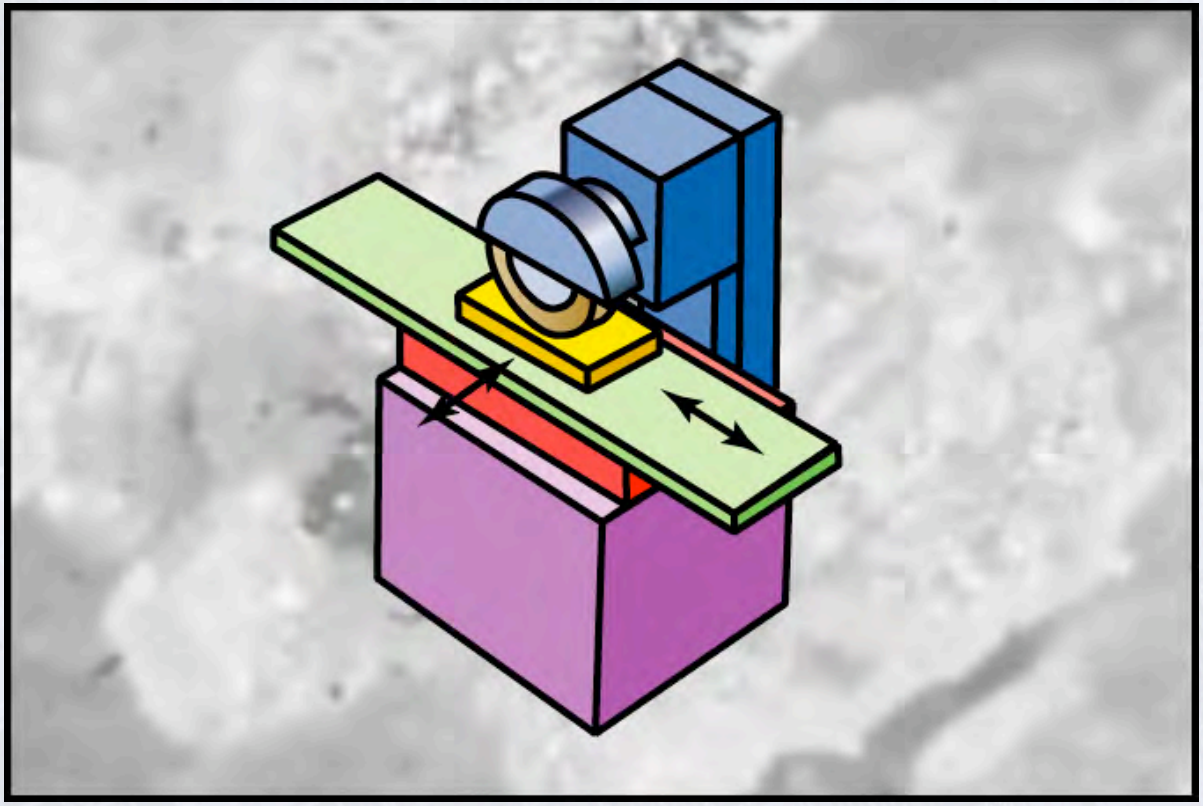
Chapter 26

Abrasive Machining and Finishing Operations



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Bonded Abrasives Used in Abrasive-Machining Processes

Figure 25.1 A variety of bonded abrasives used in abrasive-machining processes. *Source*: Courtesy of Norton Company.

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Workpieces and Operations Used in Grinding

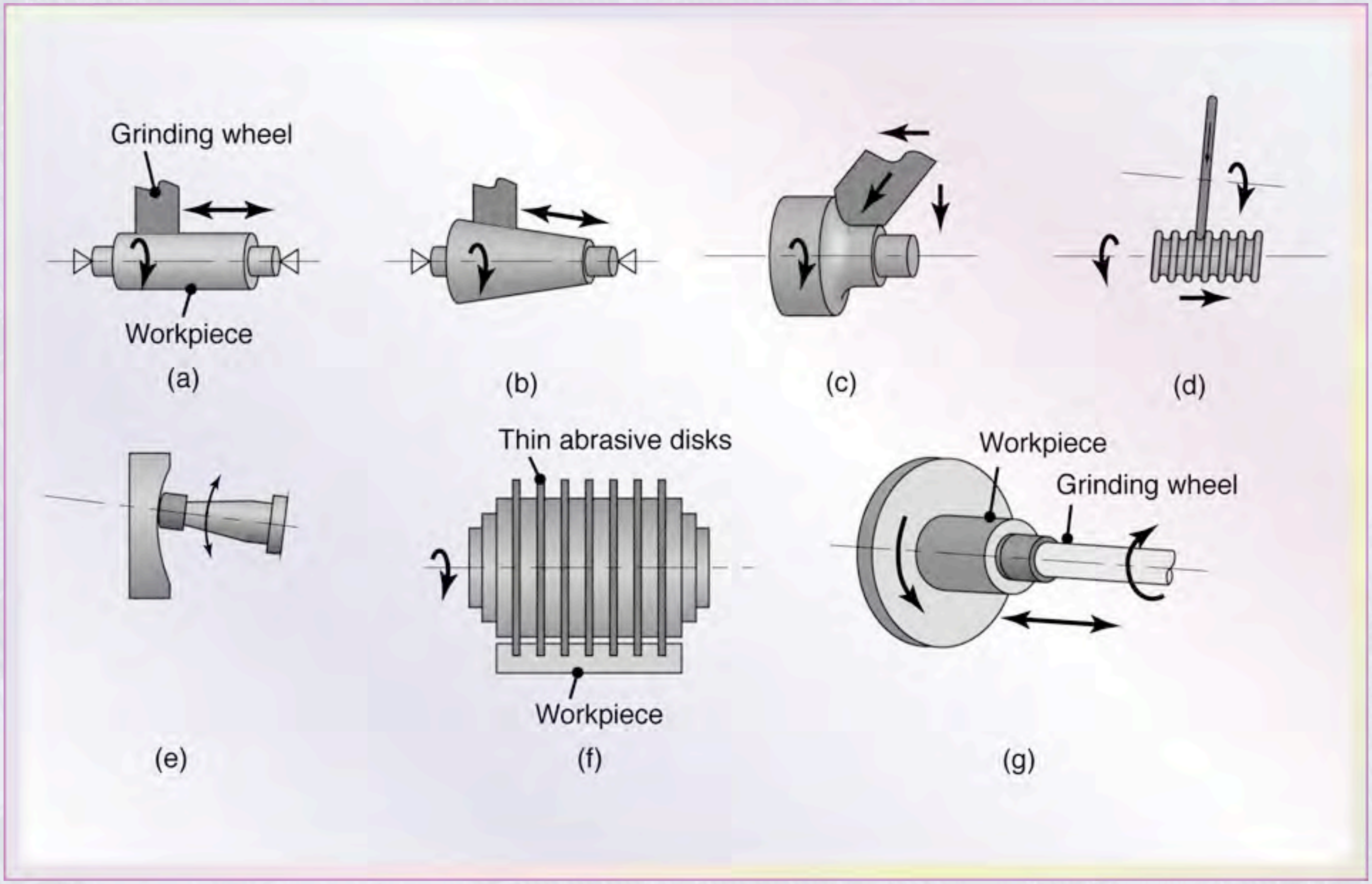

Figure 26.2 The types of workpieces and operations typical of grinding: (a) cylindrical surfaces, (b) conical surfaces. (c) fillets on a shaft, (d) helical profiles, (e) concave shape, (f) cutting off or slotting with thin wheels, and (g) internal grinding.

Ranges of Knoop Hardness for Various Materials and Abrasives

TABLE 26.1

Ranges of Knoop Hardness for Various Materials and Abrasives

Common glass	350–500	Titanium nitride	2000
Flint, quartz	800–1100	Titanium carbide	1800–3200
Zirconium oxide	1000	Silicon carbide	2100–3000
Hardened steels	700–1300	Boron carbide	2800
Tungsten carbide	1800–2400	Cubic boron nitride	4000–5000
Aluminum oxide	2000–3000	Diamond	7000–8000

Grinding Wheel Model

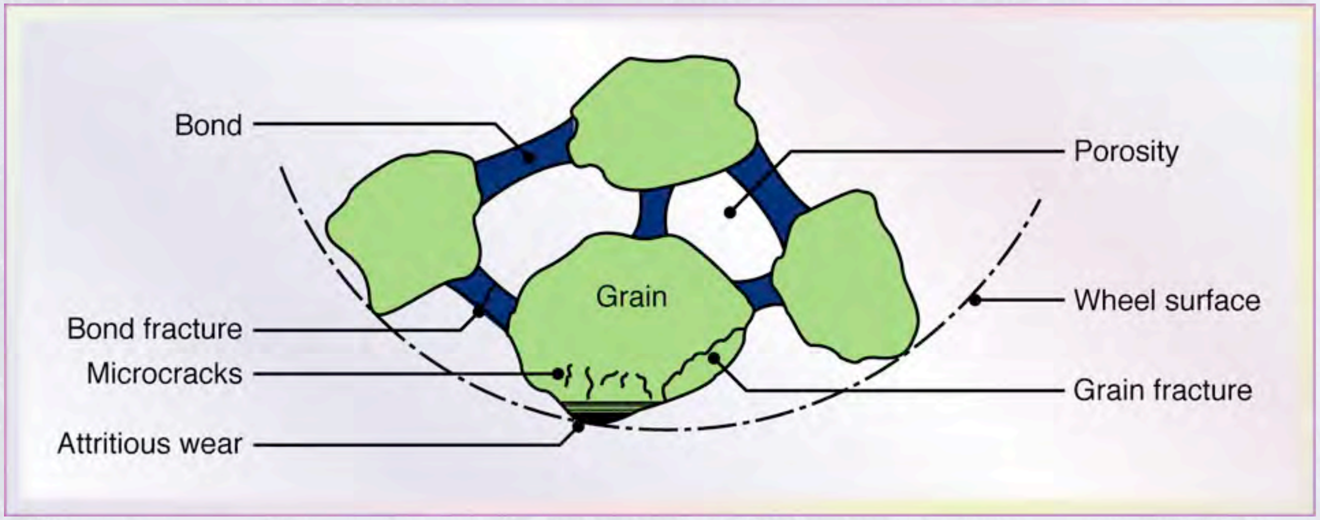

Figure 26.3 Schematic illustration of a physical model of a grinding wheel showing its structure and wear and fracture patterns.

Grinding Wheels

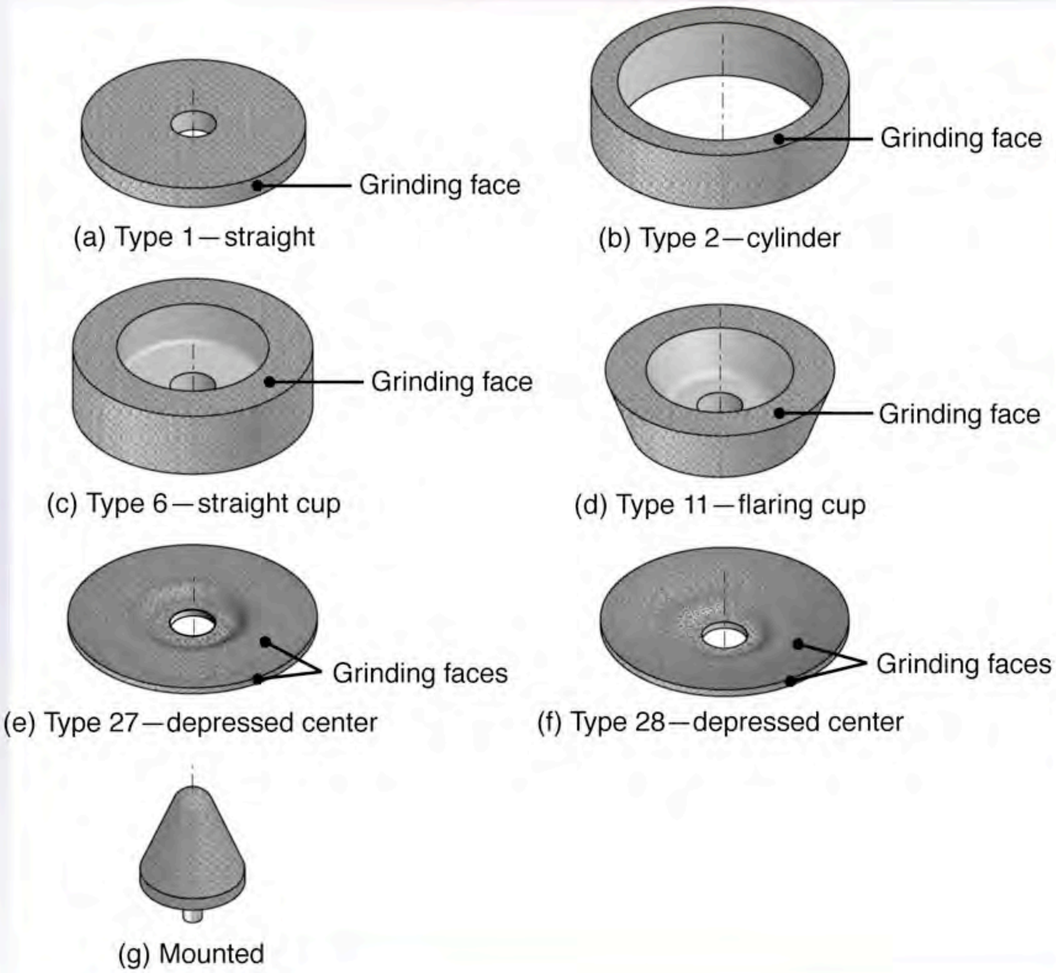

Figure 26.4 Common types of grinding wheels made with conventional abrasives. Note that each wheel has a specific grinding face; grinding on other surfaces is improper and unsafe.

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Superabrasive Wheel Configurations

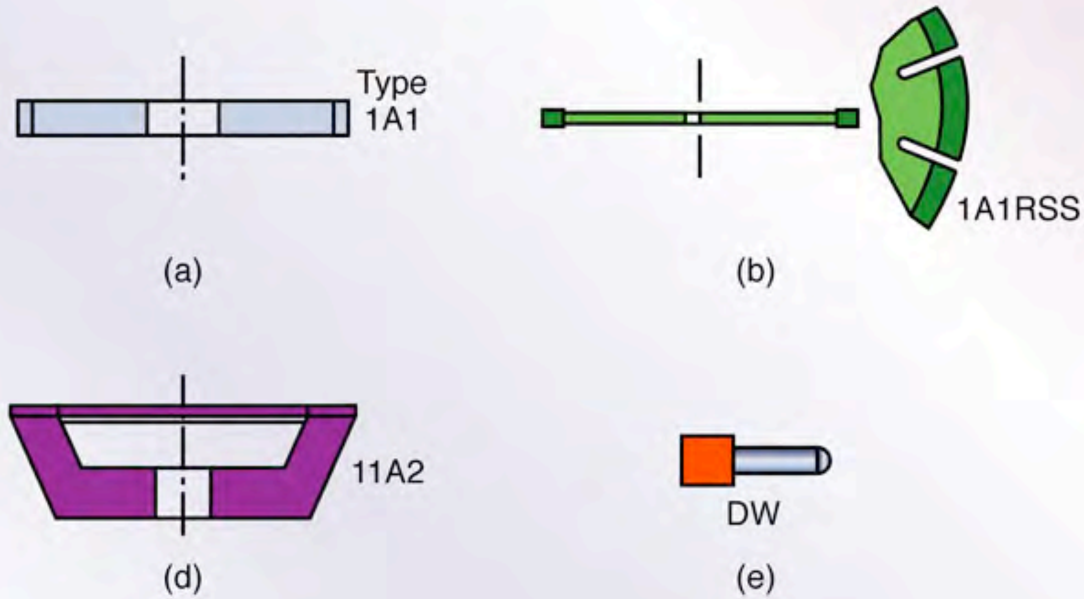

Figure 26.5 Examples of superabrasive wheel configurations. The annular regions (rim) are superabrasive grinding surfaces, and the wheel itself (core) generally is made of metal or composites. The bonding materials for the superabrasives are: (a), (d) and (e) resinoid, metal, or vitrified; (b) metal; (c) vitrified; and (f) resinoid.

Standard Marking System for Aluminum-Oxide and Silicon-Carbide Bonded Abrasives

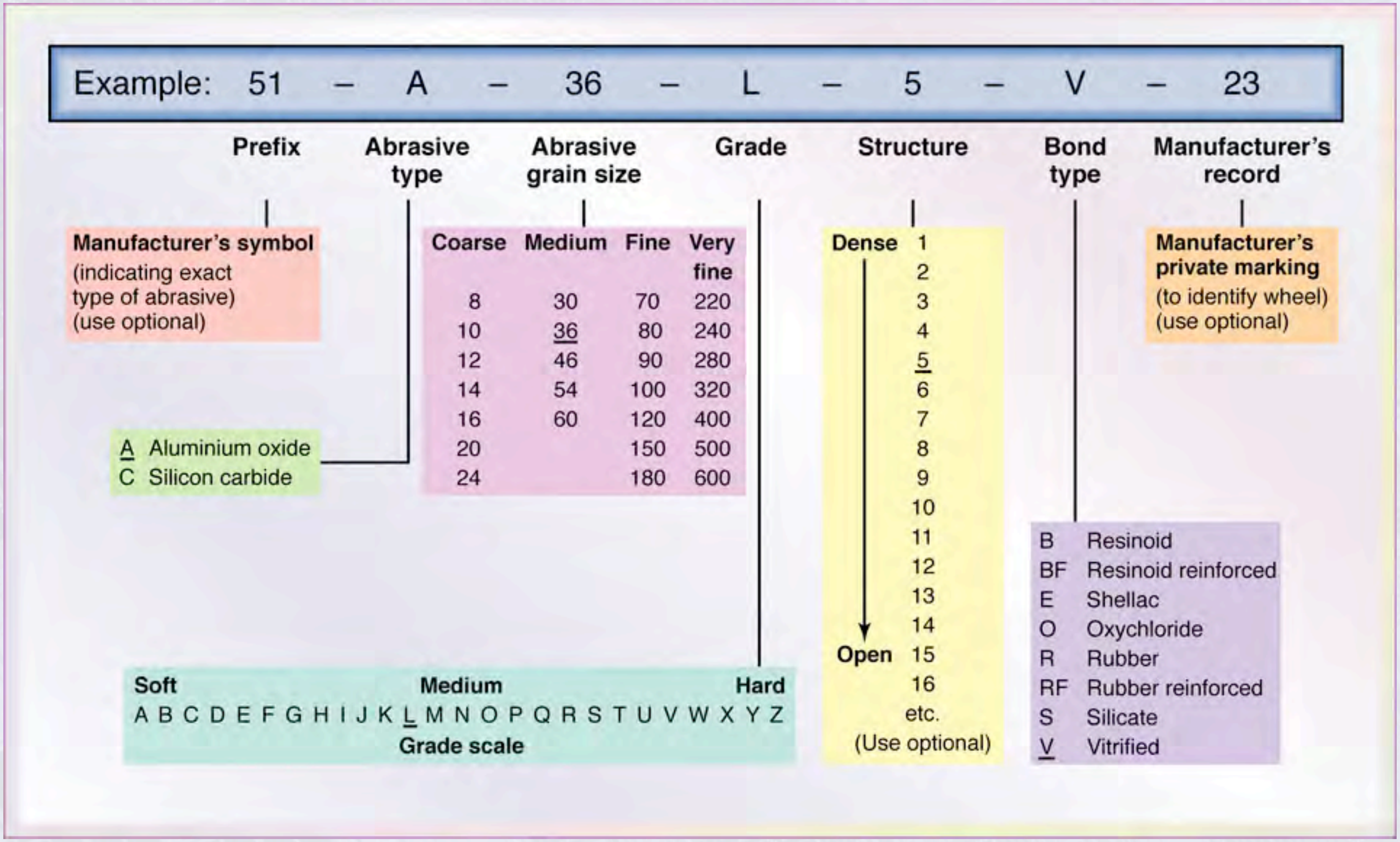

Figure 26.6 Standard marking system for aluminum-oxide and silicon-carbide bonded abrasives.

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Standard Marking System for Cubic-Boron-Nitride and Diamond Bonded Abrasives

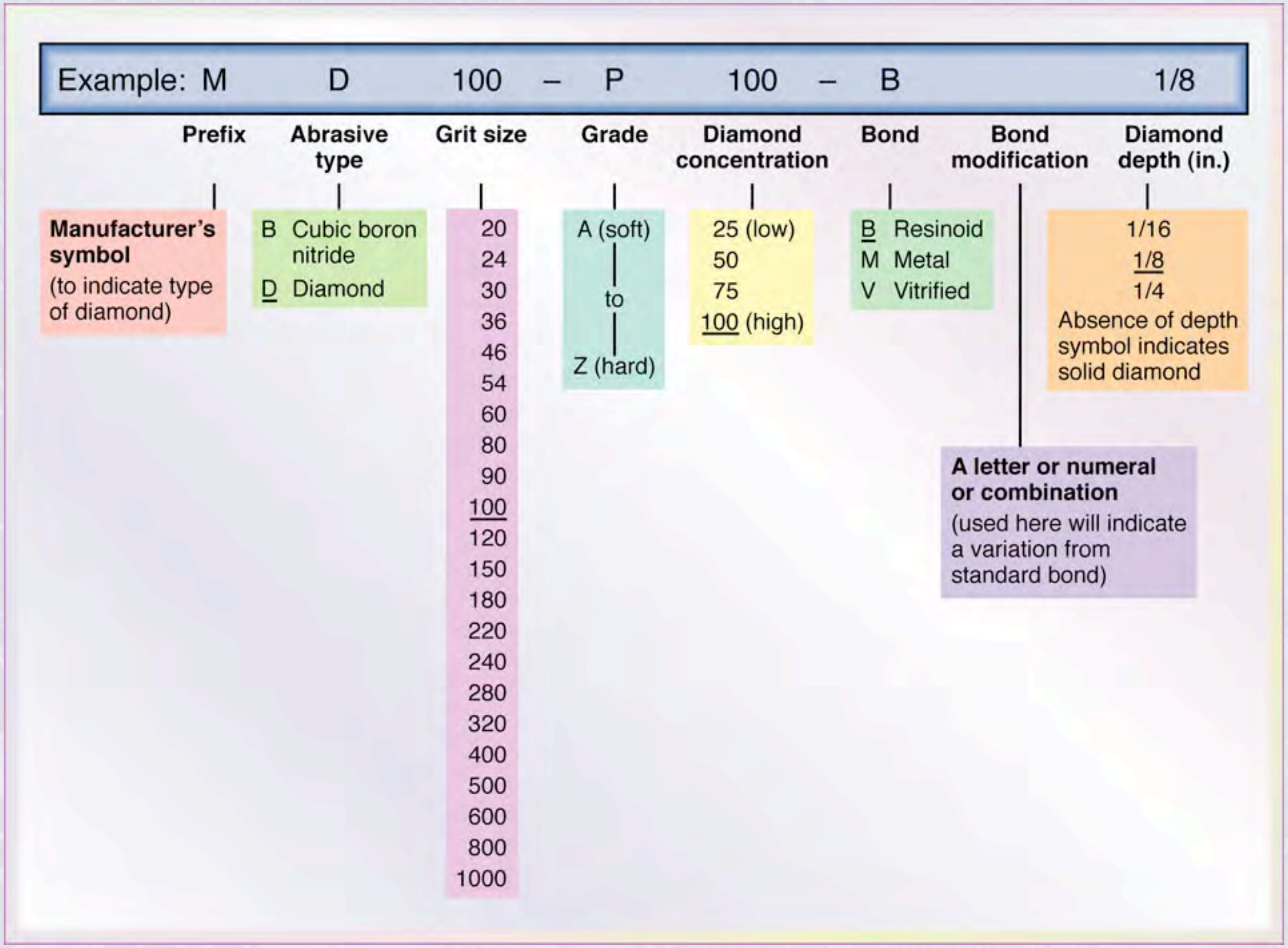

Figure 26.7 Standard marking system for cubic-boron-nitride and diamond bonded abrasives.

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Chip Formation by Abrasive Grain

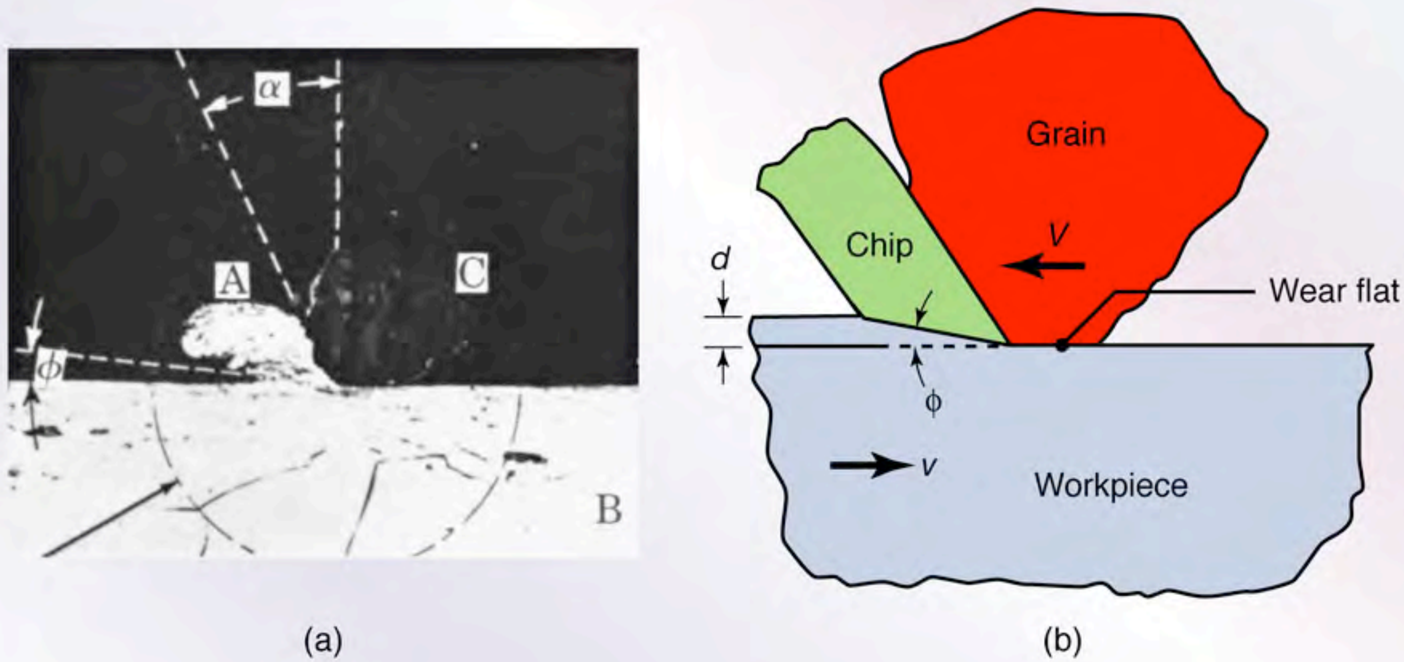

Figure 26.8 (a) Grinding chip being produced by a single abrasive grain: (A) chip, (B) workpiece, (C) abrasive grain. Note the large negative rake angle of the grain. The inscribed circle is 0.065 mm (0.0025 in.) in diameter. (b) Schematic illustration of chip formation by an abrasive grain with a wear flat. Note the negative rake angle of the grain and the small shear angle. *Source:* (a) After M.E. Merchant.

Grinding Wheel Surface

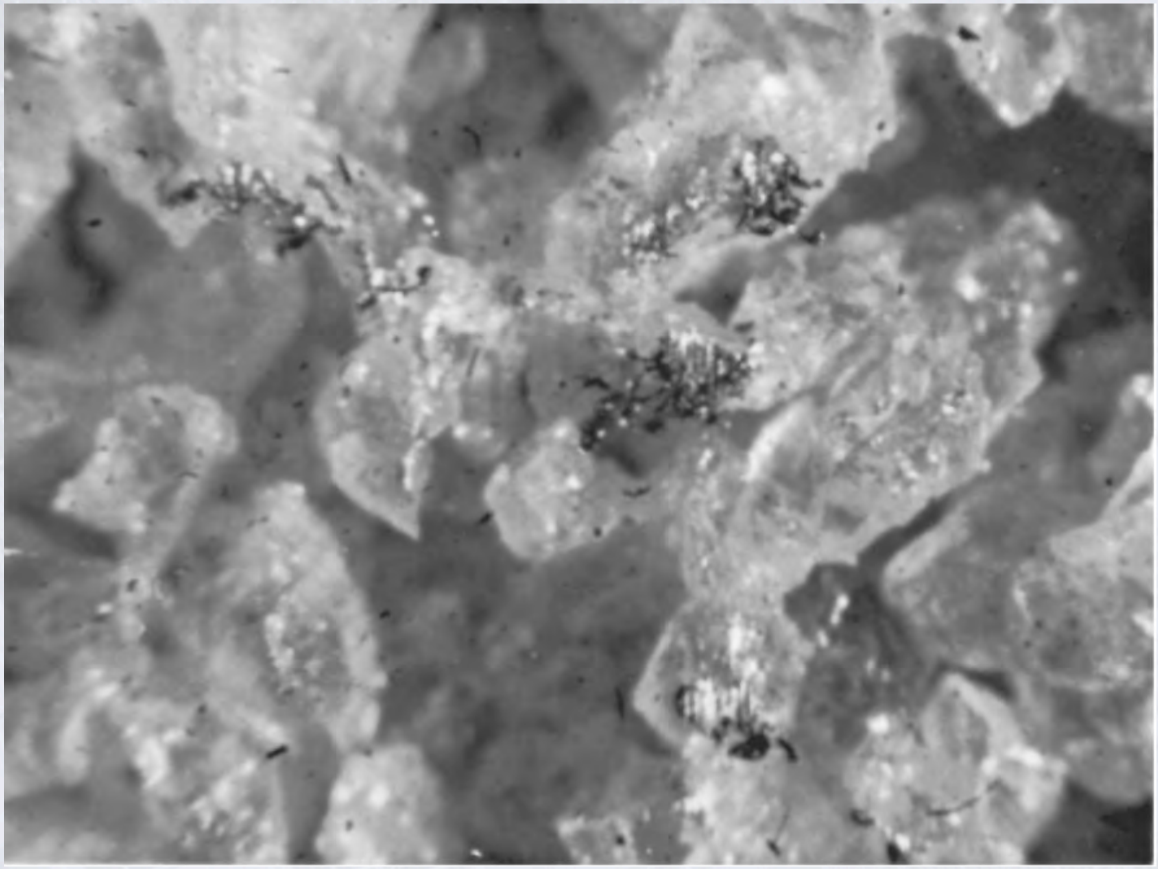

Figure 26.9 The surface of a grinding wheel (A46-J8V) showing abrasive grains, wheel porosity, wear flats on grains, and metal chips from the workpiece adhering to the grains. Note the random distribution and shape of the abrasive grains. Magnification: 50x. *Source*: S. Kalpakjian.

Surface-Grinding

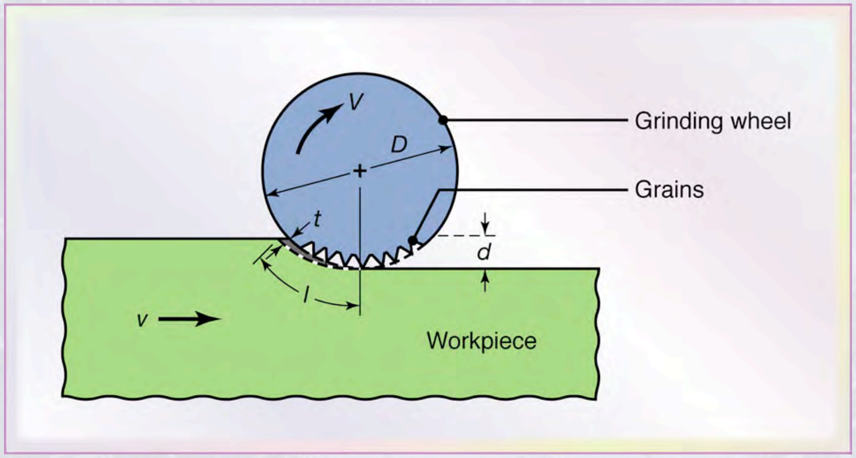

Figure 26.10 Schematic illustration of the surface-grinding process, showing various process variables. The figure depicts conventional (up) grinding.

$$\text{Undeformed chip length, } l = \sqrt{Dd}$$

$$\text{Undeformed chip thickness, } t = \sqrt{\left(\frac{4v}{VCr}\right)\sqrt{\left(\frac{d}{D}\right)}}$$

$$\text{Grain force } \propto \left(\frac{v}{V}\sqrt{\frac{d}{D}}\right)(\text{strength of the material})$$

$$\text{Temperature rise } \propto D^{1/4} d^{3/4} \left(\frac{V}{v}\right)^{1/2}$$

$$\text{Grinding ratio, } G = \frac{\text{Volume of material removed}}{\text{Volume of wheel wear}}$$

Abrasive Grain Plowing Workpiece Surface

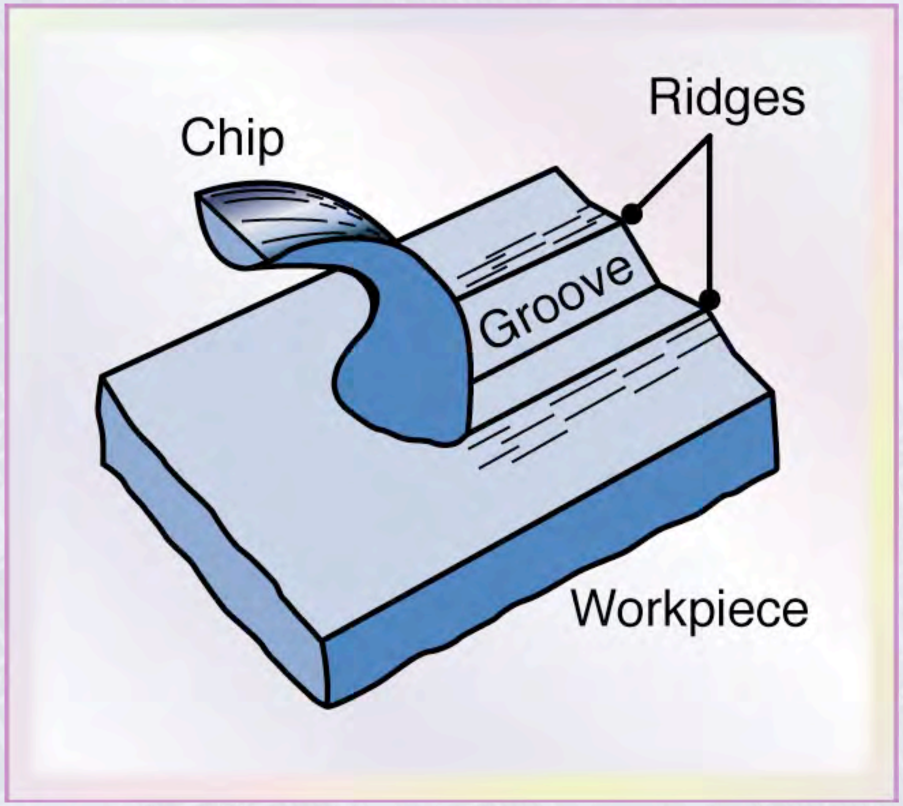

Figure 26.11 Chip formation and plowing of the workpiece surface by an abrasive grain.

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Approximate Specific-Energy Requirements for Surface Grinding

TABLE 26.2

Approximate Specific-Energy Requirements for Surface Grinding

		Specific energy	
Workpiece material	Hardness	W•s/mm^3	hp•min/in^3
Aluminum	150 HB	7-27	2.5-10
Cast iron (class 40)	215 HB	12-60	4.5-22
Low-carbon steel (1020)	110 HB	14-68	5-25
Titanium alloy	300 HB	16-55	6-20
Tool steel (T15)	67 HRC	18-82	6.5-30

Grinding-Wheel Dressing

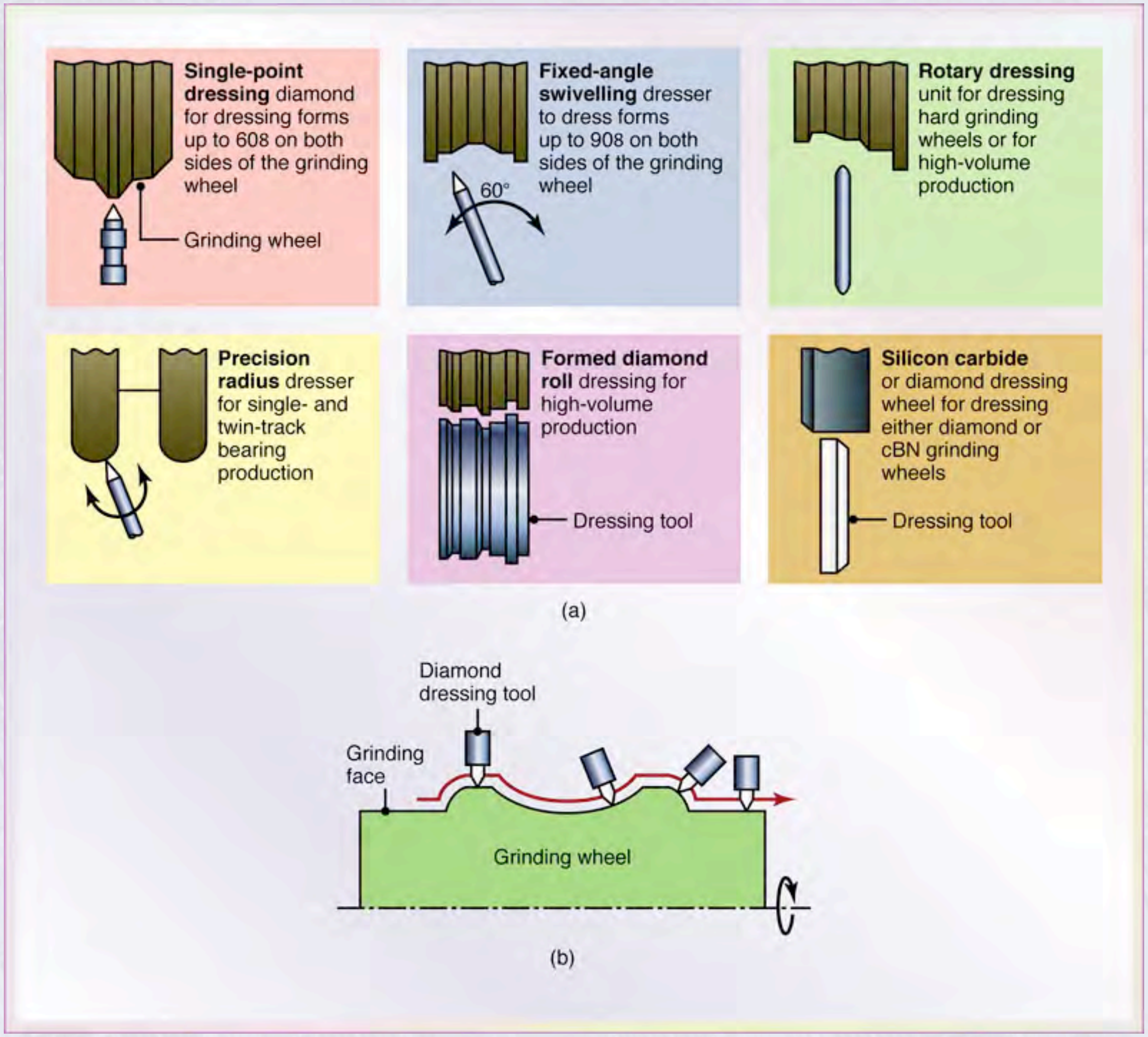

Figure 26.12 (a) Forms of grinding-wheel dressing. (b) Shaping the grinding face of a wheel by dressing it with computer control. Note that the diamond dressing tool is normal to the surface at point of contact with the wheel. *Source*: Courtesy of Okuma Machinery Works Ltd.

Typical Ranges of Speeds and Feeds for Abrasive Processes

TABLE 26.3

Typical Ranges of Speeds and Feeds for Abrasive Processes

Process variable	Grinding, conventional	Grinding, creep-feed	Polishing	Buffing
Wheel speed (m/min)	1500–3000	1500–3000	1500–2400	1800–3500
Work speed (m/min)	10–60	0.1–1	—	—
Feed (mm/pass)	0.01–0.05	1–6	—	—

General Characteristics of Abrasive Machining Processes and Machines

TABLE 26.4

General Characteristics of Abrasive Machining Processes and Machines

Process	Characteristics	Typical maximum dimensions length and diameter (m) *
Surface	Flat surfaces on most materials; production rate depends on table size and level of automation; labor skill depends on part complexity; production rate is high on vertical-spindle rotary-table machines	Reciprocating table L:6 Rotary table D:3
Cylindrical	Round workpieces with stepped diameters; low production rates unless automated; low to medium labor skill	Workpiece D: 0.8, roll grinders D:1.8, universal grinders D:2.5
Centerless	Round and slender workpieces; high production rate; low to medium labor skill	Workpiece D: 0.8
Internal	Holes in workpiece; low production rate; low to medium labor skill	Hole D:2
Honing	Holes in workpiece; low production rate; low labor skill	Spindle D:1.2
Lapping	Flat, cylindrical, or curved; high production rate; low labor skill	Table D: 3.7
Ultrasonic machining	Holes and cavities with various shapes; suitable for hard and brittle materials; medium labor skill	–

*Larger capacities are available for special applications.

Various Surface-Grinding Operations

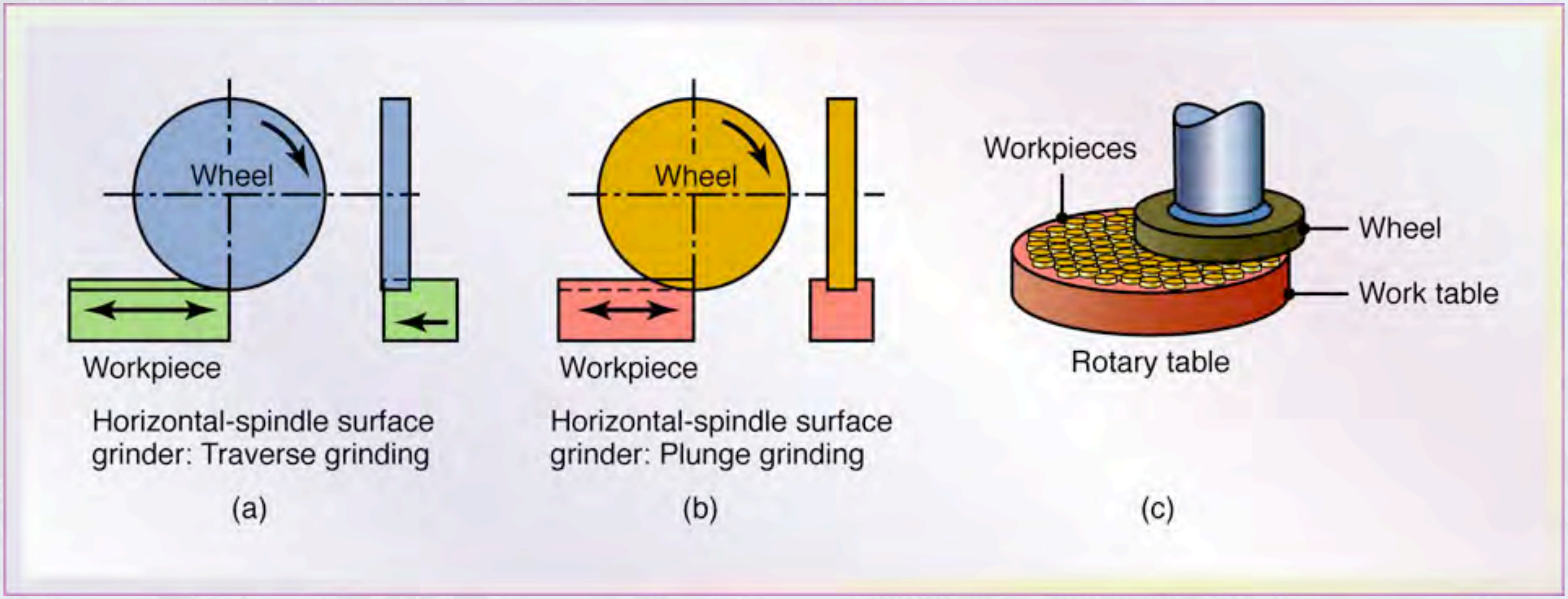

Figure 26.13 Schematic illustrations of various surface-grinding operations. (a) Traverse grinding with a horizontal-spindle surface grinder. (b) Plunge grinding with a horizontal-spindle surface grinder. (c) A vertical-spindle rotary-table grinder (also known as the *Blanchard* type.)

Horizontal-Spindle Surface Grinder

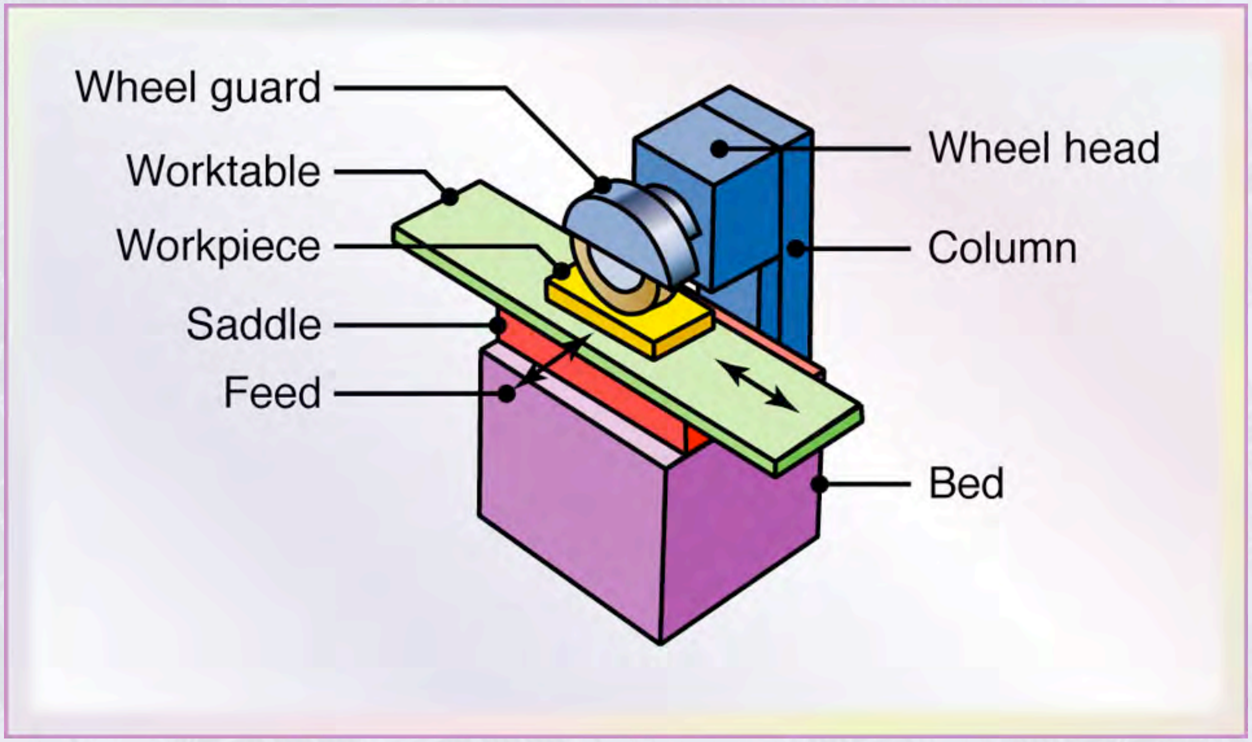

Figure 26.14 Schematic illustration of a horizontal-spindle surface grinder.

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Grinding of Balls

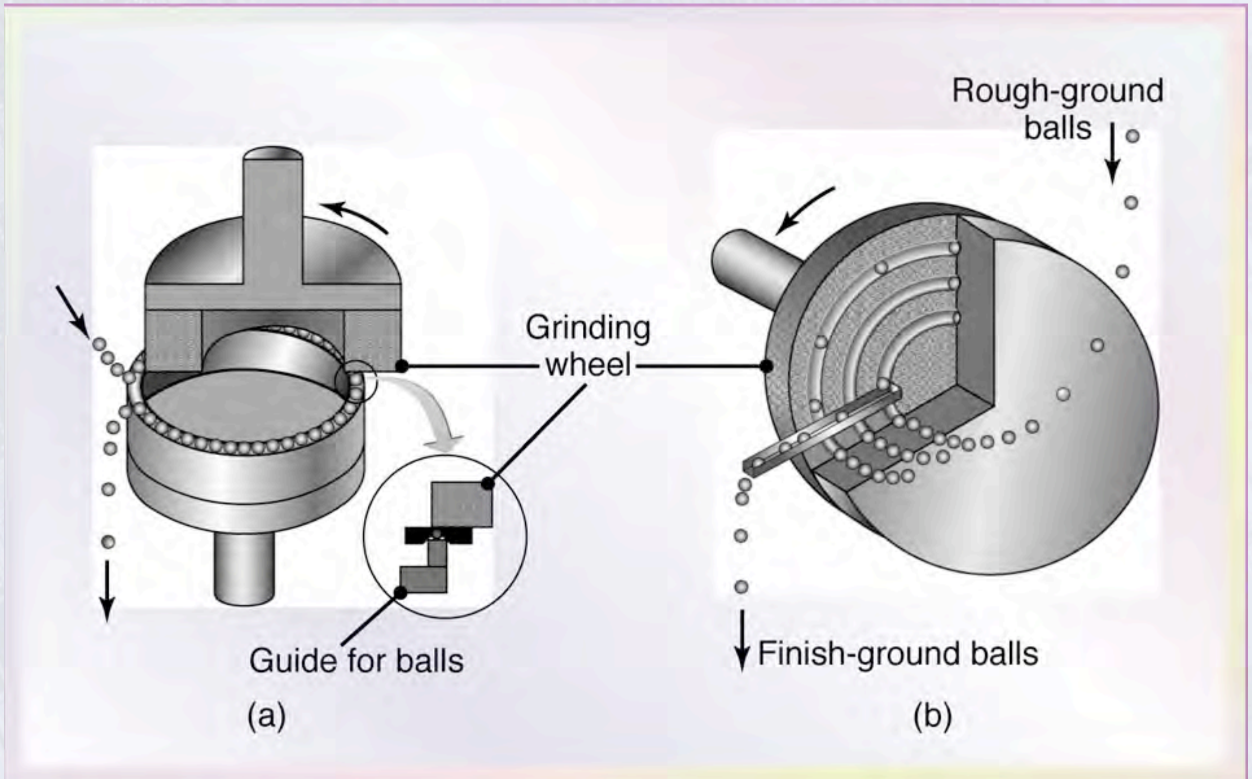

Figure 26.15 (a) Rough grinding of steel balls on a vertical-spindle grinder. The balls are guided by a special rotary fixture. (b) Finish grinding of balls in a multiple-groove fixture. The balls are ground to within 0.013 mm (0.0005 in.) of their final size.

Cylindrical-Grinding Operations

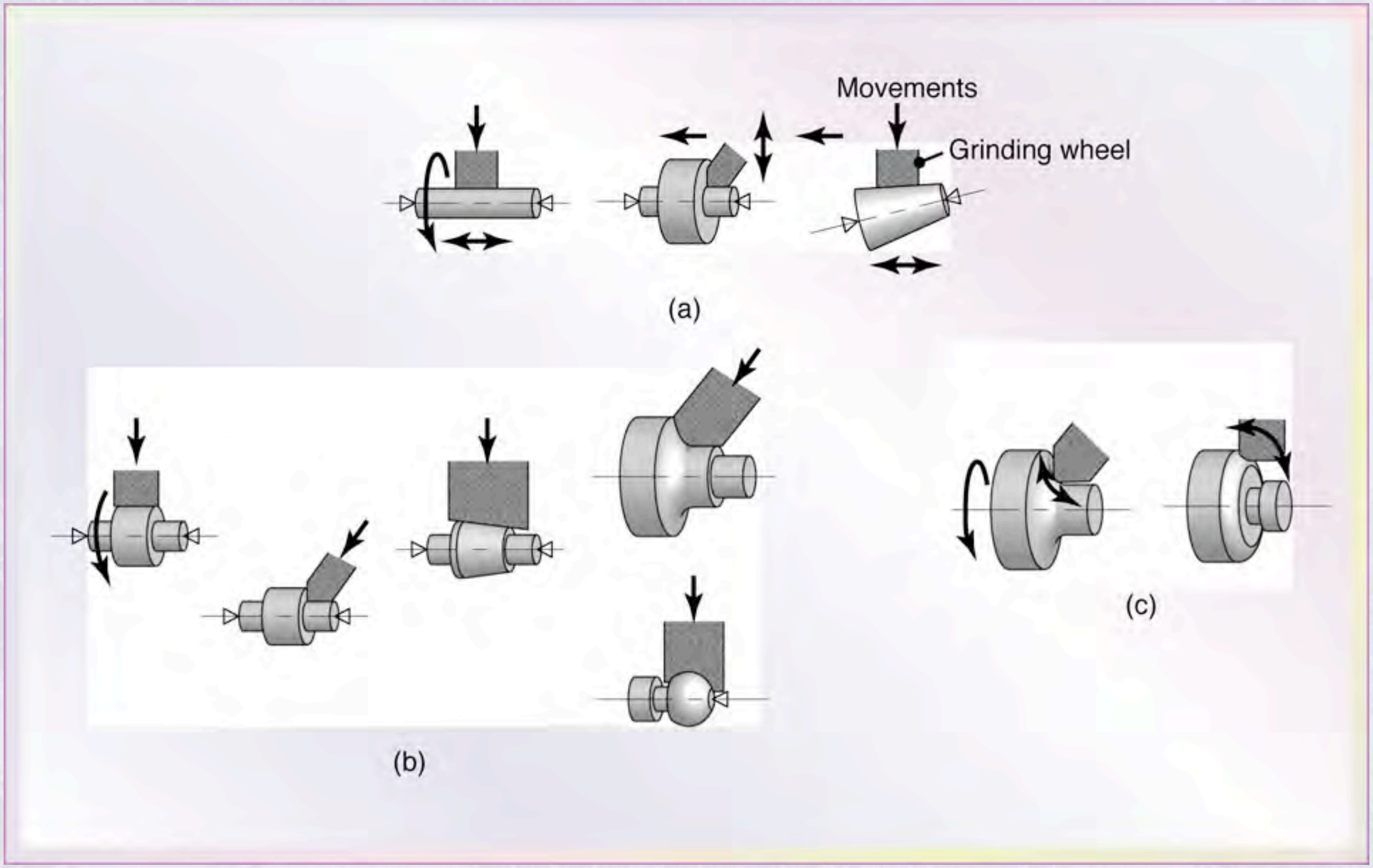

Figure 26.16 Examples of various cylindrical-grinding operations. (a) Traverse grinding, (b) plunge grinding, and (c) profile grinding. *Source:* Courtesy of Okuma Machinery Works Ltd.

Plunge Grinding on Cylindrical Grinder

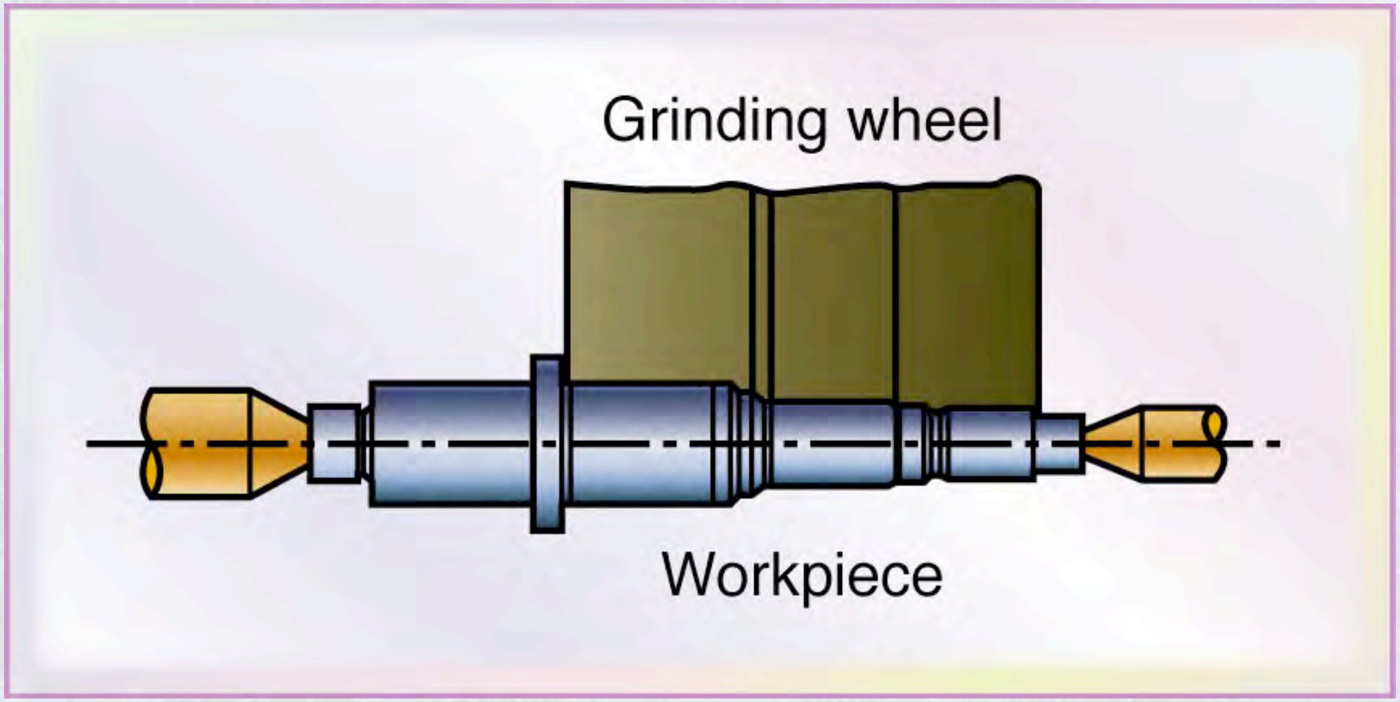

Figure 26.17 Plunge grinding of a workpiece on a cylindrical grinder with the wheel dressed to a stepped shape.

Grinding a Noncylindrical Part on Cylindrical Grinder

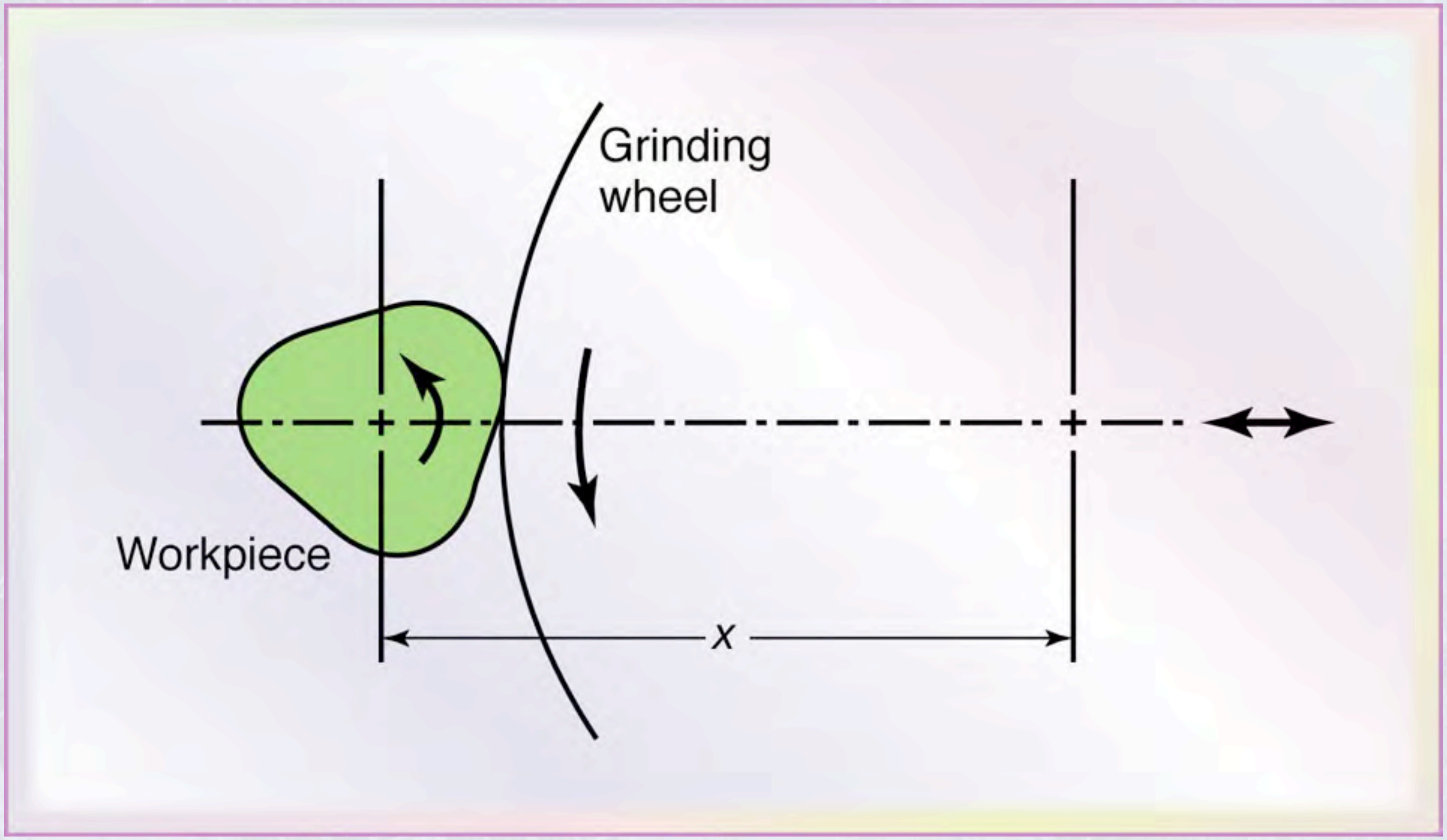

Figure 26.18 Schematic illustration of grinding a noncylindrical part on a cylindrical grinder with computer controls to produce the shape. The part rotation and the distance *x* between centers is varied and synchronized to grind the particular workpiece shape.

Thread Grinding

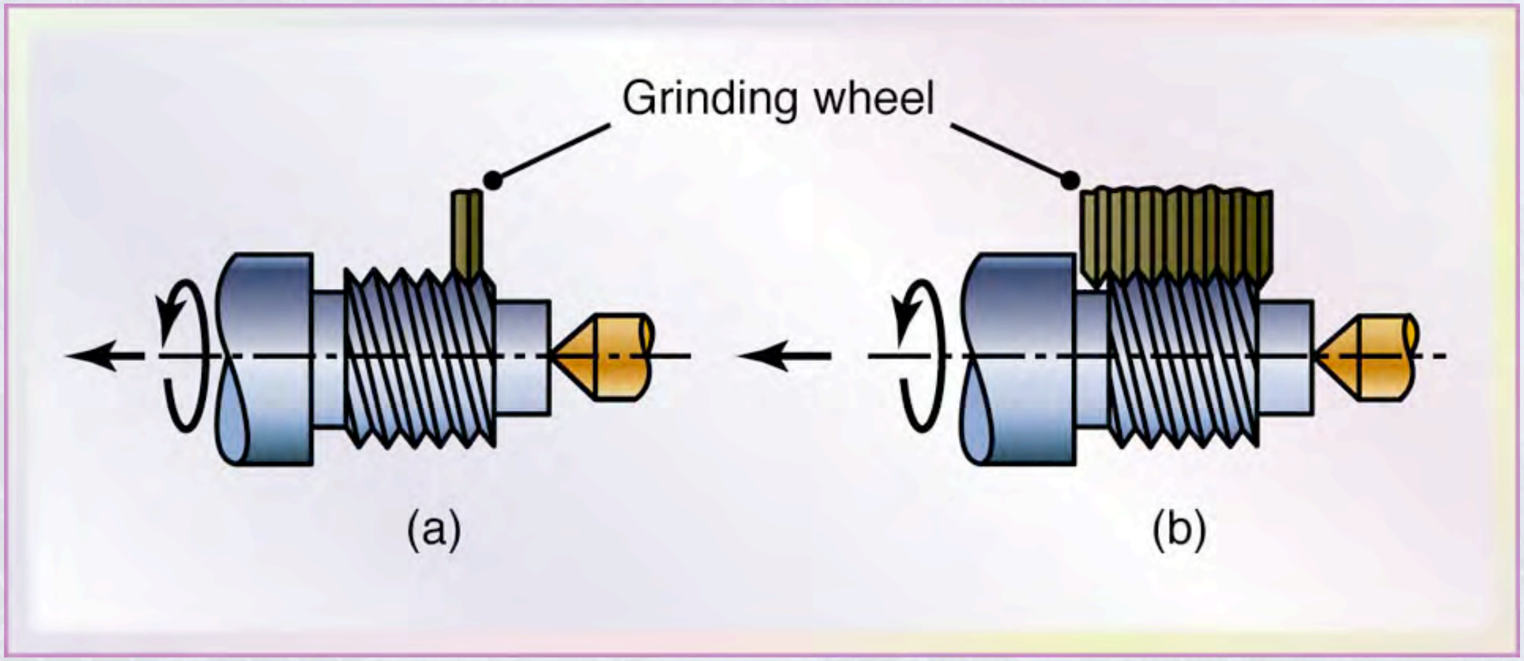

Figure 26.19 Thread grinding by (a) traverse and (b) plunge grinding.

Cycle Parts in Cylindrical Grinding

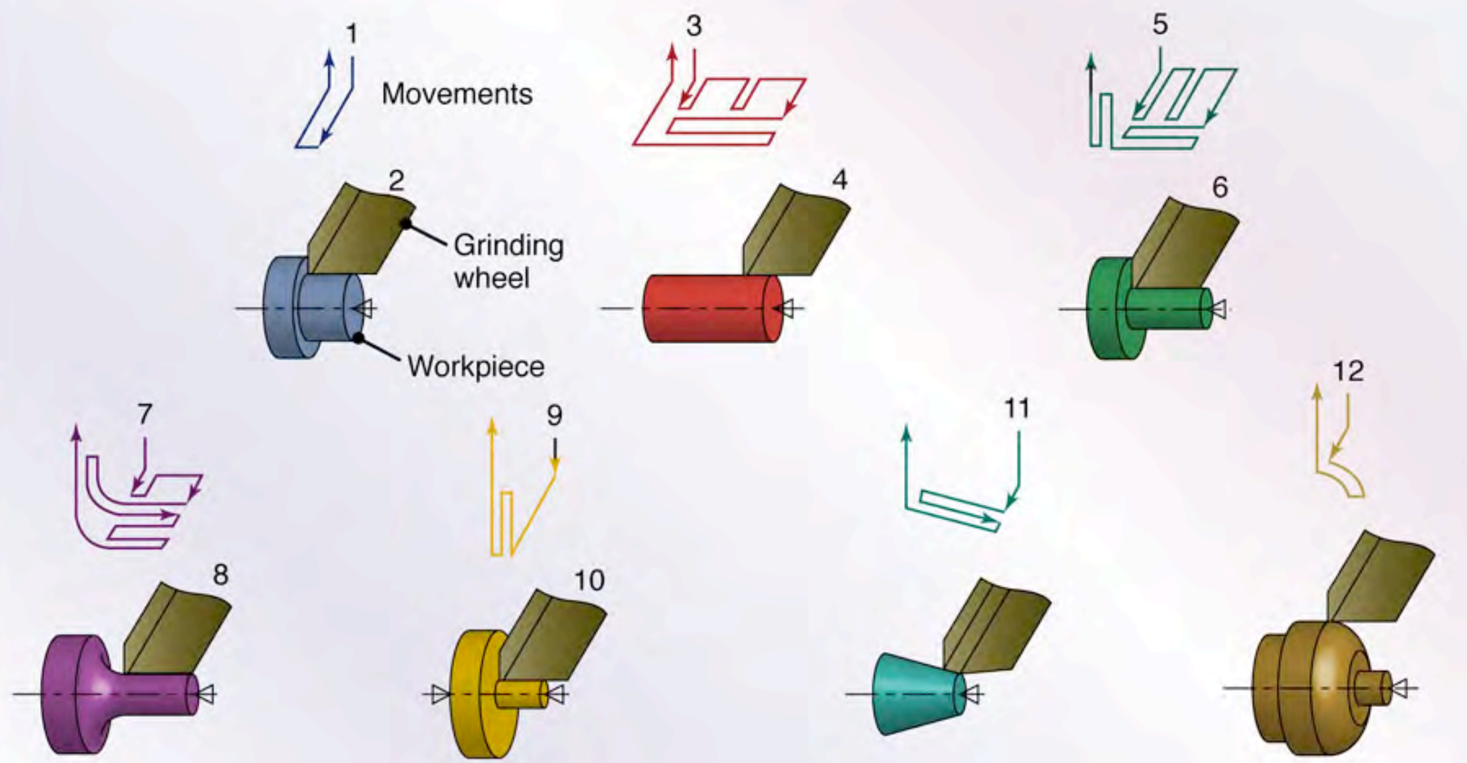

Figure 26.20 - Cycle Patterns in Cylindrical Grinding

Internal Grinding Operations

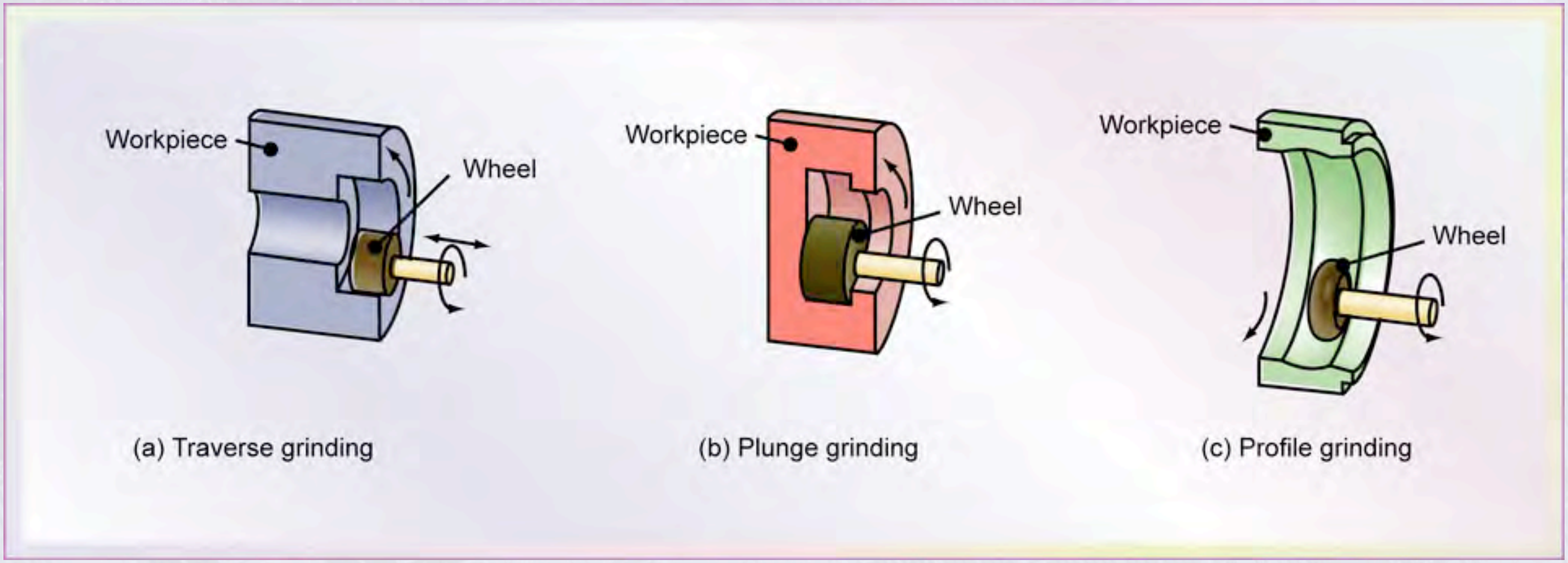

Figure 26.21 Schematic illustrations of internal grinding operations: (a) traverse grinding, (b) plunge grinding, and (c) profile grinding.

Centerless Grinding Operations

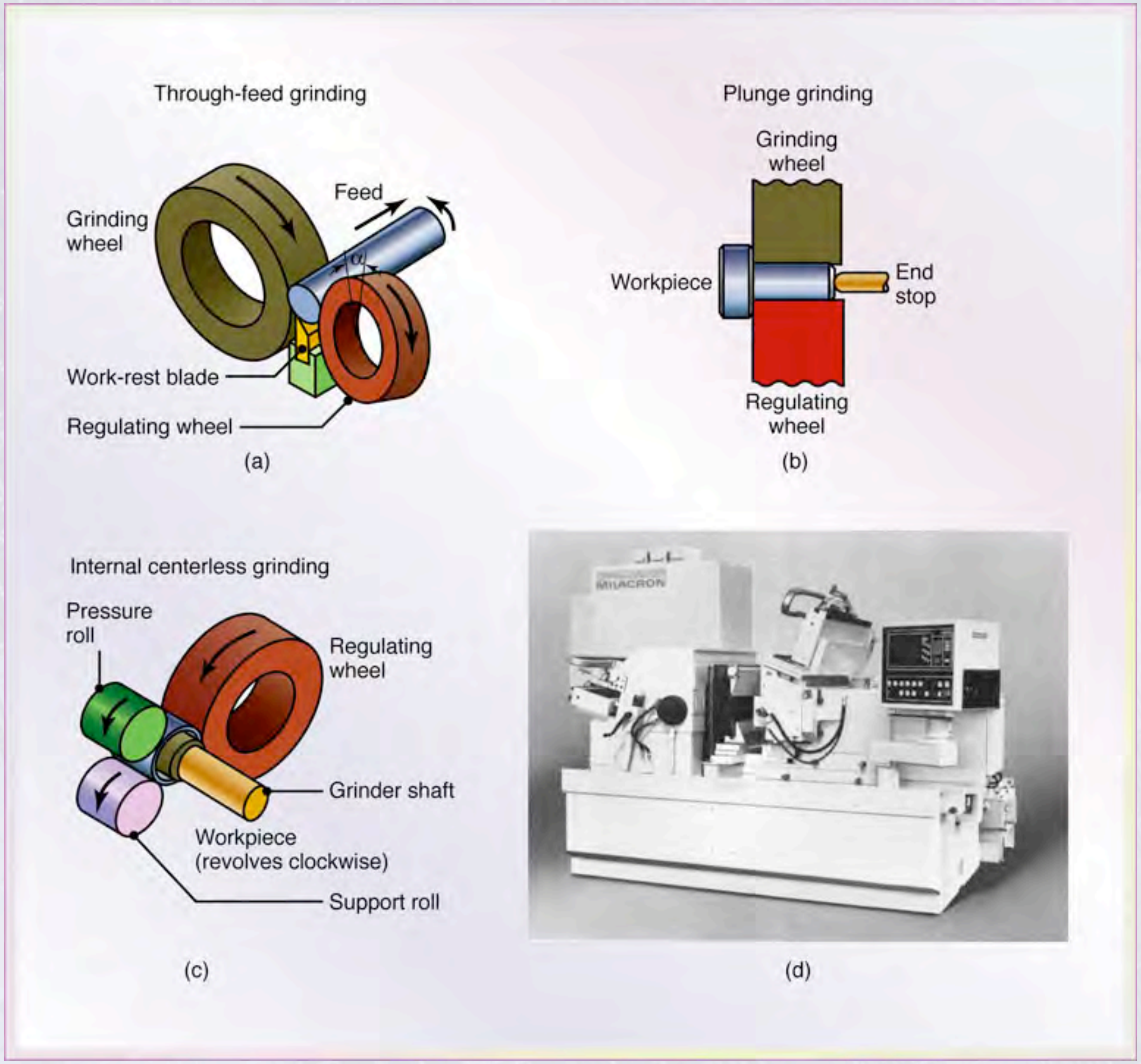

Figure 26.22 Schematic illustration of centerless grinding operations: (a) through-feed grinding, (b) plunge grinding, (c) internal grinding, and (d) a computer numerical-control cylindrical-grinding machine. *Source:* Courtesy of Cincinnati Milacron, Inc.

Creep-Feed Grinding

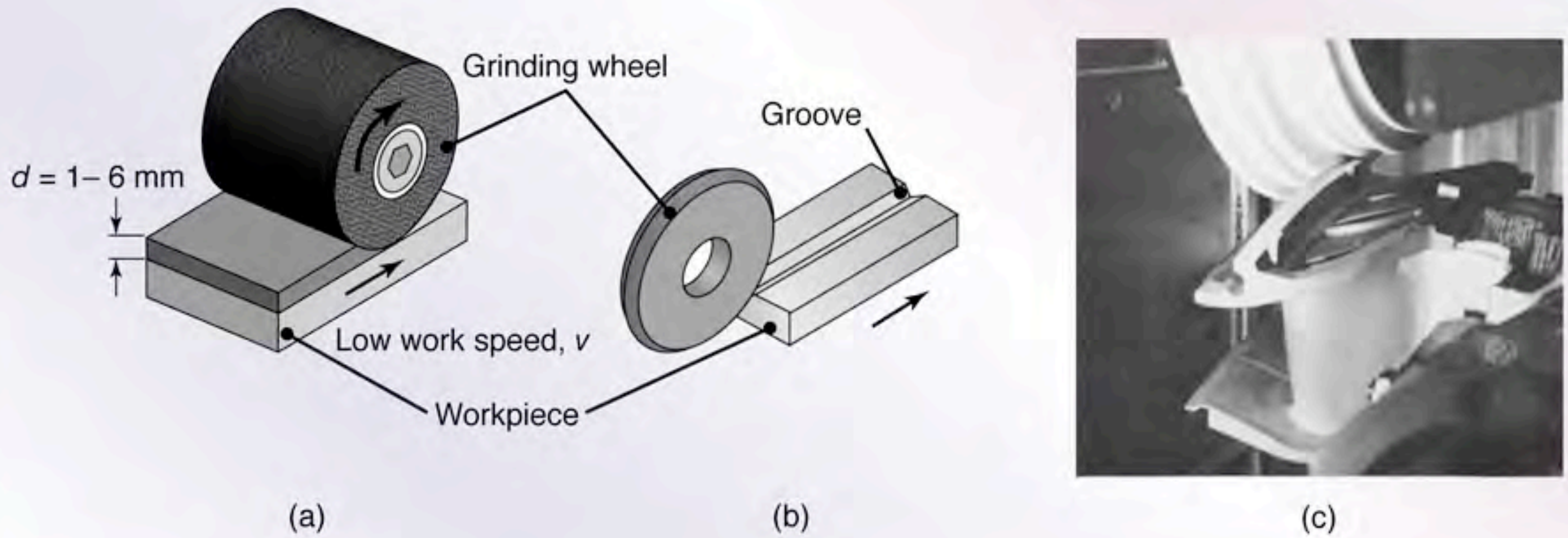

Figure 26.23 (a) Schematic illustration of the creep-feed grinding process. Note the large wheel depth-of-cut, *d*. (b) A shaped groove produced on a flat surface by creep-grinding in one pass. Groove depth is typically on the order of a few mm. (c) An example of creep-feed grinding with a shaped wheel. This operation also can be performed by some of the processes described in Chapter 27. *Source:* Courtesy of Blohm, Inc.

General Recommendations for Grinding Fluids

TABLE 26.5

General Recommendations for Grinding Fluids

Material	Grinding fluid
Aluminum	E, EP
Copper	CSN, E, MO+FO
Magnesium	D, MO
Nickel	CSN, EP
Refractory metals	EP
Steels	CSN, E
Titanium	CSN, E

D = dry; E = emulsion; EP = extreme pressure; CSN = chemicals and synthetics; MO = mineral oil; FO = fatty oil.

Ultrasonic Machining Process

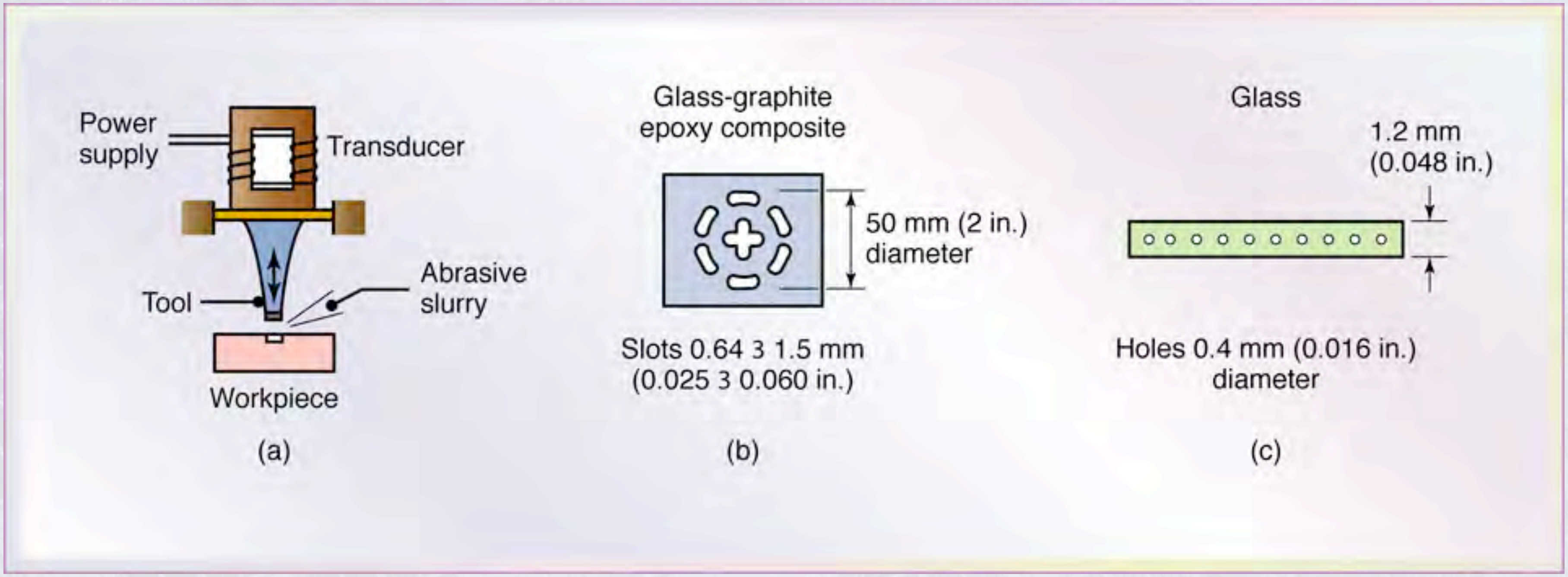

Figure 26.24 (a) Schematic illustration of the ultrasonic machining process. (b) and (c) Types of parts made by this process. Note the small size of holes produced.

Coated Abrasive

Figure 26.25 Schematic illustration of the structure of a coated abrasive. Sandpaper (developed in the 16th century) and emery cloth are common examples of coated abrasives.

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Belt Grinding of Turbine Nozzle Vanes

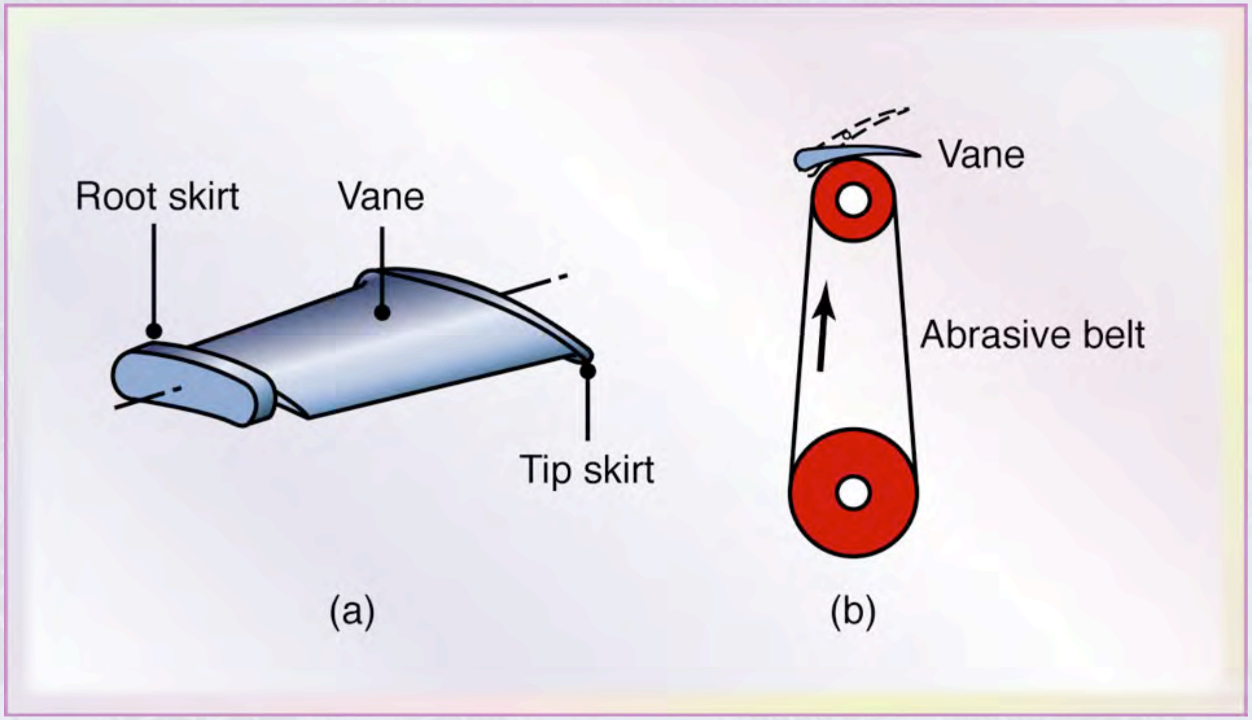

Figure 26.26 – Belt grinding of turbine nozzle vanes.

Honing Tool

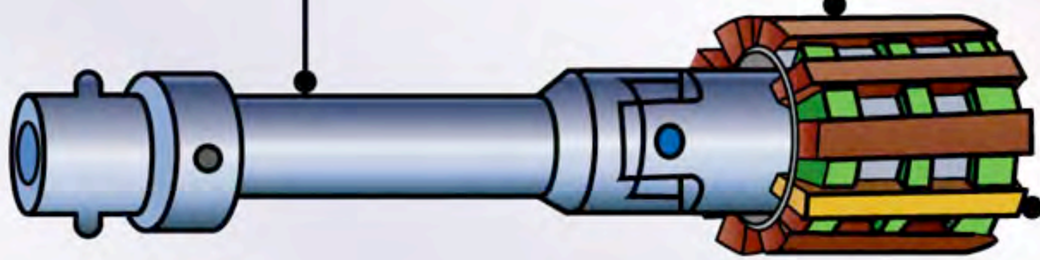

Figure 26.27 Schematic illustration of a honing tool used to improve the surface finish of bored or ground holes.

Superfinishing Process

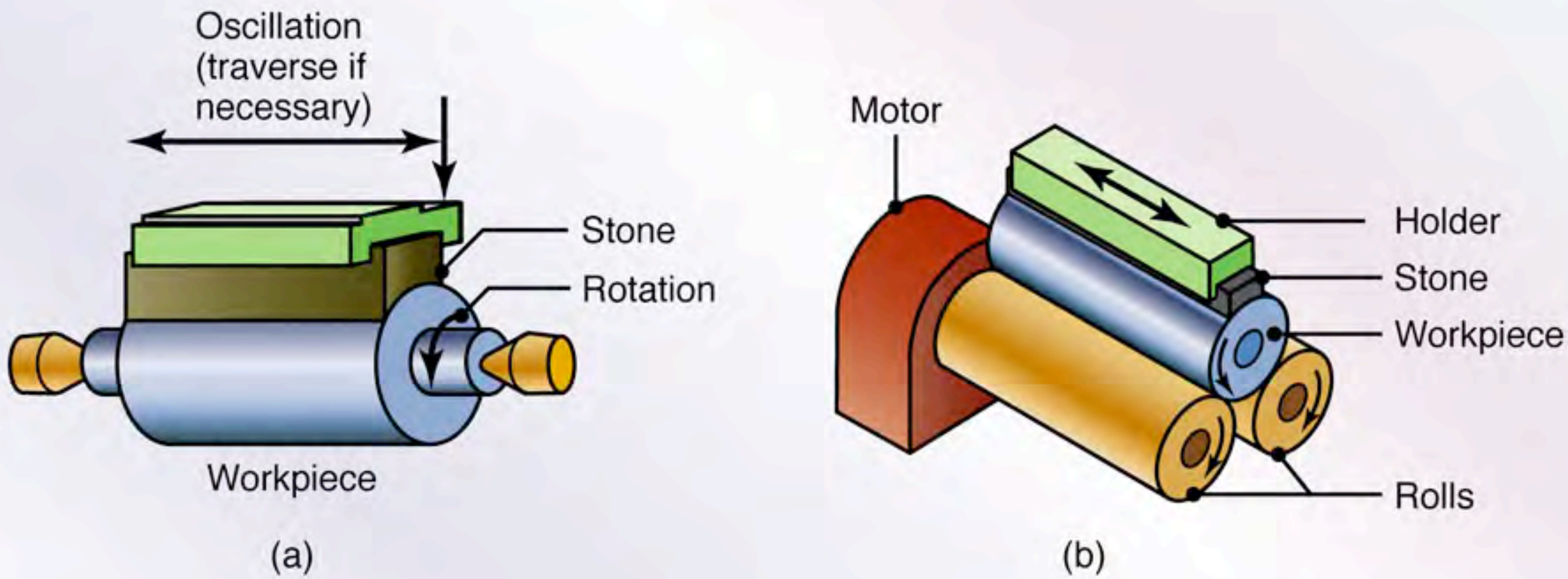

Figure 26.28 Schematic illustration of the superfinishing process for a cylindrical part. (a) Cylindrical microhoning. (b) Centerless microhoning.

Production Lapping

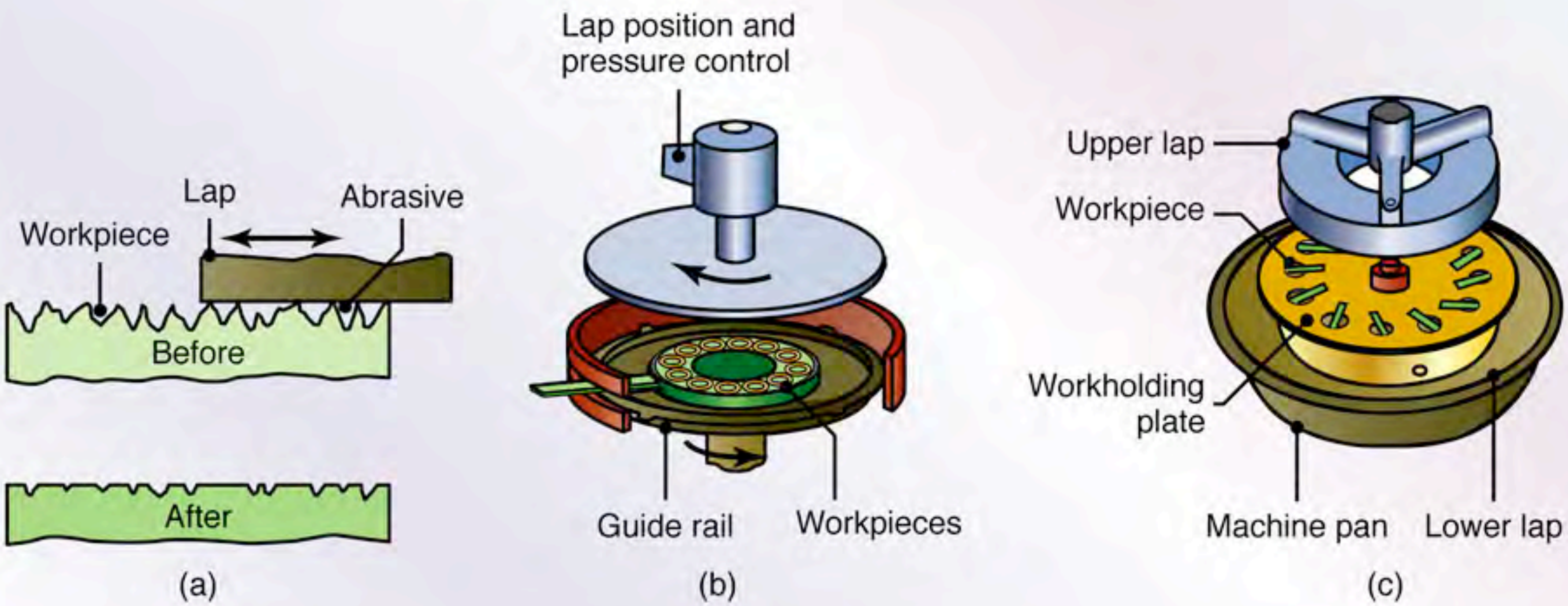

Figure 26.29 (a) Schematic illustration of the lapping process. (b) Production lapping on flat surfaces. (c) Production lapping on cylindrical surfaces.

CMP Process

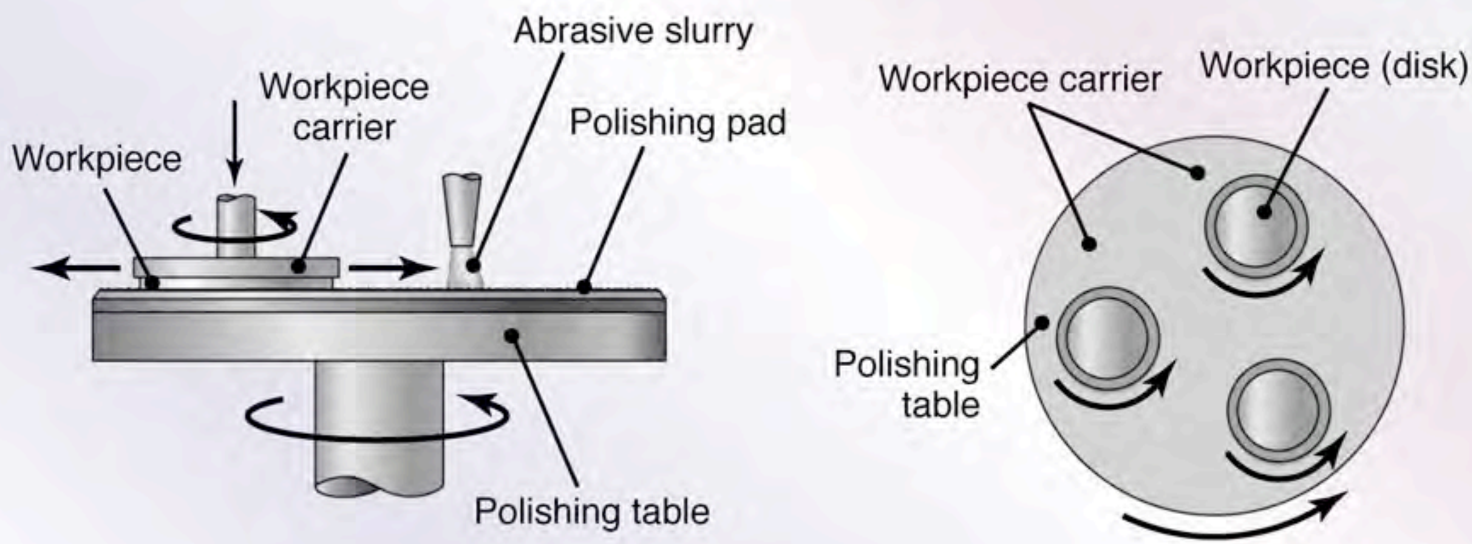

Figure 26.30 (a) Schematic illustration of the chemical-mechanical polishing (CMP) process. This process is used widely in the manufacture of silicon wafers and integrated circuits and also is known as chemical-mechanical planarization. For other materials, more carriers and more disks per carrier are possible.

Polishing Using Magnetic Fields

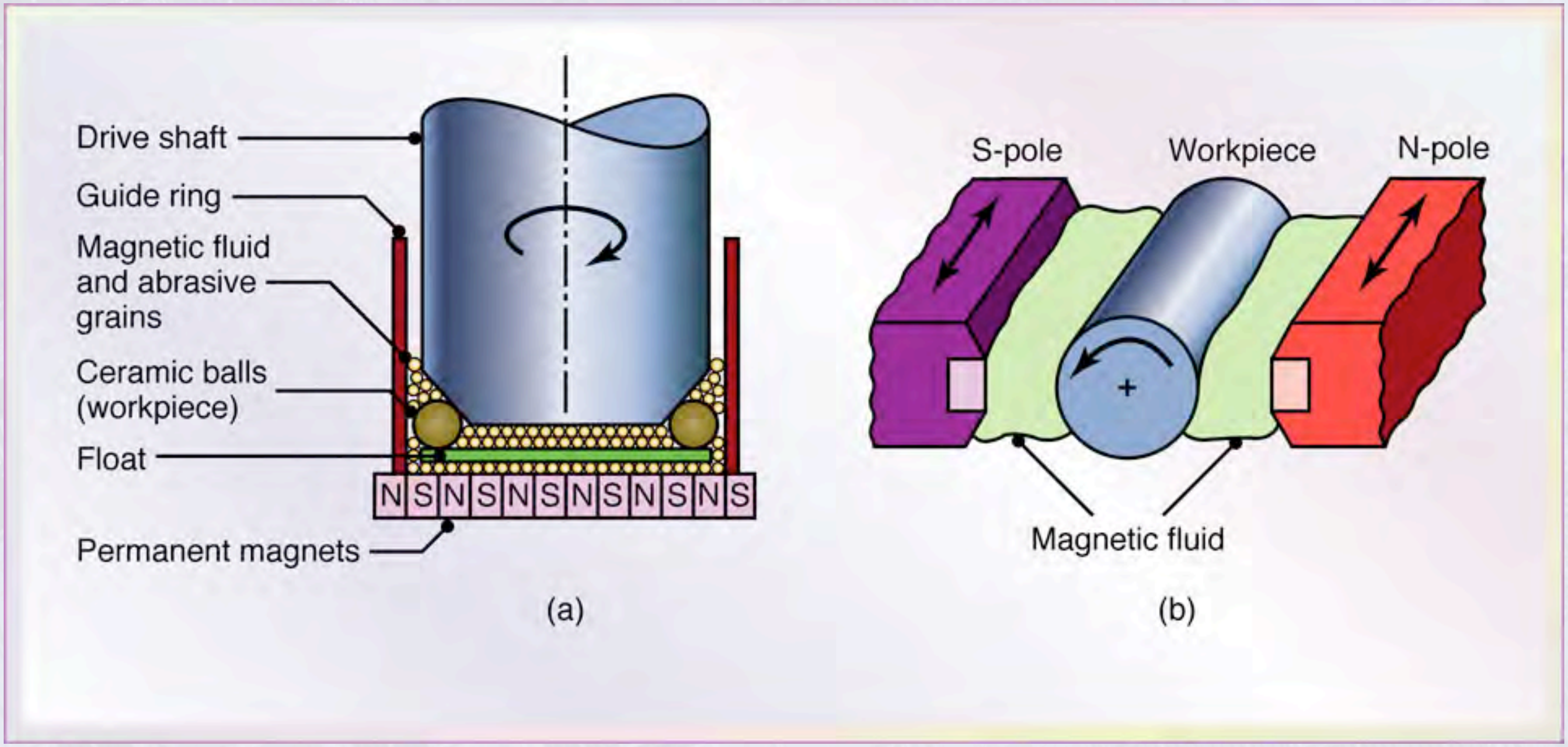

Figure 26.31 Schematic illustration of polishing of balls and rollers using magnetic fields. (a) Magnetic-float polishing of ceramic balls. (b) Magnetic-field-assisted polishing of rollers. *Source*: After R. Komanduri, M. Doc, and M. Fox.

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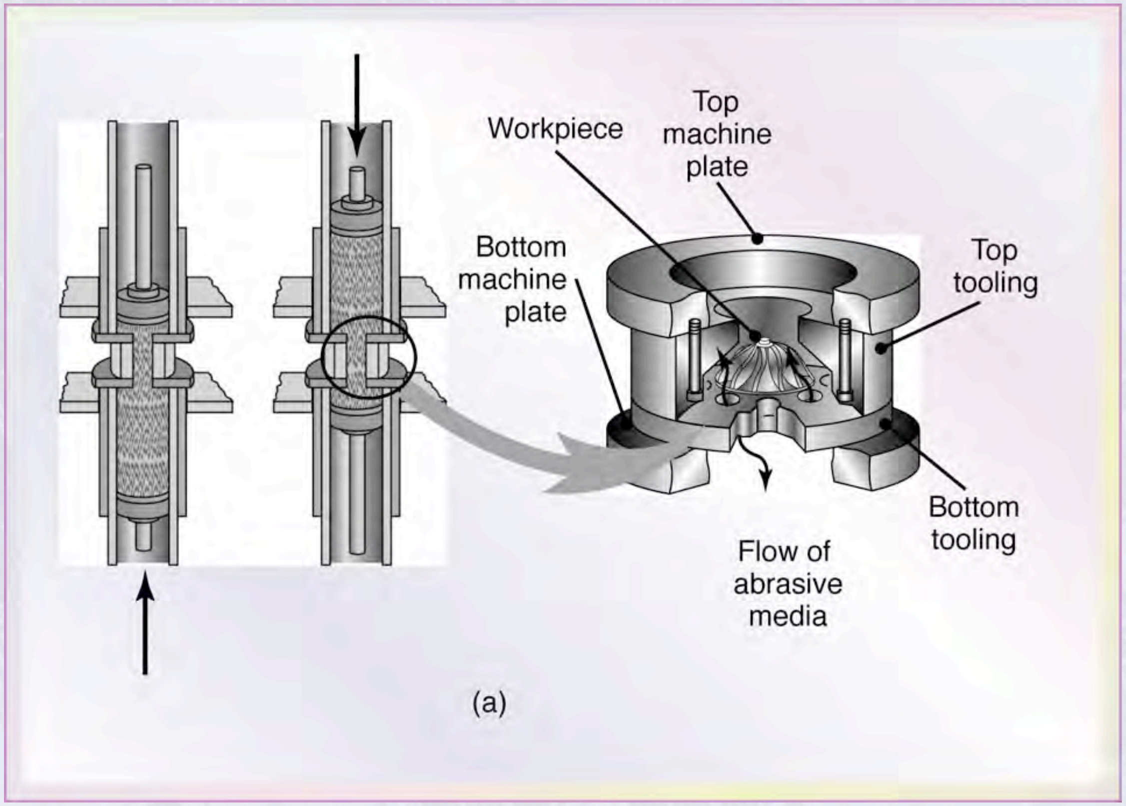
Abrasive-Flow Machining



(b)

Figure 26.32 (a) Schematic illustration of abrasive-flow machining to deburr a turbine impeller. The arrows indicate movement of the abrasive media. Note the special fixture, which is usually different for each part design. (b) Value fittings treated by abrasive-flow machining to eliminate burrs and improve surface quality. *Source:* (b) Courtesy of Extrude Hone Corp.

Deburring Operation on a Die-Cast Part Using Grinding Wheel

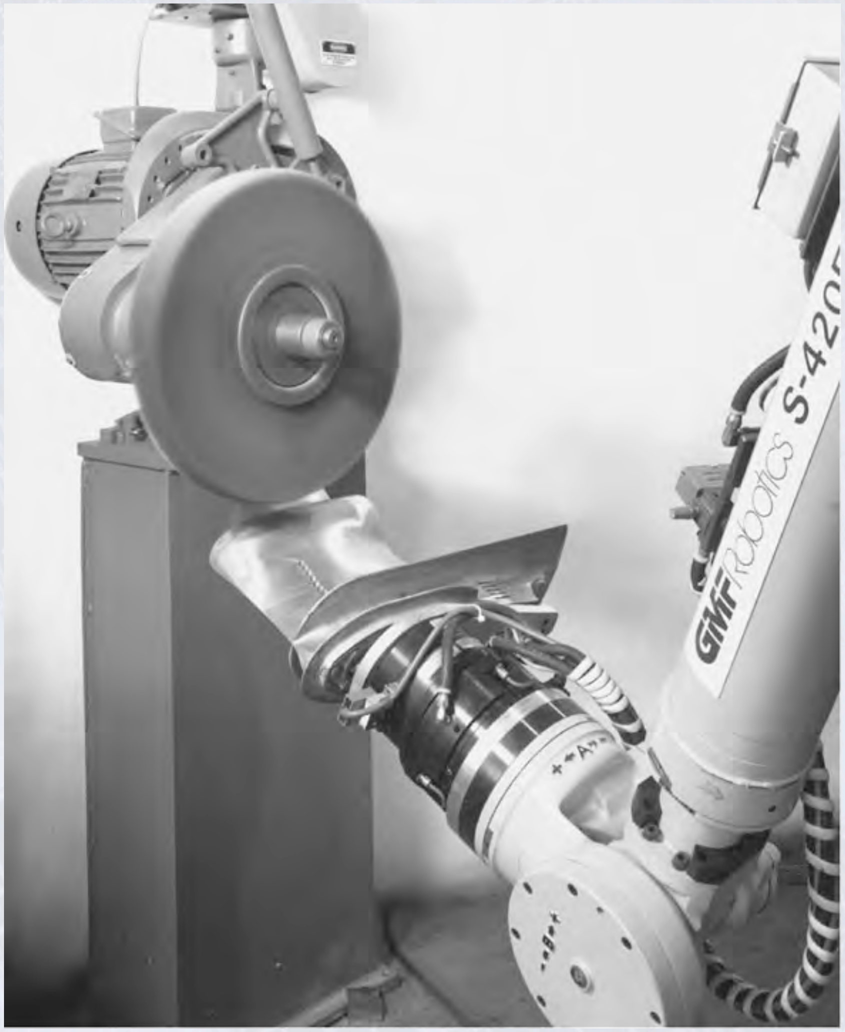


Figure 26.33 A deburring operation on a robot-held die-cast part for an outboard motor housing using a grinding wheel. Abrasive belts (Fig. 26.26) or flexible abrasive radial-wheel brushes also can be used for such operations. *Source:* Courtesy of Acme Manufacturing Company.

Increase in Machining and Finishing Cost as a Function of Surface Finish Required

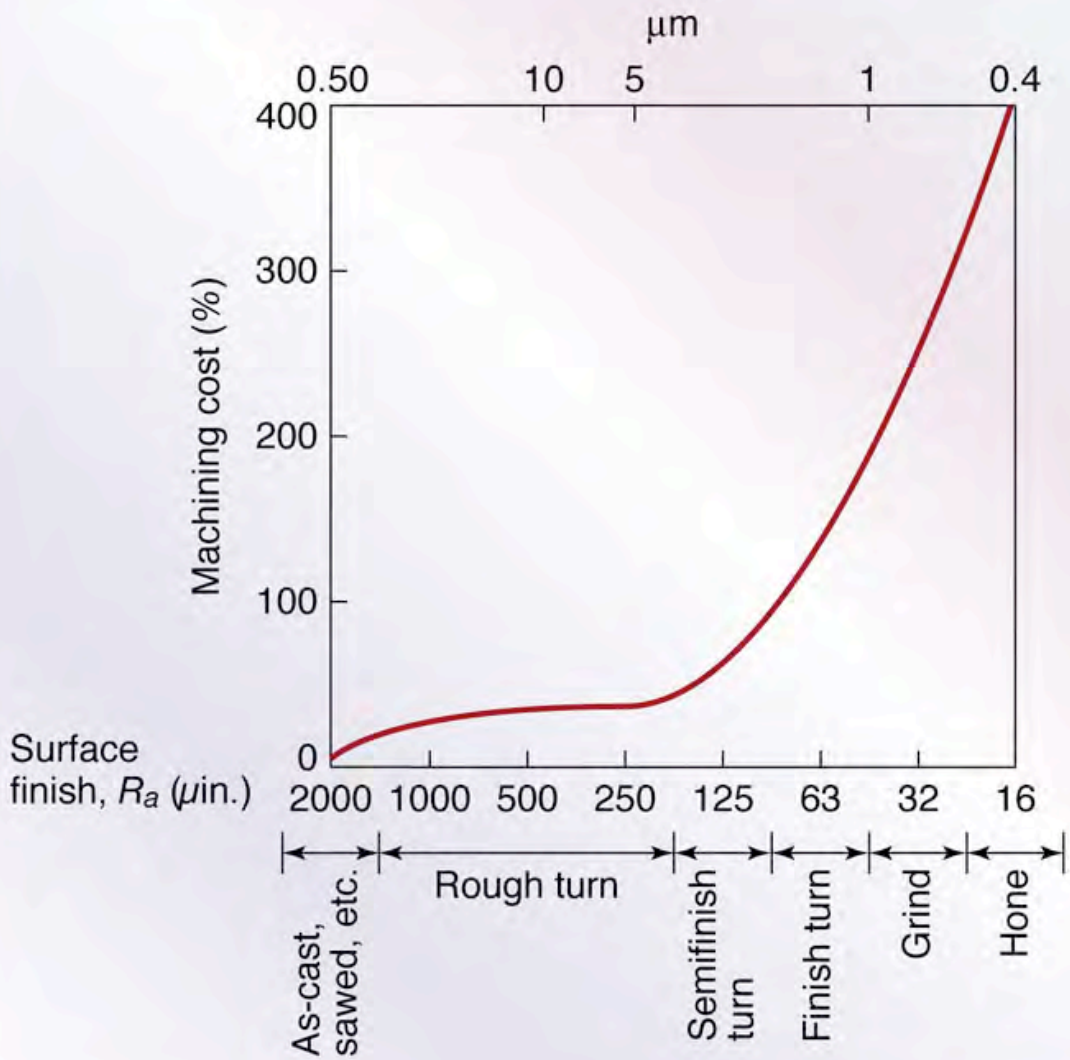


Figure 26.34 Increase in the cost of machining and finishing a part as a function of the surface finish required. This is the main reason that the surface finish specified on parts should not be any finer than necessary for the part to function properly.

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