0.75 (0.004–0.03)	75–185 (250–600)
	Ceramic-coated carbide	"	"	200 (650)	"	"	120–365 (400–1200)
	TiN-coated carbide	"	"	90–135 (300–450)	"	"	60–215 (200–700)
	Al_2O_3 ceramic	"	0.25 (0.010)	455–490 (1500–1600)	"	"	365–855 (1200–2800)
	SiN ceramic	"	0.32 (0.013)	730 (2400)	"	"	200–990 (650–3250

(*Continued*)

7. Machining

7.6. Machinability of materials

General Recommendations for Turning Operations, con't.



Stainless steel, austenitic	Triple-coated carbide	1.5–4.4 (0.06–0.175)	0.35 (0.014)	150 (500)	0.5–12.7 (0.02–0.5)	0.08–0.75 (0.003–0.03)	75–230 (250–750)
	TiN-coated carbide	"	"	85–160 (275–525)	"	"	55–200 (175–650)
	Cermet	"	0.30 (0.012)	185–215 (600–700)	"	"	105–290 (350–950)
High-temperature alloys, nickel based	Uncoated carbide	2.5 (0.10)	0.15 (0.006)	25–45 (75–150)	0.25–6.3 (0.01–0.25)	0.1–0.3 (0.004–0.012)	15–30 (50–100)
	Ceramic-coated carbide	"	"	45 (150)	"	"	20–60 (65–200)
	TiN-coated carbide	"	"	30–55 (95–175)	"	"	20–85 (60–275)
	Al_2O_3 ceramic	"	"	260 (850)	"	"	185–395 (600–1300)
	SiN ceramic	"	"	215 (700)	"	"	90–215 (300–700)
	Polycrystalline cBN	"	"	150 (500)	"	"	120–185 (400–600)
Titanium alloys	Uncoated carbide	1.0–3.8 (0.04–0.15)	0.15 (0.006)	35–60 (120–200)	0.25–6.3 (0.01–0.25)	0.1–0.4 (0.004–0.015)	10–75 (30–250)
	TiN-coated carbide	"	"	30–60 (100–200)	"	"	10–100 (30–325)
Aluminum alloys							
Free machining	Uncoated carbide	1.5–5.0 (0.06–0.20)	0.45 (0.018)	490 (1600)	0.25–8.8 (0.01–0.35)	0.08–0.62 (0.003–0.025)	200–670 (650–2000)
	TiN-coated carbide	"	"	550 (1800)	"	"	60–915 (200–3000)
	Cermet	"	"	490 (1600)	"	"	215–795 (700–2600)
	Polycrystalline diamond	"	"	760 (2500)	"	"	305–3050 (1000–10,000)
High silicon	Polycrystalline diamond	"	"	530 (1700)	"	"	365–915 (1200–3000)

(Continued)

7. Machining

7.4. Cutting tools and cutting fluids

☐ **Cutting fluids: lubricants and coolants**

- Cutting fluids can be used to:
  - Reduce friction and wear in order to improve tool life and workpiece surface finish
  - Cool the cutting zone in order to improve tool life and reduce temperature and thermal distortion of the workpiece
  - Reduce cutting forces and energy consumption
  - Flush chips away from the cutting zone in order to prevent interfering of chips with the cutting process
  - Protect the machined surface from environmental corrosion

- There are 2 main classes of cutting fluids:
  - **Coolants**, e.g. water, are very important where temperature rise can be significant. The main purpose is not to reduce frictions.
  - **Lubricants**, e.g. oil, are used where temperature rise is not critical. The Purpose is to reduce friction
  - Emulsions (soluble oils): mixture of oil, water and additives are used when both cooling and lubrication are needed

7. Machining

7.5. Surface finish and surface integrity of machined components

7.5. Surface finish and surface integrity of machined components

❑Surface finish

- Surface finish is more an issue for finish/fine machining since the final surface geometry is produced.
- In contrast, surface finish is less important for rough machining since the previous surface is removed or improved during subsequent finer machining

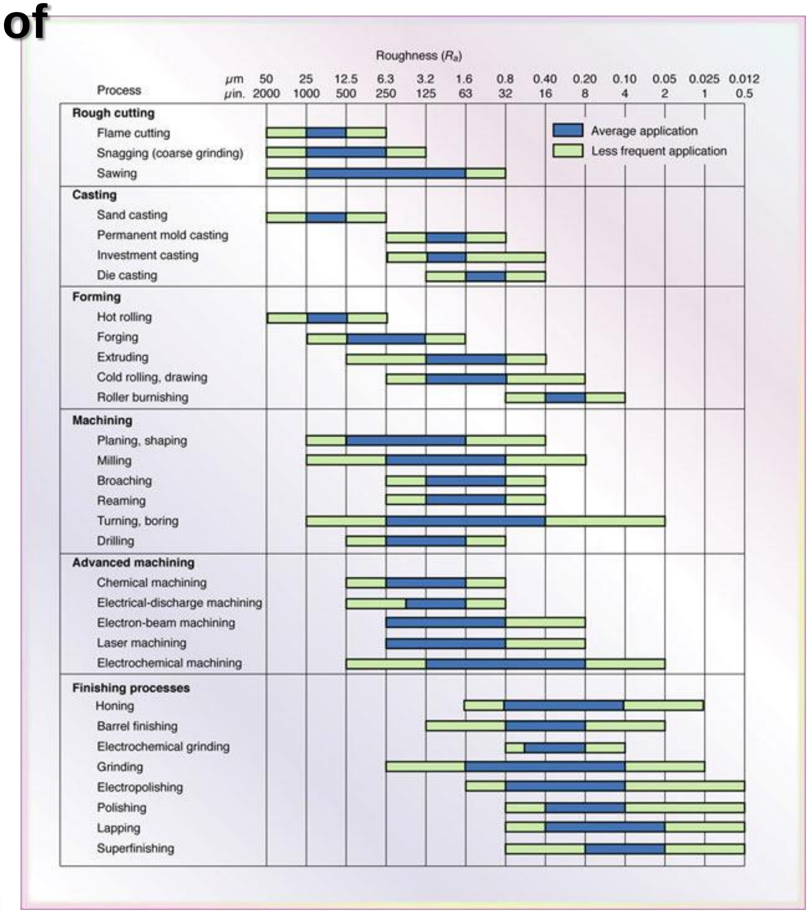


Figure 23.13 The range of surface roughnesses obtained in various machining processes. Note the wide range within each group, especially in turning and boring.

7. Machining

7.6. Machinability of materials

7.6. Machinability of materials

- Good machinability of a material is defined in terms of 4 factors:
  - Good surface finish and good surface integrity of machined parts
  - Long tool life
  - Low force and power requirement
  - (Discontinuous) chips that can be easily controlled

- Too ductile materials generally have poor machinability. They tend to produce built-up edge leading to poor surface finish. Furthermore, they tend to produce continuous chips that are difficult to control.

- Too hard materials also generally have poor machinability. They tend to cause abrasive wear of the tool.

- Cold worked materials generally show good machinability. Because they do not tend to produce built-up edge.

7. Machining

7.7. Some illustrations of machining practices (machining sub-processes)

7.7. Some illustrations of machining practices (machining sub-processes)

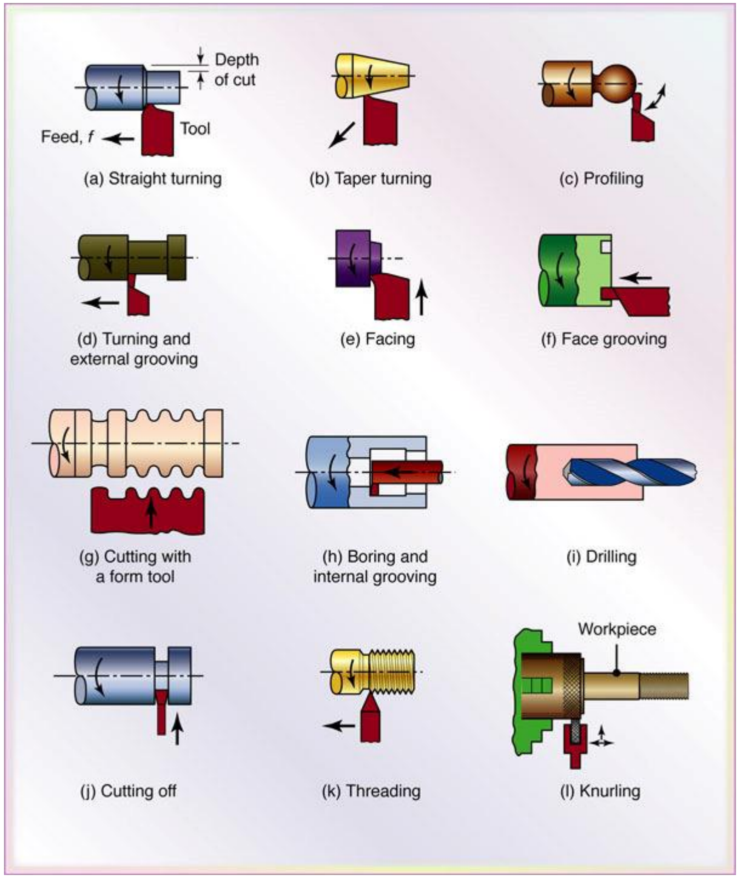


Figure 23.1 Miscellaneous cutting operations that can be performed on a lathe. Note that all parts are circular – a property known as axisymmetry. The tools used, their shape, and the processing parameters are described throughout this chapter.

7. Machining

7.7. Some illustrations of machining practices (machining sub-processes)

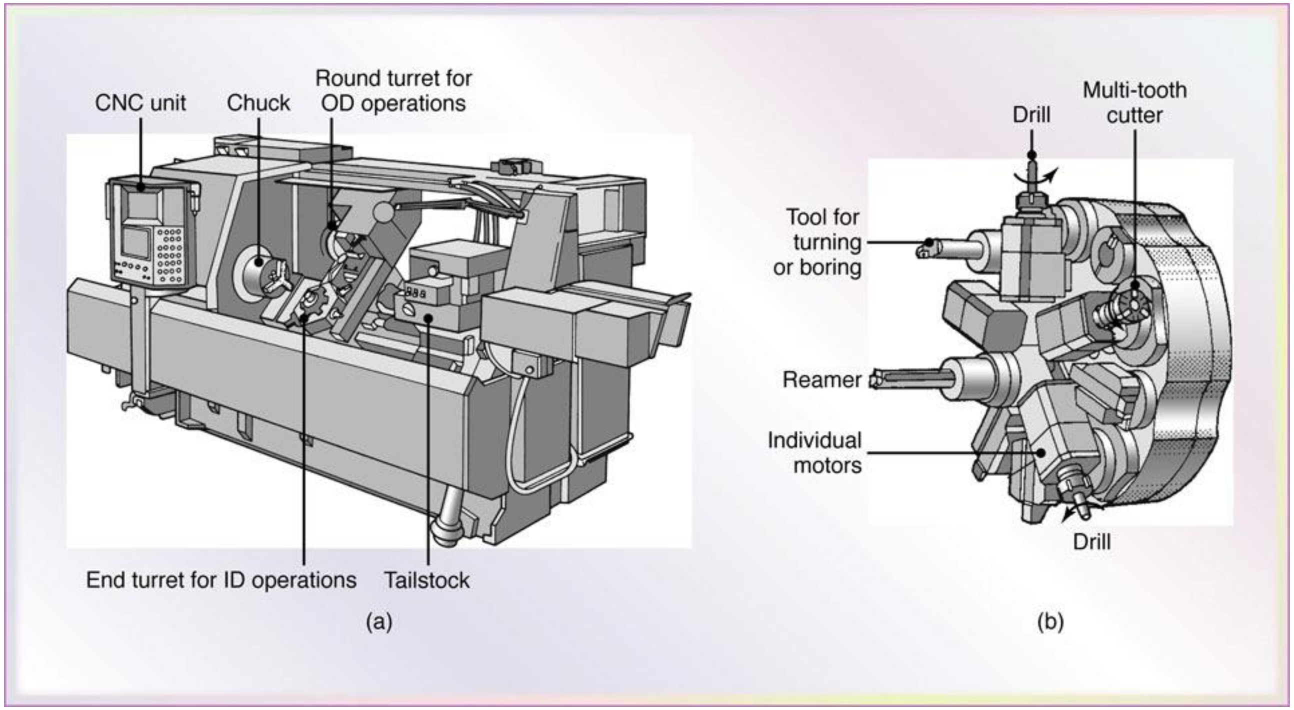


Figure 23.10 (a) A computer numerical-control lathe. Note the two turrets on this machine. These machines have higher power and spindle speed than other lathes in order to take advantage of new cutting tools with enhanced properties. (b) A typical turret equipped with ten tools, some of which are powered.

7. Machining

7.7. Some illustrations of machining practices (machining sub-processes)

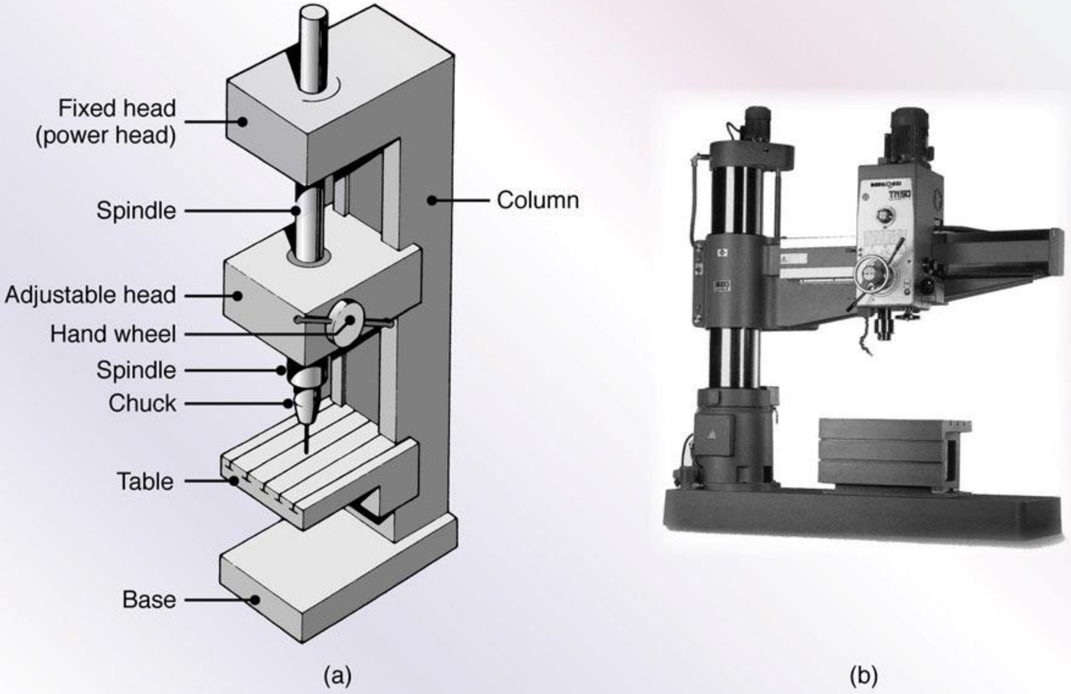


Figure 23.24 (a) Schematic illustration of the components of a vertical drill press. (b) A radial drilling machine. *Source*: (b) Courtesy of Willis Machinery and Tools.

7. Machining

7.7. Some illustrations of machining practices (machining sub-processes)

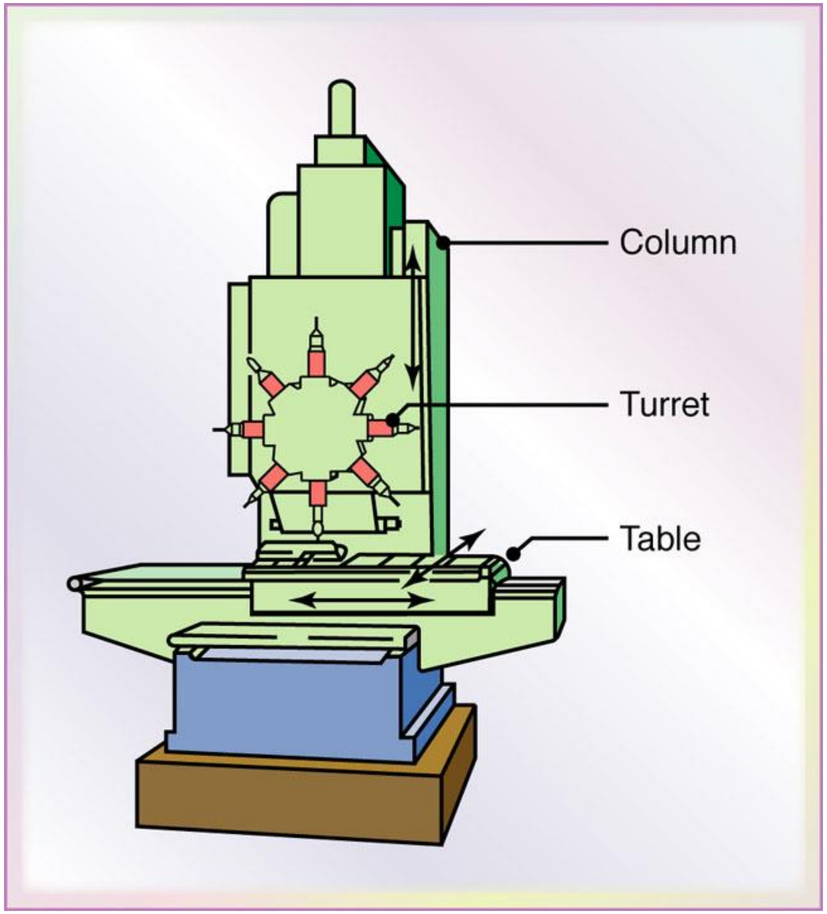


Figure 23.25 A three-axis computer numerical-control drilling machine. The turret holds as many as eight different tools, such as drills, taps, and reamers.

7. Machining

7.7. Some illustrations of machining practices (machining sub-processes)

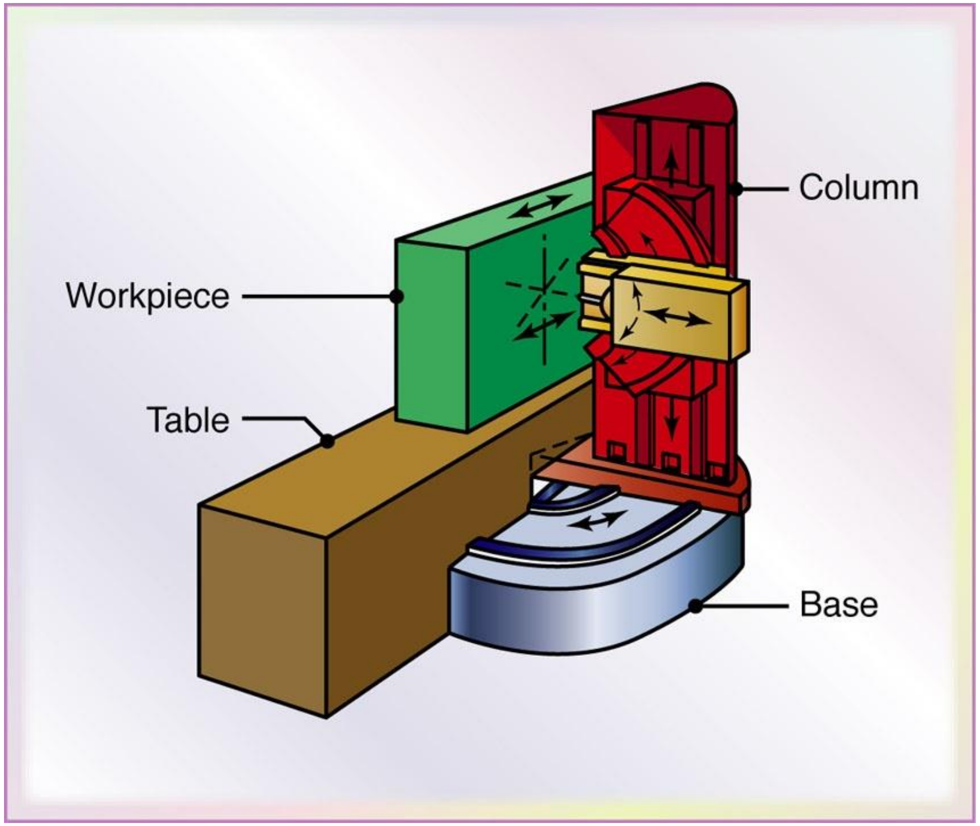


Figure 24.18 Schematic illustration of a five-axis profile milling machine. Note that there are three principal linear and two angular movements of machine components.

7. Machining

7.7. Some illustrations of machining practices (machining sub-processes)

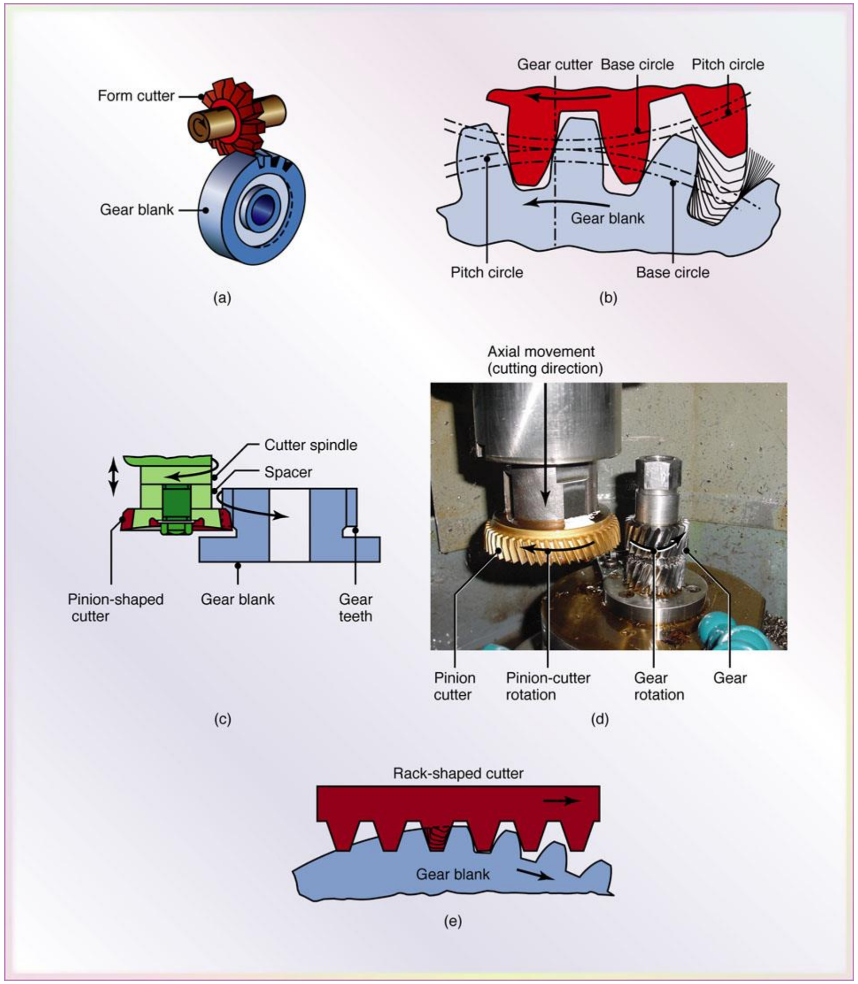


Figure 24.30 (a) Producing gear teeth on a blank by form cutting. (b) Schematic illustration of gear generating with a pinion-shaped gear cutter. (c) and (d) Gear generating on a gear shaper using a pinion-shaped cutter. Note that the cutter reciprocates vertically. (e) Gear generating with rack-shaped cutter. *Source*: (d) Schafer Gear Works, Inc.

7. Machining

References:

[1] Kalpakjian, S.; Schmid, S.R.: “Manufacturing Engineering and Technology”; Pearson Education Inc.; 6th ed. (2010).