

CHAPTER 20

Fundamentals of Cutting

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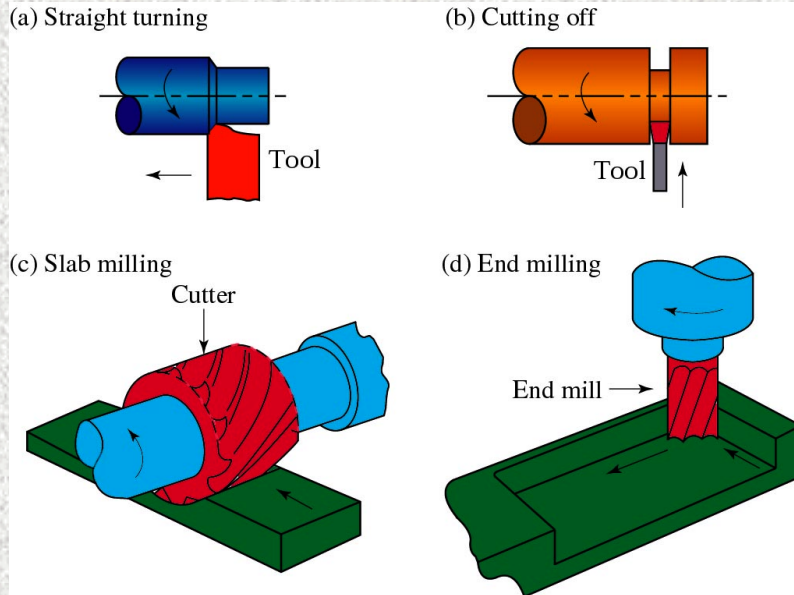


Figure 20.1 Examples of cutting processes.

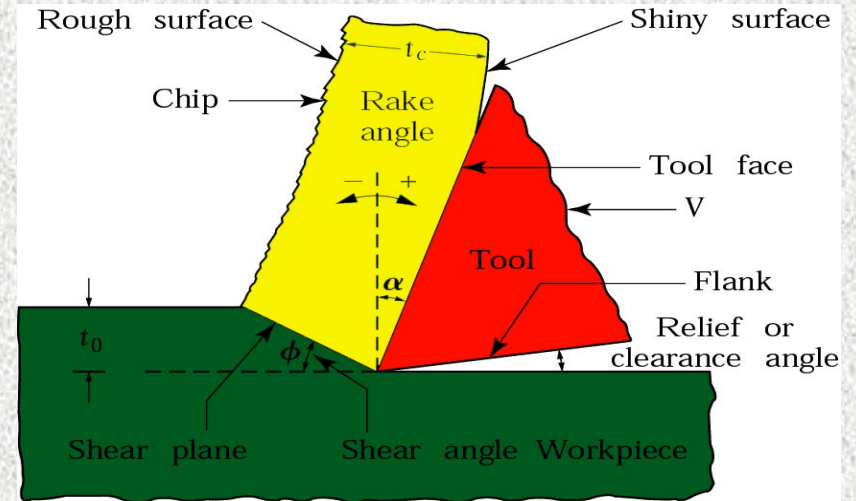


Figure 20.3 Schematic illustration of a two-dimensional cutting process, also called orthogonal cutting. Note that the tool shape and its angles, depth of cut, t_o , and the cutting speed, V , are all independent variables.

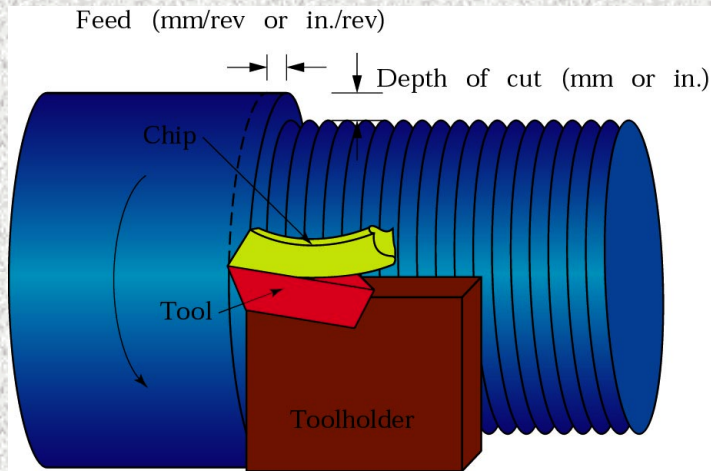


Figure 20.2 Basic principle of the turning operations.

Factors Influencing Cutting Processes

TABLE 20.1

Parameter	Influence and interrelationship
Cutting speed, depth of cut, feed, cutting fluids	Forces, power, temperature rise, tool life, type of chip, surface finish.
Tool angles	As above; influence on chip flow direction; resistance to tool chipping.
Continuous chip	Good surface finish; steady cutting forces; undesirable in automated machinery.
Built-up edge chip	Poor surface finish; thin stable edge can protect tool surfaces.
Discontinuous chip	Desirable for ease of chip disposal; fluctuating cutting forces; can affect surface finish and cause vibration and chatter.
Temperature rise	Influences tool life, particularly crater wear, and dimensional accuracy of workpiece; may cause thermal damage to workpiece surface.
Tool wear	Influences surface finish, dimensional accuracy, temperature rise, forces and power.
Machinability	Related to tool life, surface finish, forces and power.

Mechanics of Chip Formation

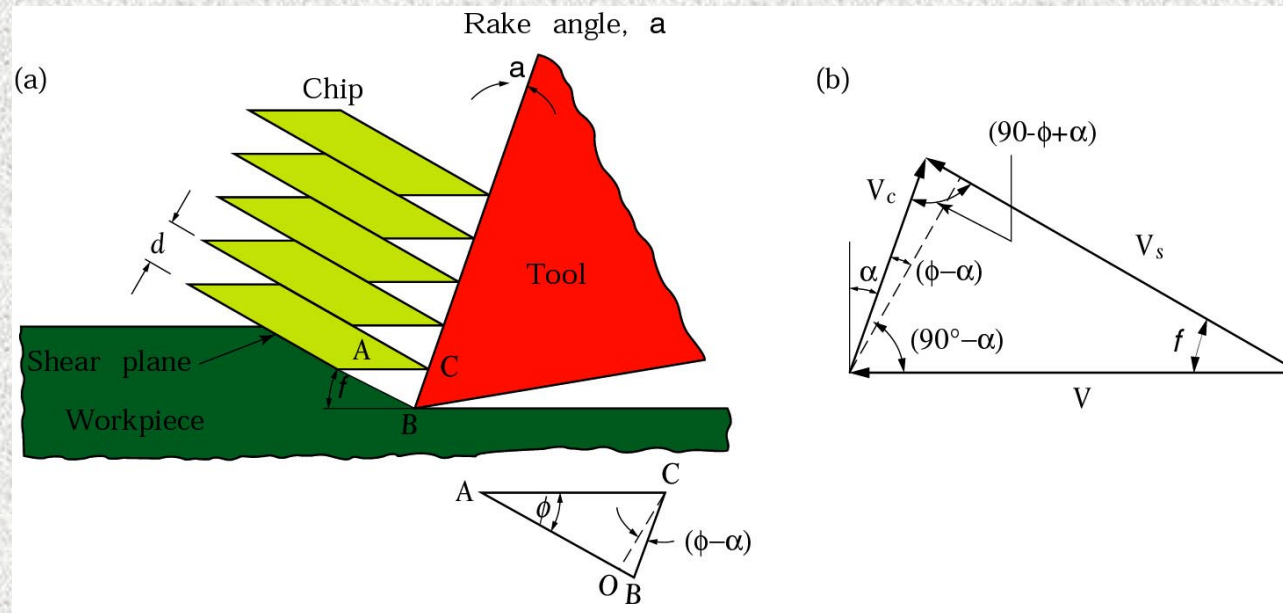
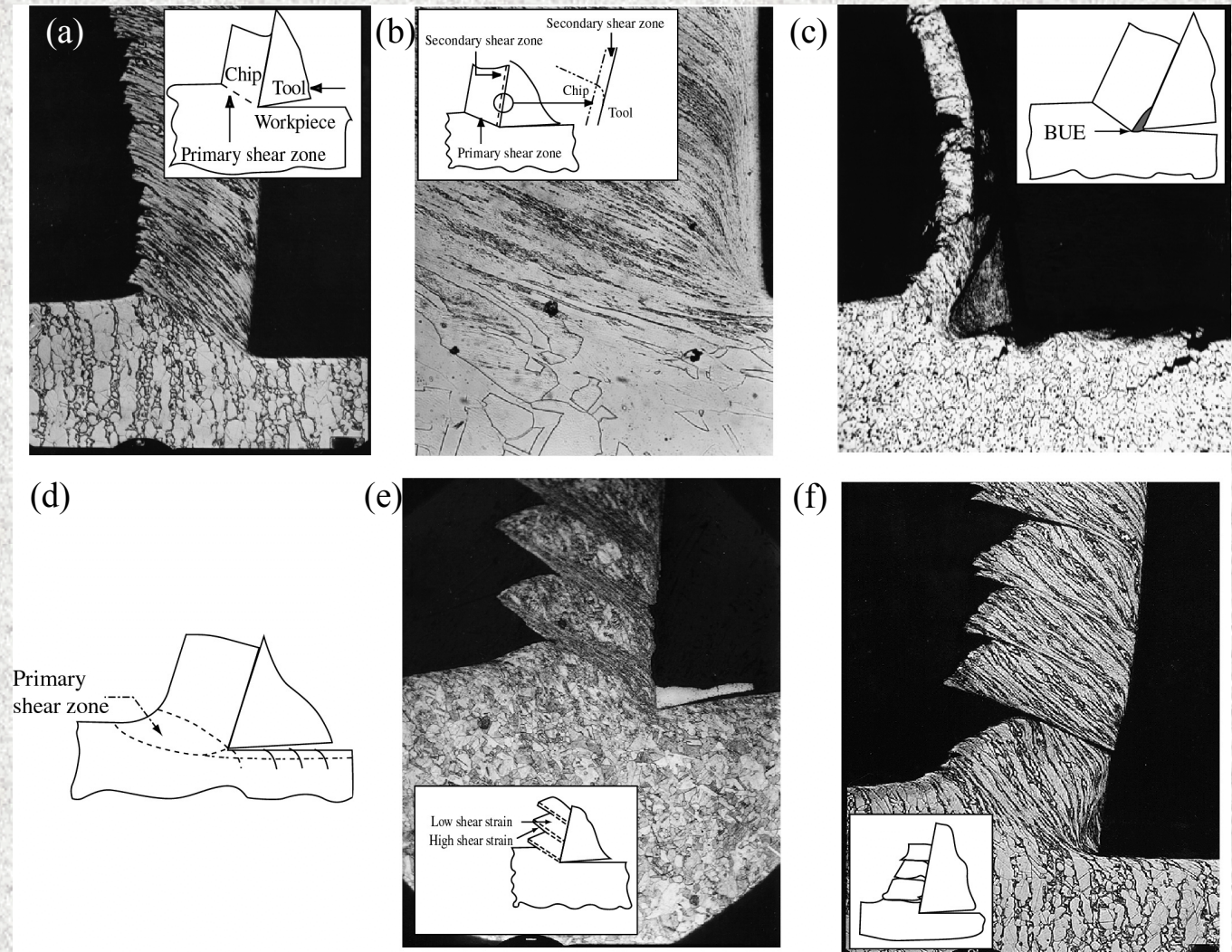


Figure 20.4 (a) Schematic illustration of the basic mechanism of chip formation in metal cutting. (b) Velocity diagram in the cutting zone. See also Section 20.5.3. *Source:* M. E. Merchant.

Chips and Their Photomicrographs

Figure 20.5 Basic types of chips and their photomicrographs produced in metal cutting: (a) continuous chip with narrow, straight primary shear zone; (b) secondary shear zone at the chip-tool interface; (c) continuous chip with large primary shear zone; (d) continuous chip with built-up edge; (e) segmented or nonhomogeneous chip and (f) discontinuous chip. *Source:* After M. C. Shaw, P. K. Wright, and S. Kalpakjian.



Built-Up Edge Chips

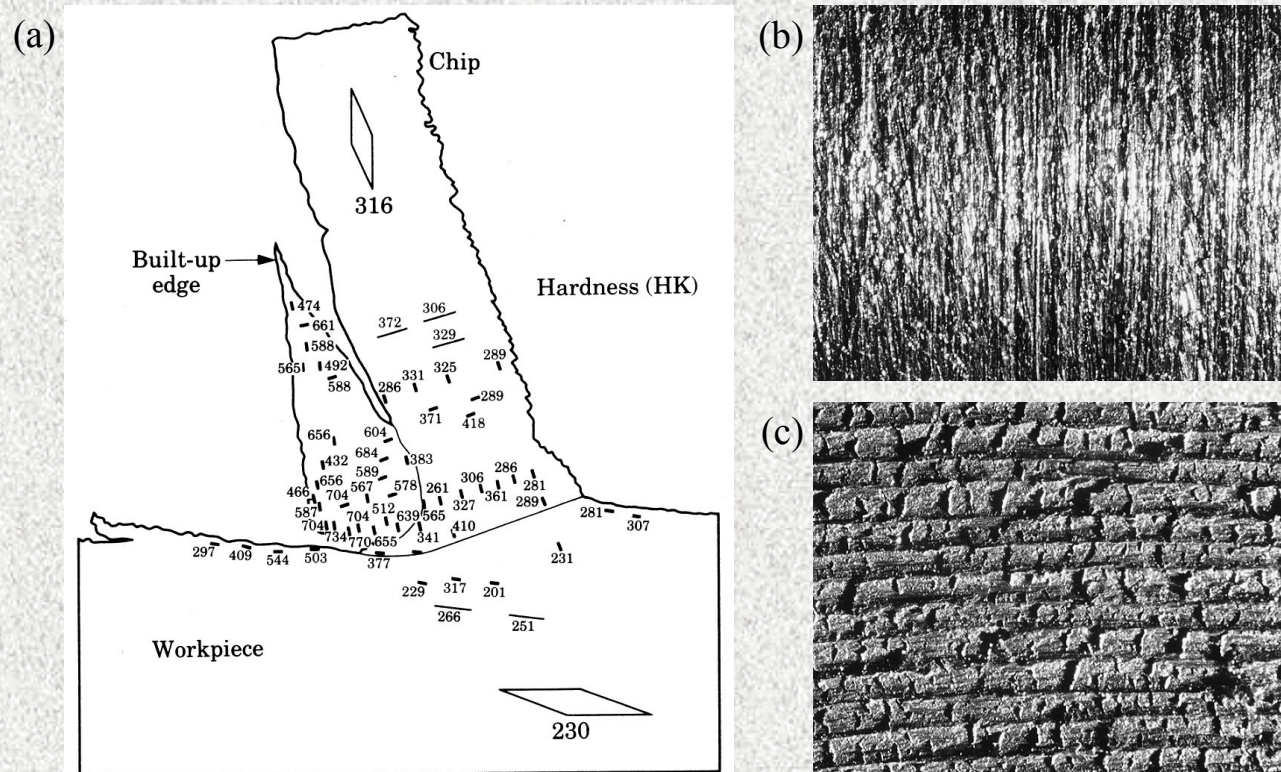
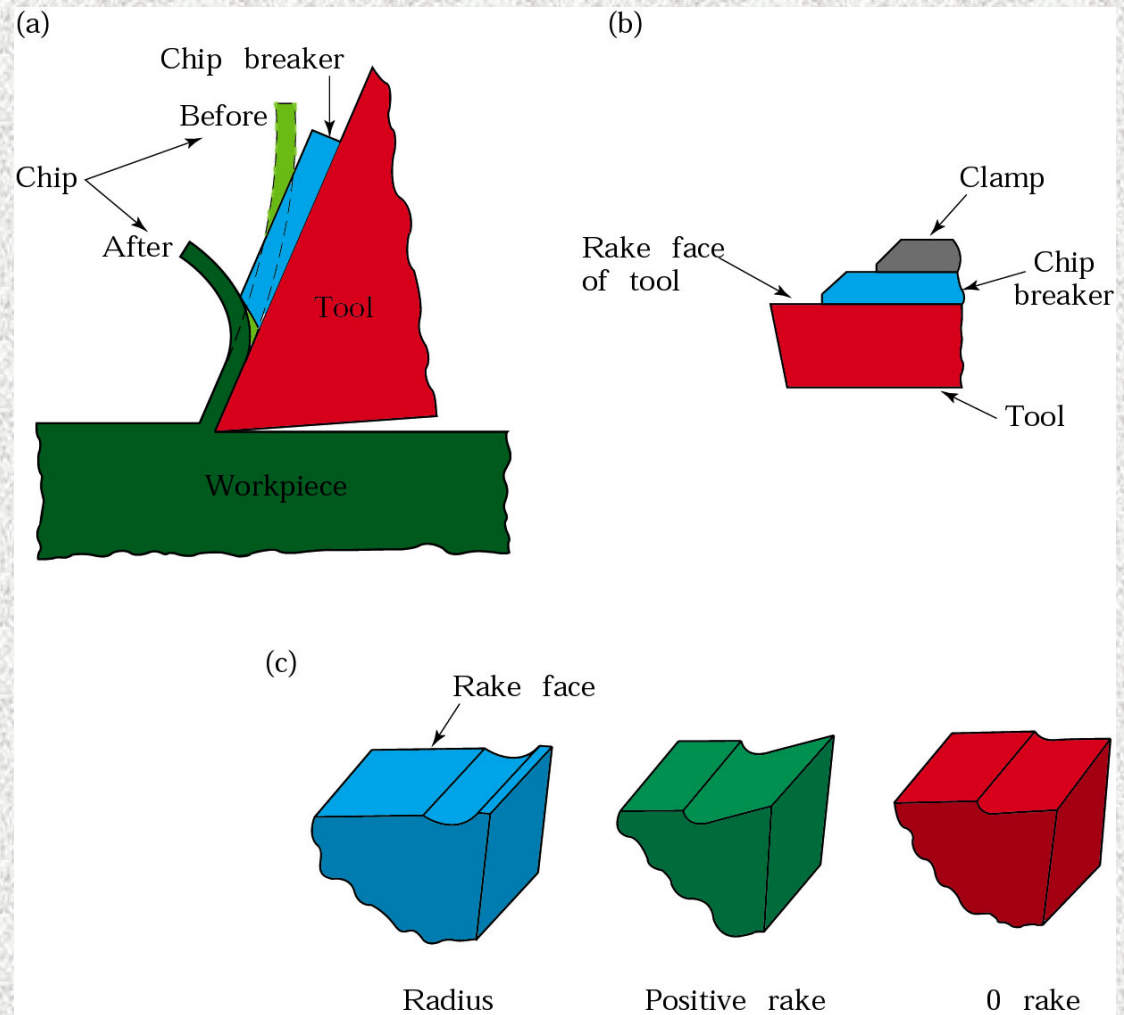


Figure 20.6 (a) Hardness distribution in the cutting zone for 3115 steel. Note that some regions in the built-up edge are as much as three times harder than the bulk metal. (b) Surface finish in turning 5130 steel with a built-up edge. (c) surface finish on 1018 steel in face milling. Magnifications: 15X. *Source:* Courtesy of Metcut Research Associates, Inc.

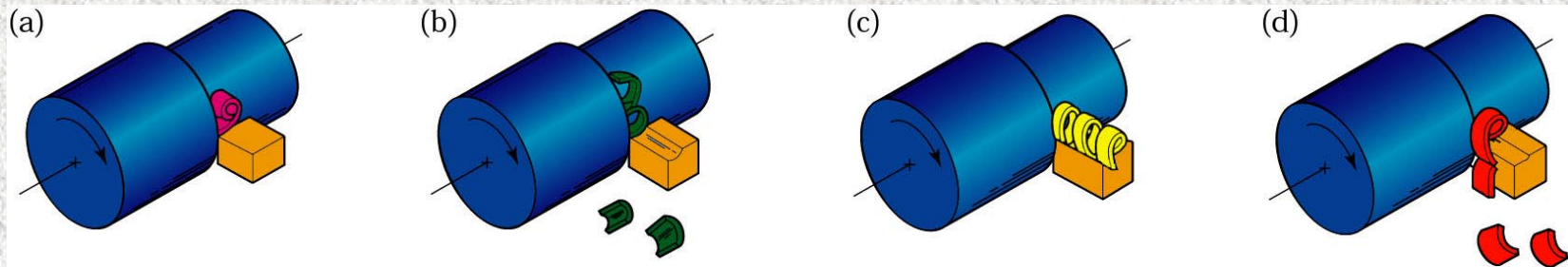
Chip Breakers

Figure 20.7 (a) Schematic illustration of the action of a chip breaker. Note that the chip breaker decreases the radius of curvature of the chip. (b) Chip breaker clamped on the rake face of a cutting tool. (c) Grooves in cutting tools acting as chip breakers; see also Fig. 21.2.



Examples of Chips Produced in Turning

Figure 20.8 Various chips produced in turning: (a) tightly curled chip; (b) chip hits workpiece and breaks; (c) continuous chip moving away from workpiece; and (d) chip hits tool shank and breaks off.
Source: G. Boothroyd, *Fundamentals of Metal Machining and Machine Tools*. Copyright ©1975; McGraw-Hill Publishing Company. Used with permission.



Cutting With an Oblique Tool

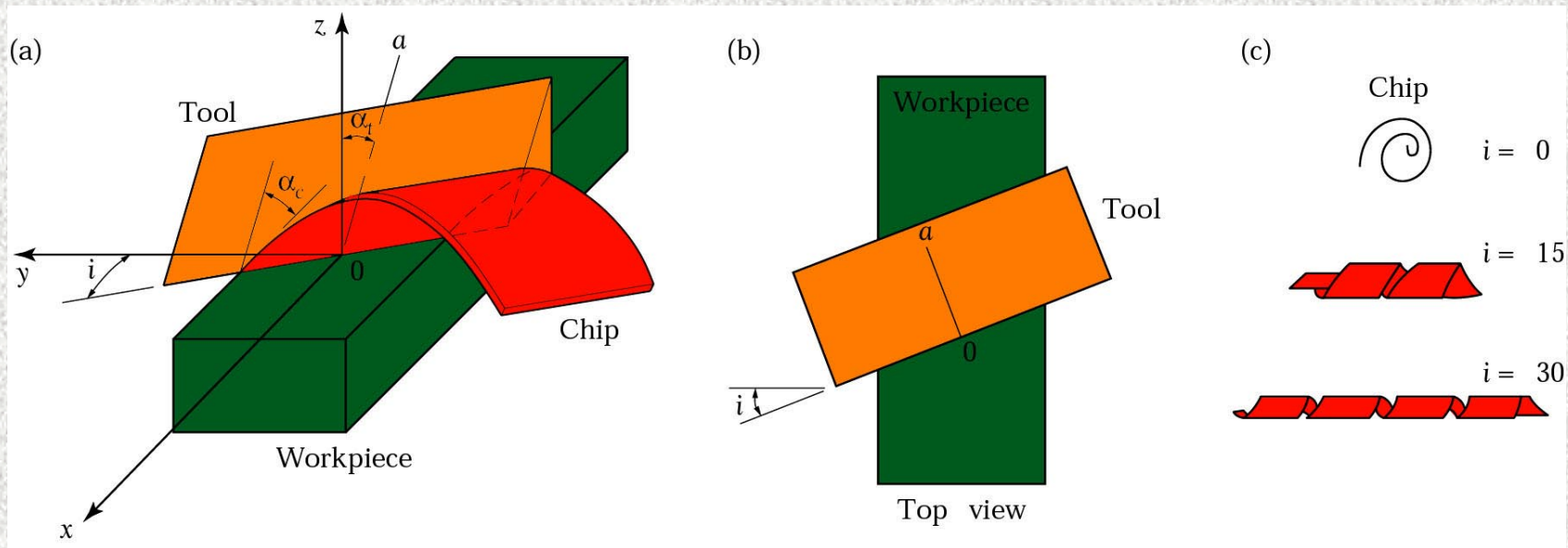
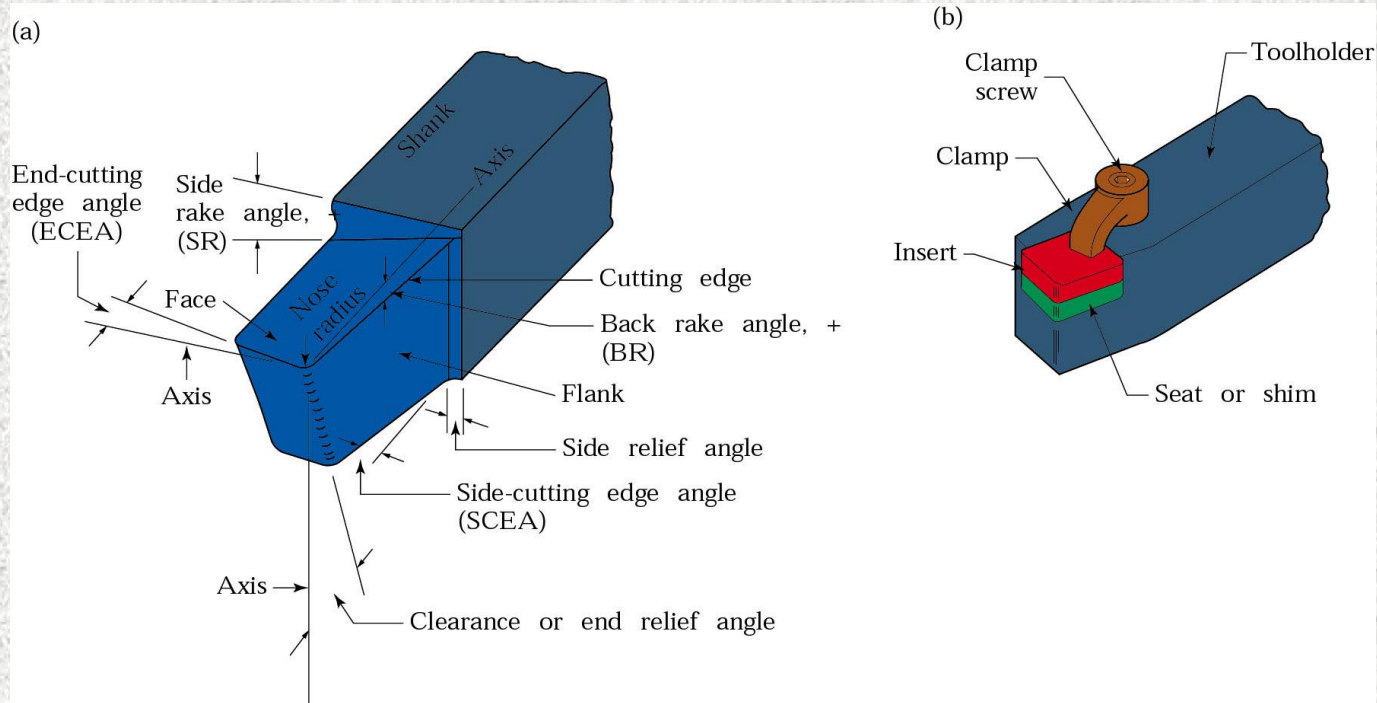


Figure 20.9 (a) Schematic illustration of cutting with an oblique tool. (b) Top view showing the inclination angle, i . (c) Types of chips produced with different inclination.

Right-Hand Cutting Tool

Figure 20.10 (a) Schematic illustration of a right-hand cutting tool. Although these tools have traditionally been produced from solid tool-steel bars, they have been largely replaced by carbide or other inserts of various shapes and sizes, as shown in (b). The various angles on these tools and their effects on machining are described in Section 22.3.1.



Forces in Two-Dimensional Cutting

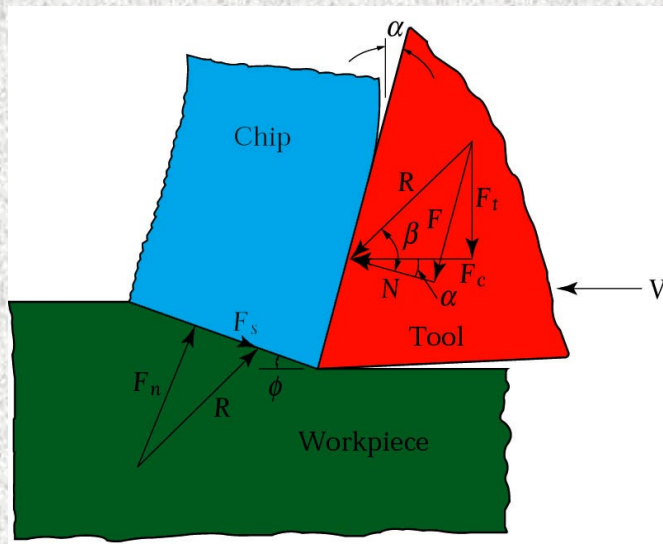


Figure 20.11 Forces acting on a cutting tool in two-dimensional cutting. Note that the resultant force, R , must be colinear to balance the forces.

Approximate Energy Requirements in Cutting Operations

TABLE 20.2 Approximate Energy Requirements in Cutting Operations (at drive motor, corrected for 80% efficiency; multiply by 1.25 for dull tools).

Material	Specific energy	
	W-s/mm ³	hp-min/in. ³
Aluminum alloys	0.4–1.1	0.15–0.4
Cast irons	1.6–5.5	0.6–2.0
Copper alloys	1.4–3.3	0.5–1.2
High-temperature alloys	3.3–8.5	1.2–3.1
Magnesium alloys	0.4–0.6	0.15–0.2
Nickel alloys	4.9–6.8	1.8–2.5
Refractory alloys	3.8–9.6	1.1–3.5
Stainless steels	3.0–5.2	1.1–1.9
Steels	2.7–9.3	1.0–3.4
Titanium alloys	3.0–4.1	1.1–1.5

Temperature Distribution and Heat Generated

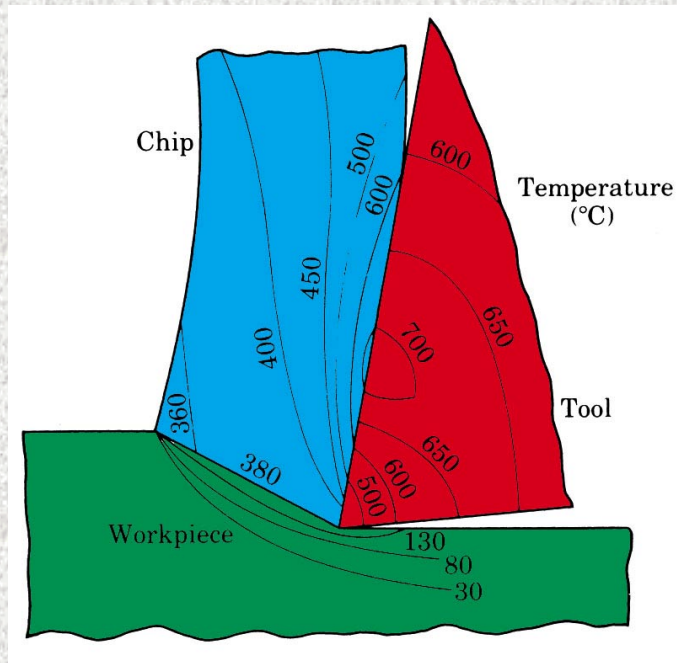
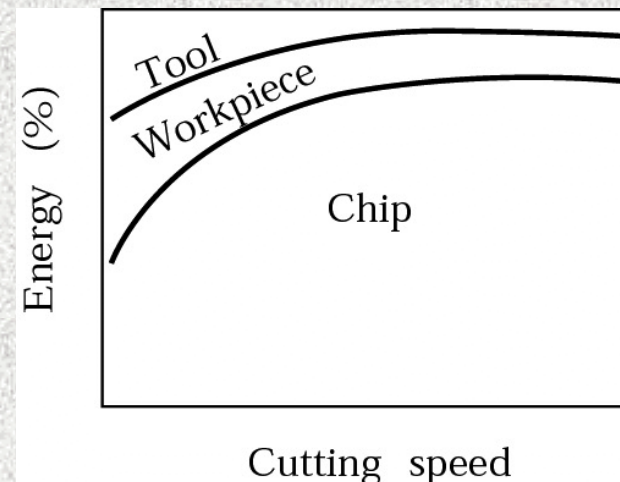


Figure 20.12 Typical temperature distribution the cutting zone. Note the steep temperature gradients within the tool and the chip. *Source: G. Vieregge.*

Figure 20.14 Percentage of the heat generated in cutting going into the workpiece, tool, and chip, as a function of cutting speed. Note that the chip carries away most of the heat.



Temperature Distributions

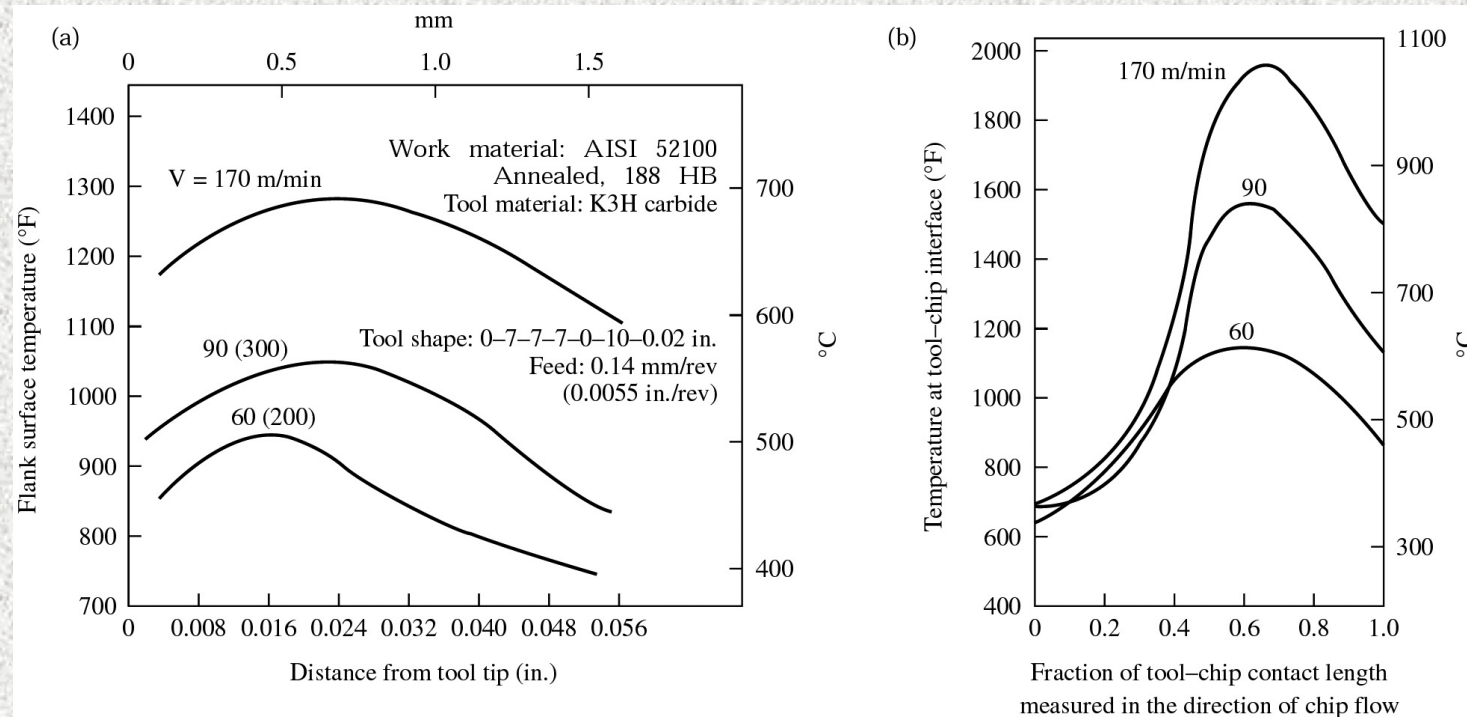


Figure 20.13 Temperatures developed in turning 52100 steel: (a) flank temperature distribution; and (b) tool-chip interface temperature distribution. *Source:* B. T. Chao and K. J. Trigger.

Flank and Crater Wear

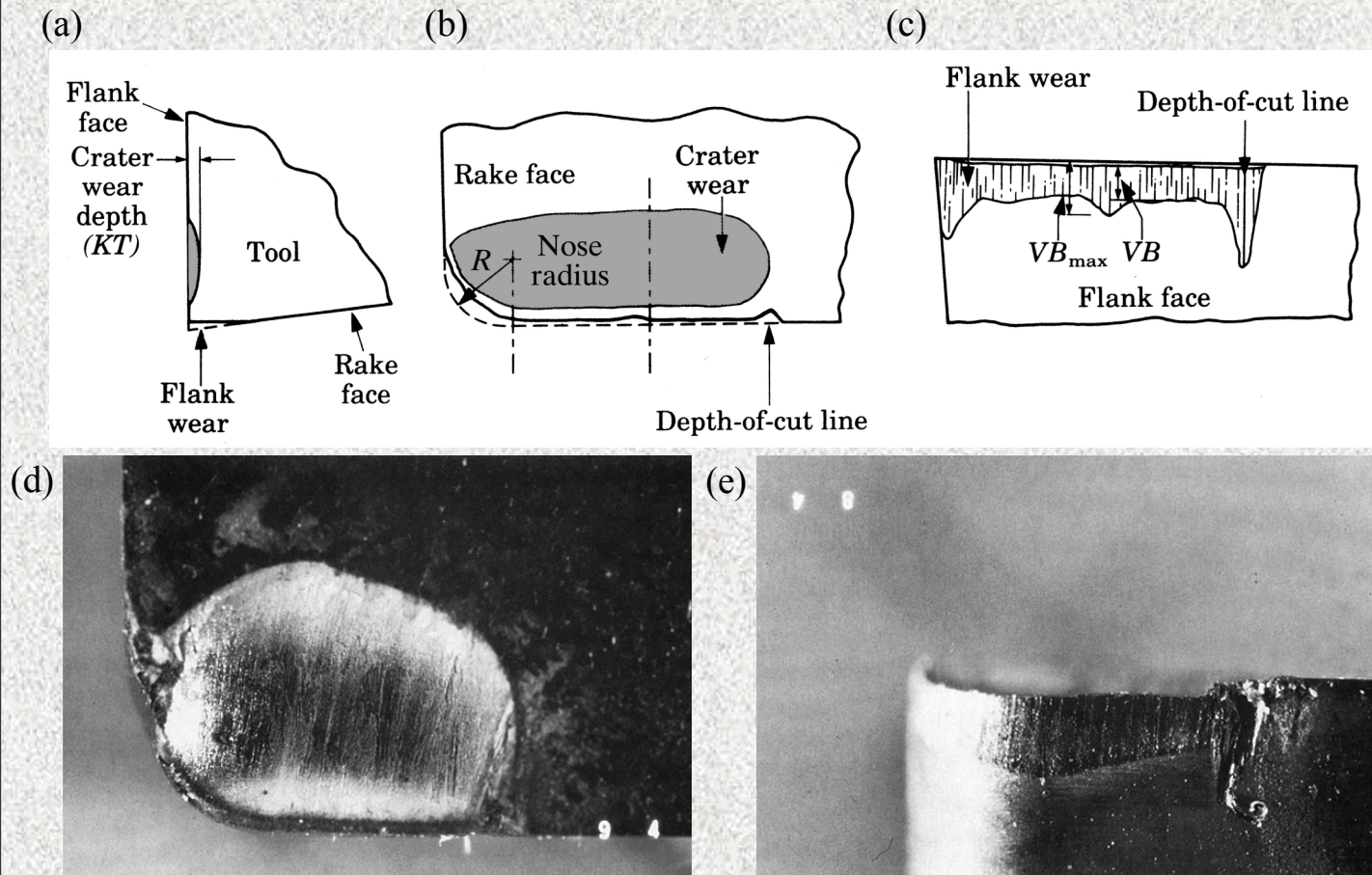


Figure 20.15 (a) Flank and crater wear in a cutting tool. Tool moves to the left. (b) View of the rake face of a turning tool, showing nose radius R and crater wear pattern on the rake face of the tool. (c) View of the flank face of a turning tool, showing the average flank wear land VB and the depth-of-cut line (wear notch). See also Fig. 20.18. (d) Crater and (e) flank wear on a carbide tool. *Source:* J.C. Keefe, Lehigh University.

Tool Life

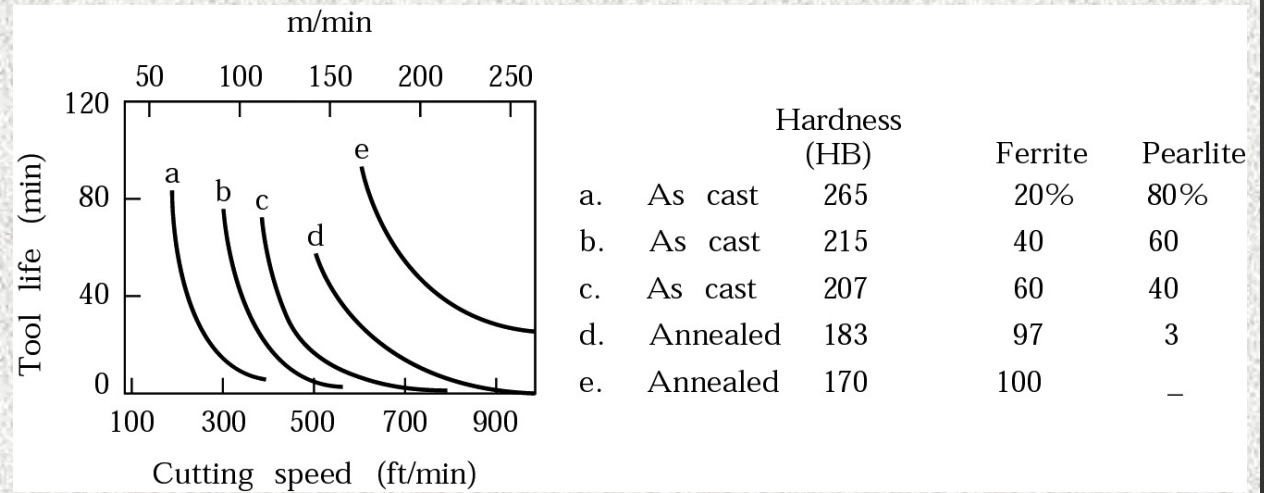


Figure 20.16 Effect of workpiece microstructure and hardness on tool life in turning ductile cast iron. Note the rapid decrease in tool life as the cutting speed increases. Tool materials have been developed that resist high temperatures such as carbides, ceramics, and cubic boron nitride, as described in Chapter 21.

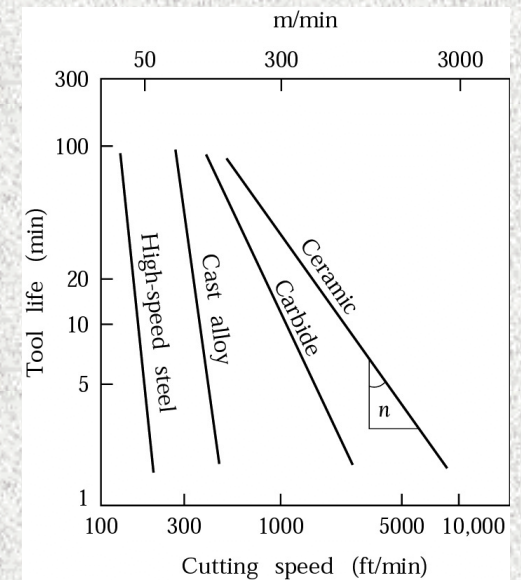


Figure 20.17 Tool-life curves for a variety of cutting-tool materials. The negative inverse of the slope of these curves is the exponent n in the Taylor tool-life equations and C is the cutting speed at $T = 1$ min.

Tool Wear

TABLE 20.3 Range of n Values for Eq. (20.20) for Various Tool Materials

High-speed steels	0.08–0.2
Cast alloys	0.1–0.15
Carbides	0.2–0.5
Ceramics	0.5–0.7

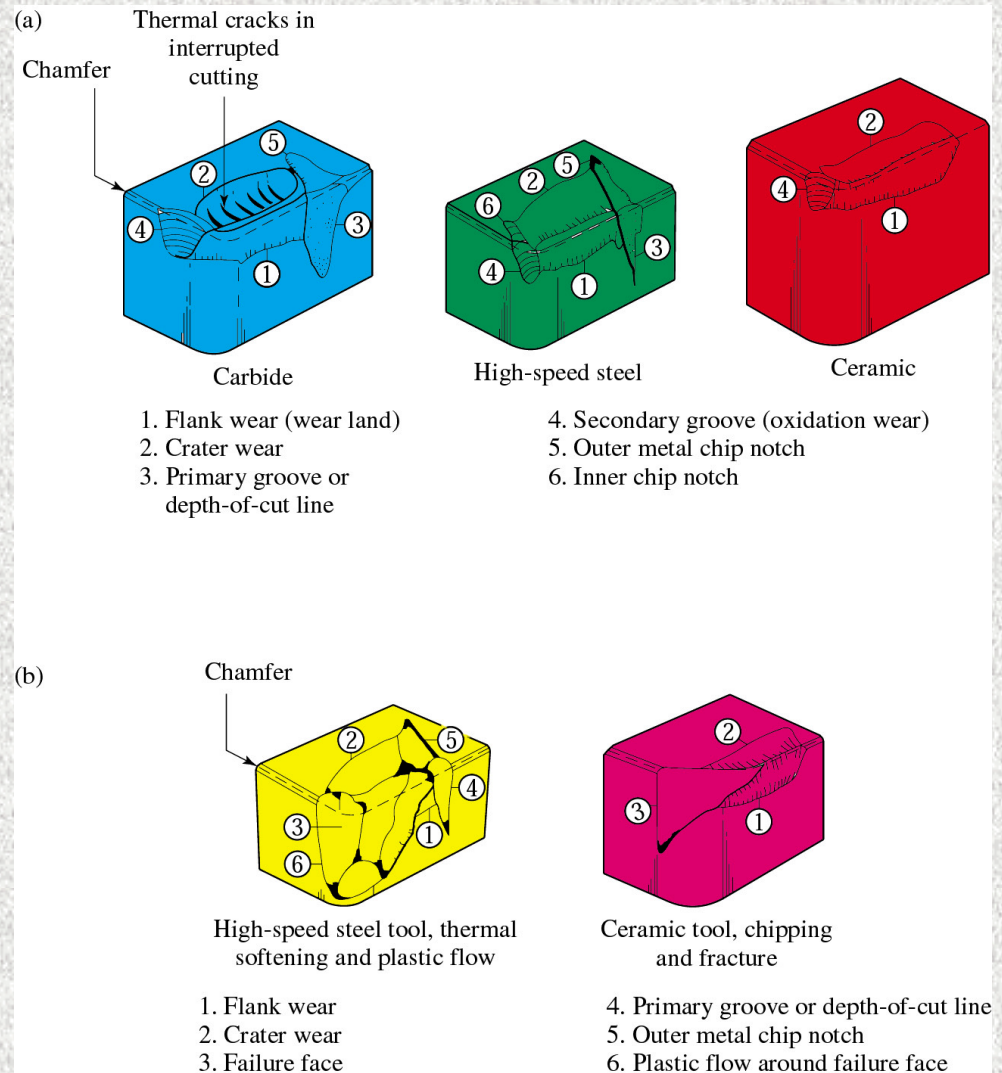
TABLE 20.4 Allowable Average Wear Land (VB) for Cutting Tools in Various Operations

Operation	Allowable wear land (mm)	
	High-speed Steels	Carbides
Turning	1.5	0.4
Face milling	1.5	0.4
End milling	0.3	0.3
Drilling	0.4	0.4
Reaming	0.15	0.15

Note: 1 mm = 0.040 in.

Examples of Wear and Tool Failures

Figure 20.18 (a) Schematic illustrations of types of wear observed on various types of cutting tools. (b) Schematic illustrations of catastrophic tool failures. A study of the types and mechanisms of tool wear and failure is essential to the development of better tool materials.



Crater Wear

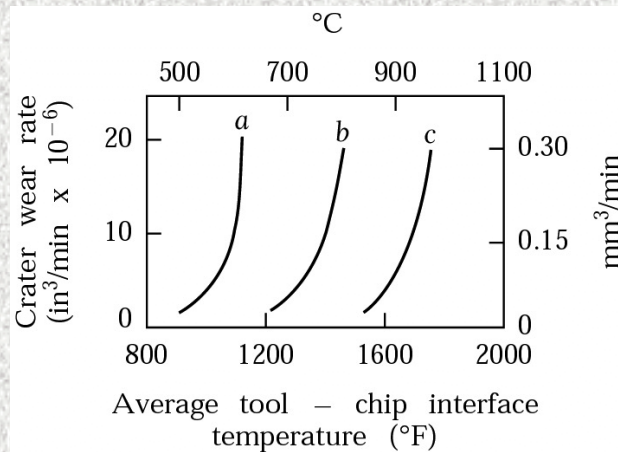
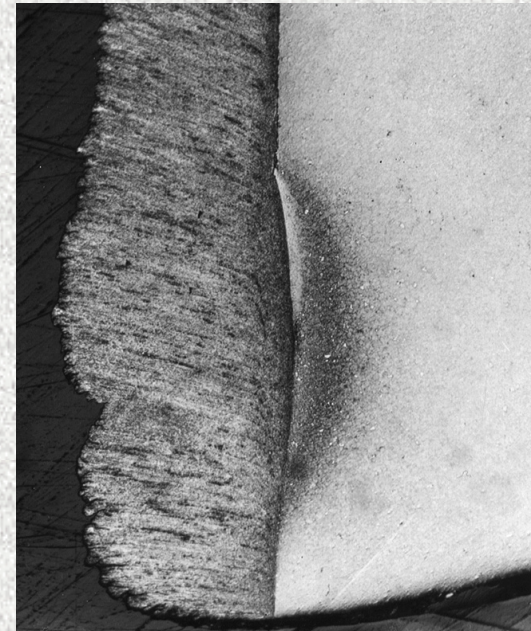


Figure 20.19 Relationship between crater-wear rate and average tool-chip interface temperature: (a) High-speed steel; (b) C-1 carbide; and (c) C-5 carbide. Note how rapidly crater-wear rate increases as the temperature increases. *Source:* B. T. Chao and K. J. Trigger.

Figure 20.20 Cutting tool (right) and chip (left) interface in cutting plain-carbon steel. The discoloration of the tool indicates the presence of high temperatures. Compare this figure with Fig. 20.12. *Source:* P. K. Wright.



Surfaces Produced by Cutting

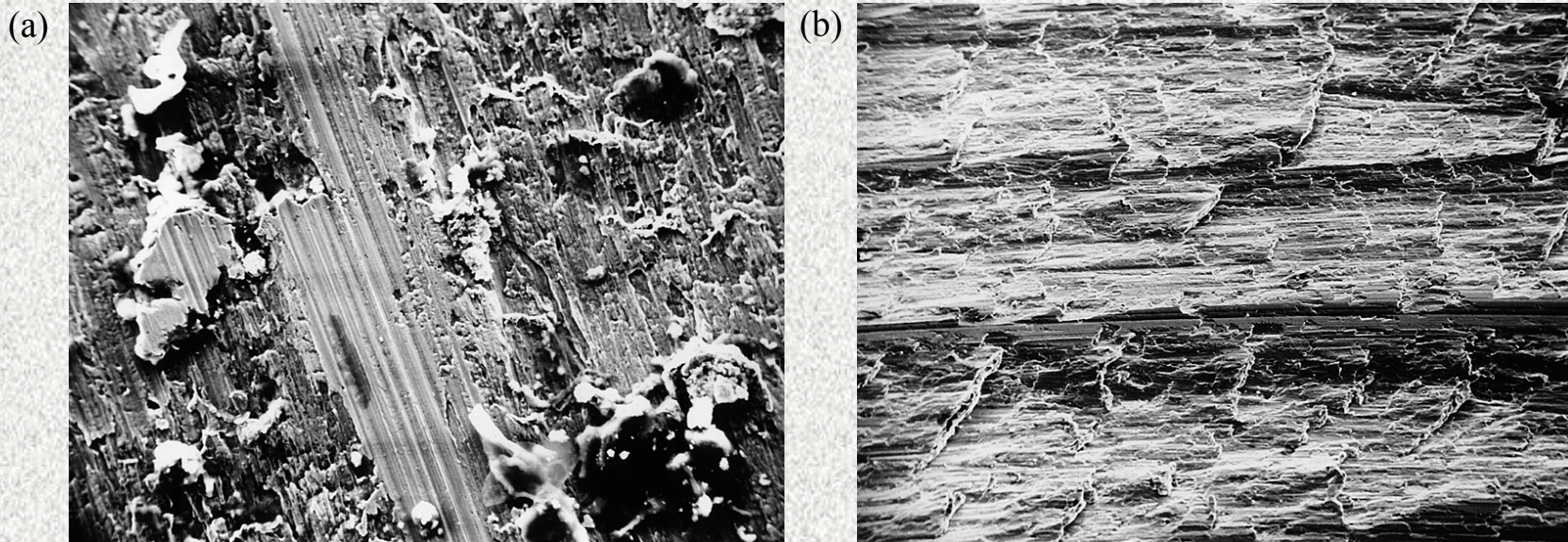


Figure 20.21 Surfaces produced on steel by cutting, as observed with a scanning electron microscope: (a) turned surface and (b) surface produced by shaping. *Source:* J. T. Black and S. Ramalingam.

Dull Tool in Orthogonal Cutting and Feed Marks

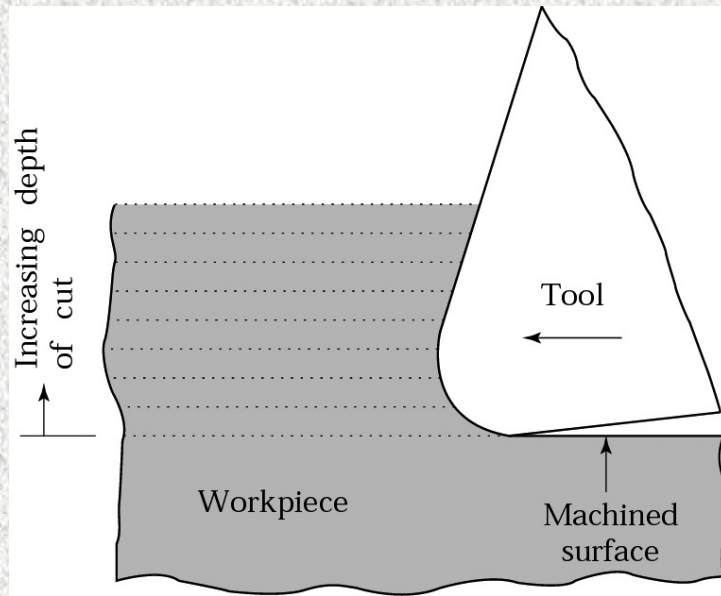


Figure 20.22 Schematic illustration of a dull tool in orthogonal cutting (exaggerated). Note that at small depths of cut, the positive rake angle can effectively become negative, and the tool may simply ride over and burnish the workpiece surface.

Figure 20.23 Schematic illustration of feed marks in turning (highly exaggerated). See also Fig. 20.2.

