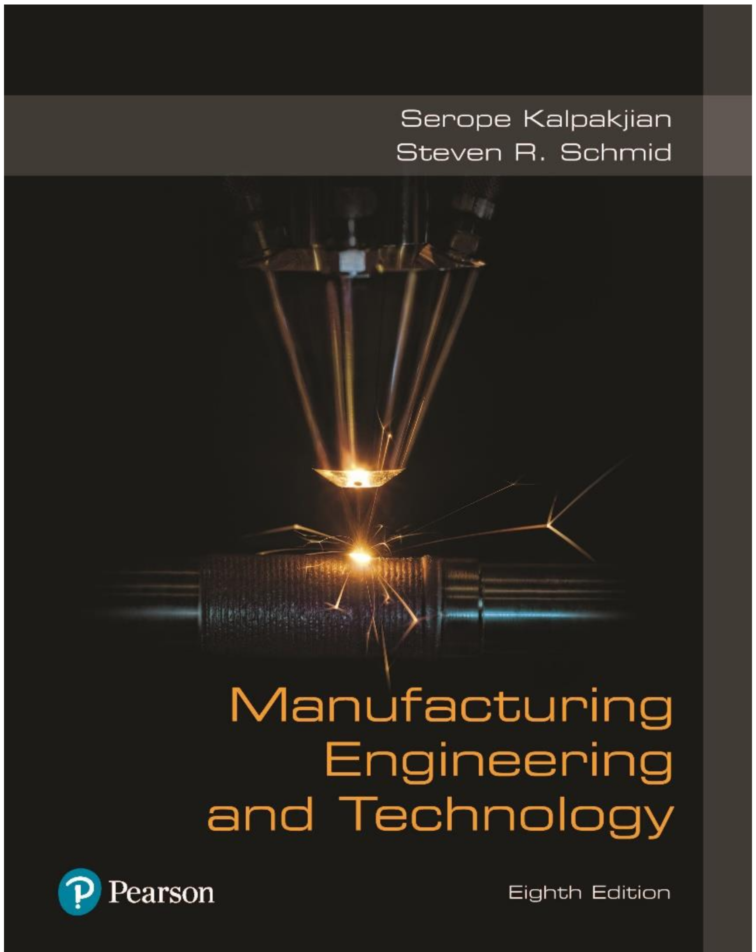
Manufacturing Engineering and Technology

Eighth Edition



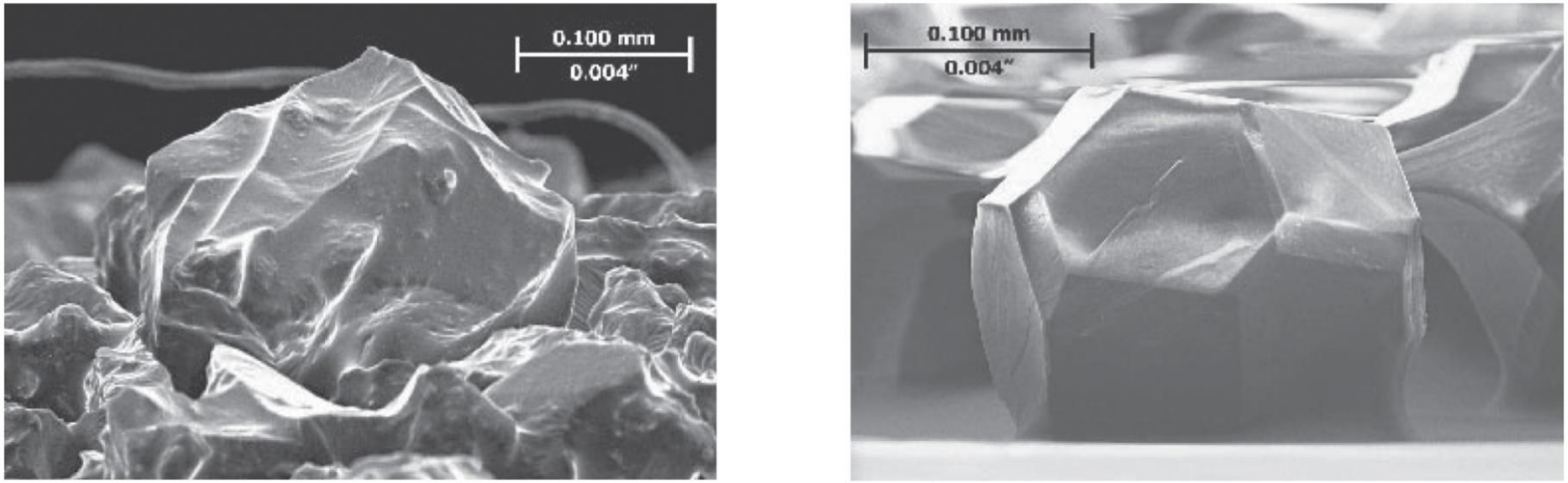
Chapter 26-27

Abrasive Machining and Finishing Operations

Pearson

Figure 26.1

Typical abrasive grains; note the angular shape with sharp edges. (a) A single, 80-mesh Al_2O_3 grit in a freshly dressed grinding wheel, (b) an 80/100 mesh diamond grit. Diamond and cubic boron nitride grains can be manufactured in various geometries, including the "blocky" shape shown.



(a) (b)

Figure 26.2

A variety of bonded abrasives used in abrasive machining processes.

Source: Shutterstock/Praethip Docekalova.

Figure 26.3

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, (g) internal grinding.

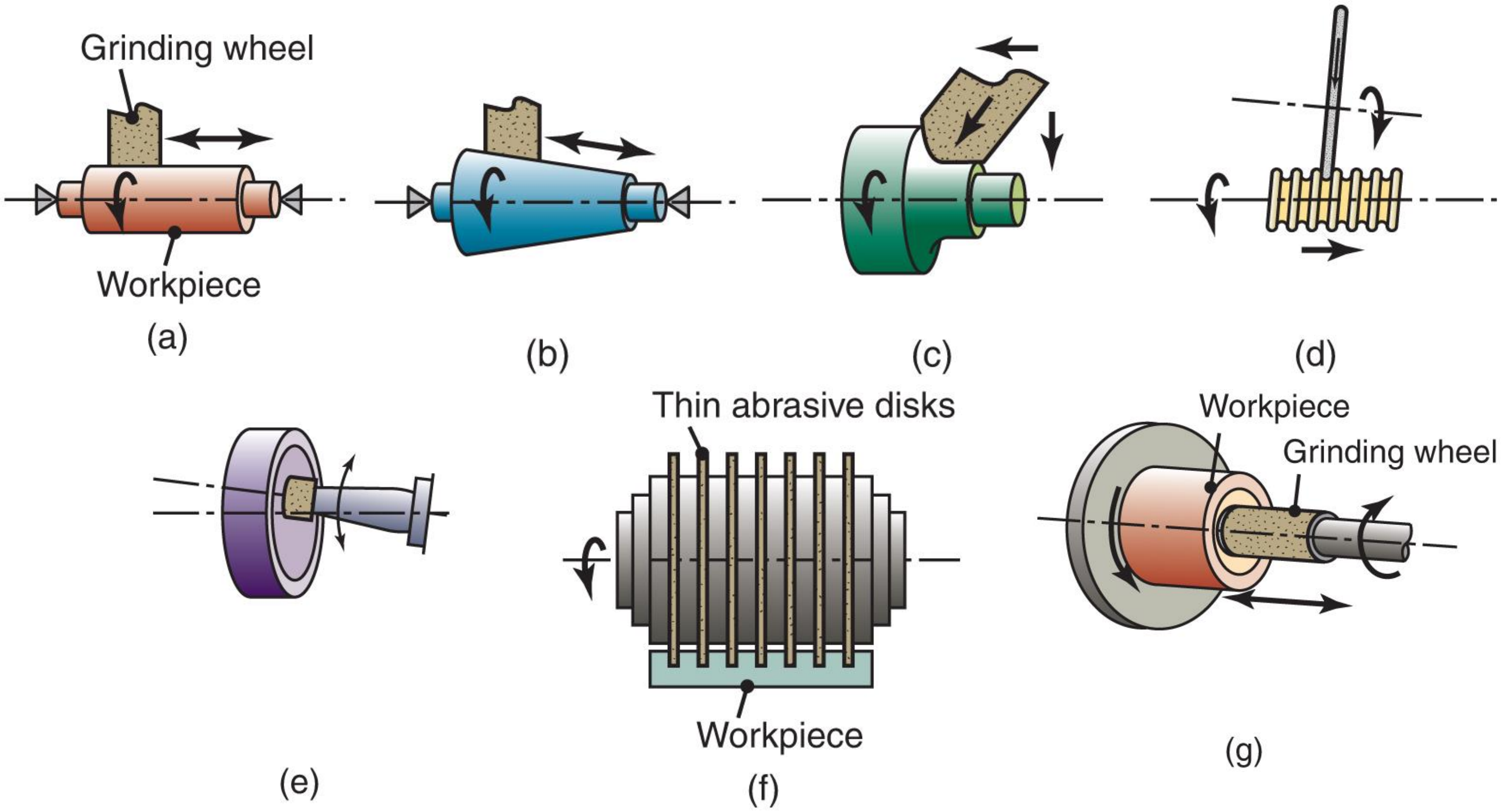


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Table 26.1

Ranges of Knoop Hardness for Various Materials and Abrasives.

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

Figure 26.4

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

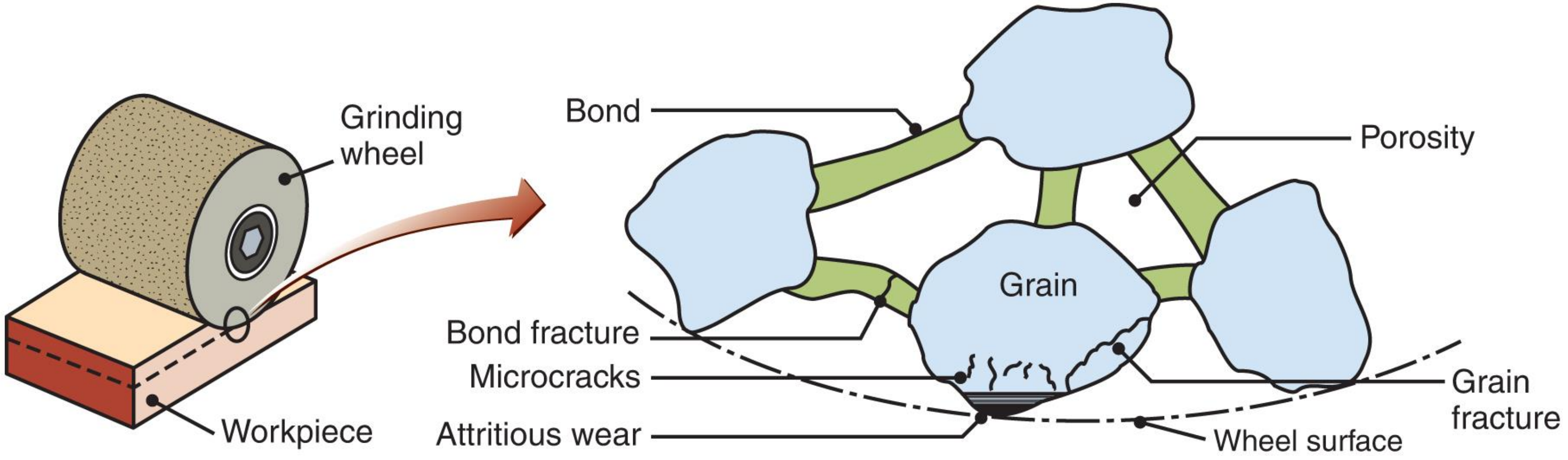

Figure 26.7

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.

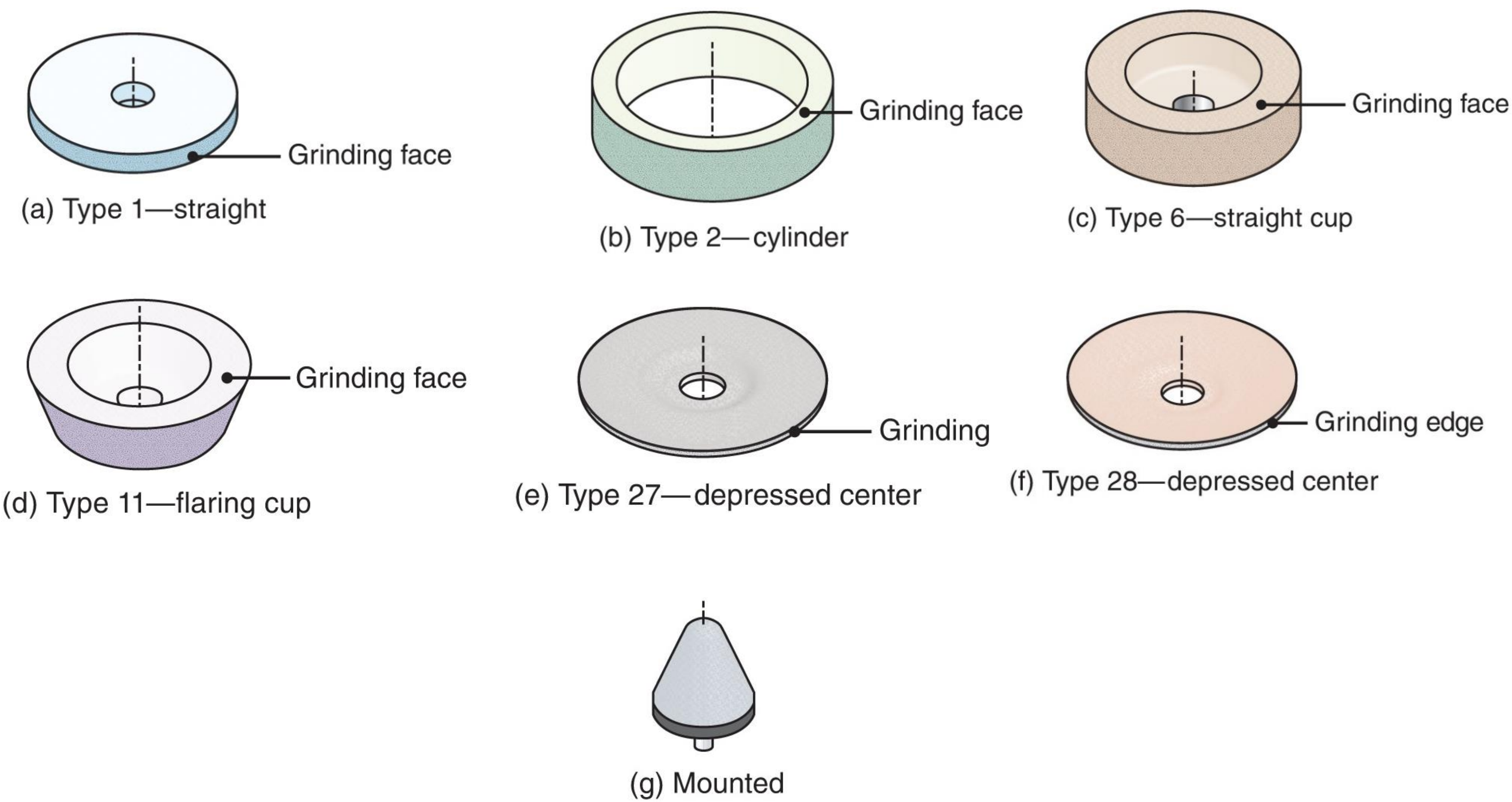

Figure 26.7

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

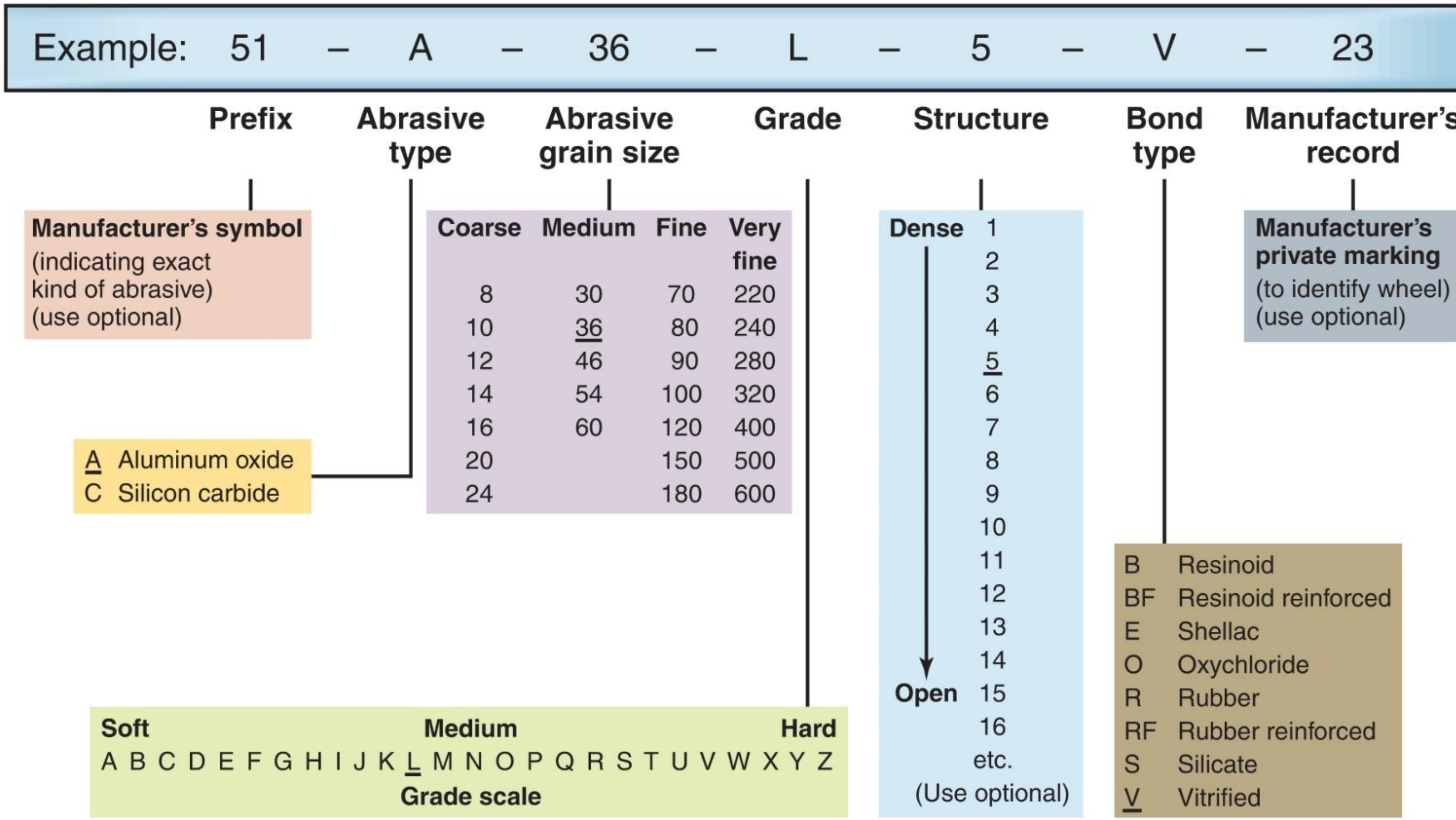

Figure 26.8

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

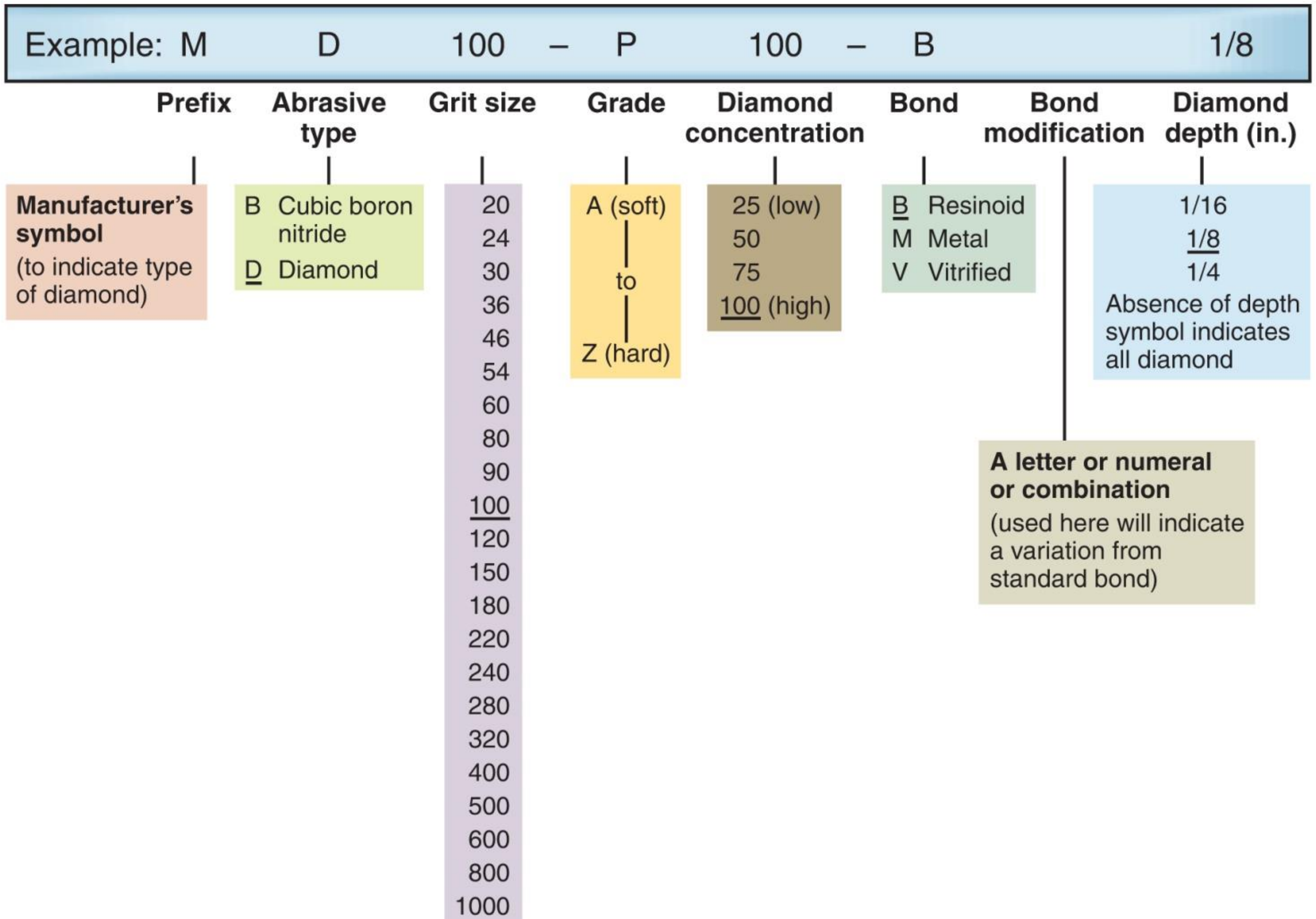

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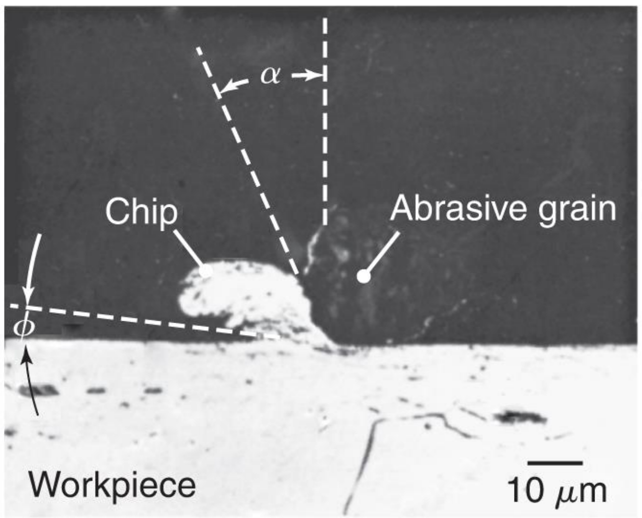
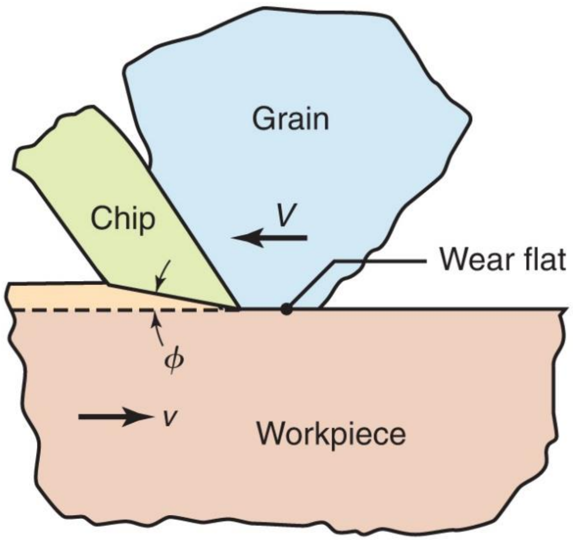
Figure 26.9

(a) Grinding chip being produced by a single abrasive grain; note the large negative rake angle of the grain, (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.



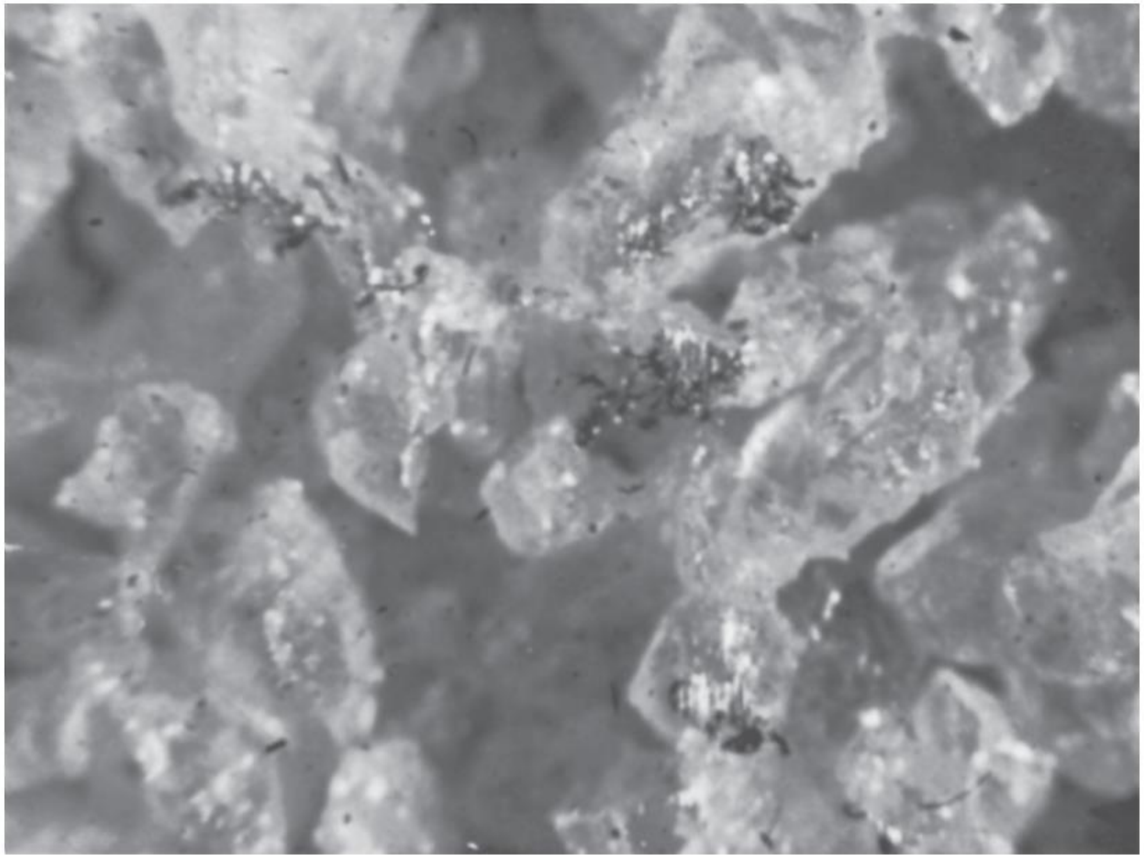
(a)



(b)

Figure 26.10

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: 50×.



Source: S. Kalpakjian.

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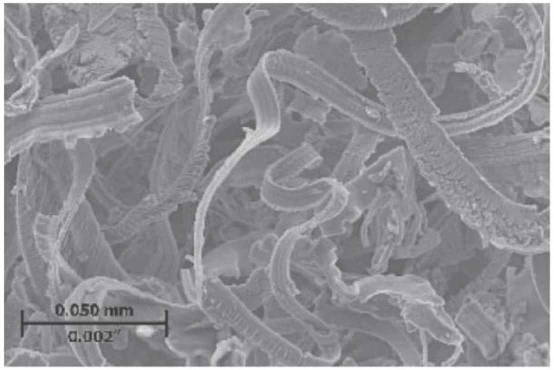
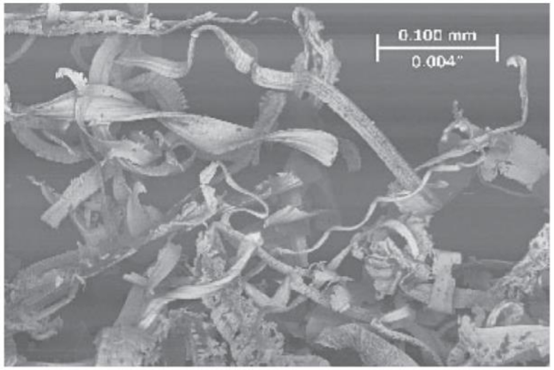
Figure 26.12

Typical chips, or swarf, from grinding operations. (a) Swarf from grinding a conventional HSS drill bit, (b) swarf of nickel-alloy workpiece using an Al_2O_3 wheel, (c) swarf of M2 high-speed steel using an Al_2O_3 wheel, showing a melted globule among the chips



(a)



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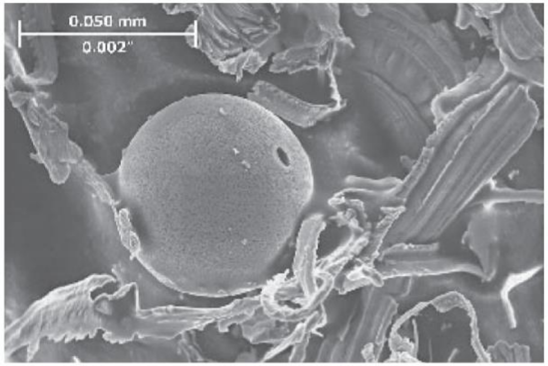


(c)

Source: Courtesy of J. Badger, *The Grinding Doc*.

Figure 26.13

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

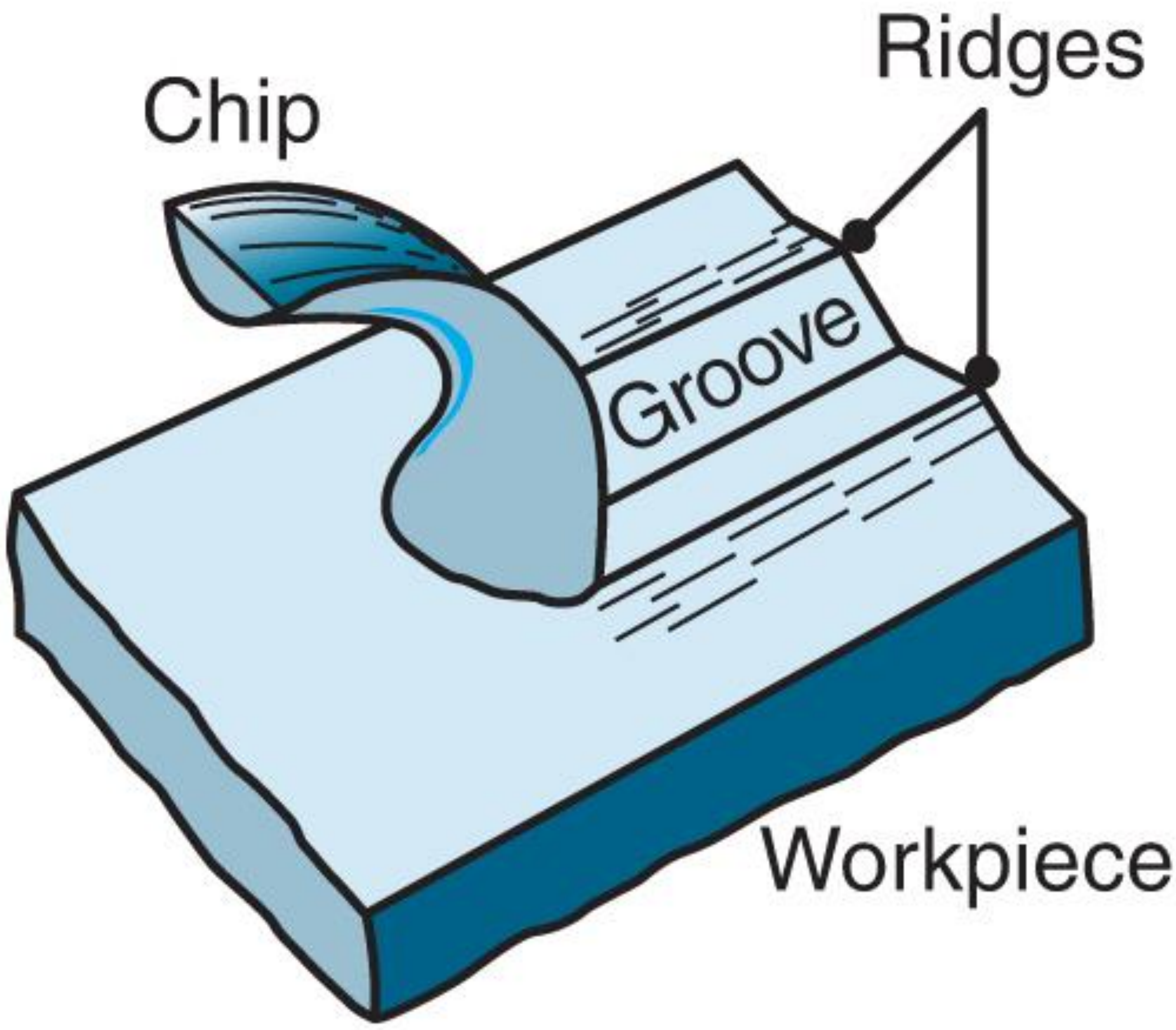


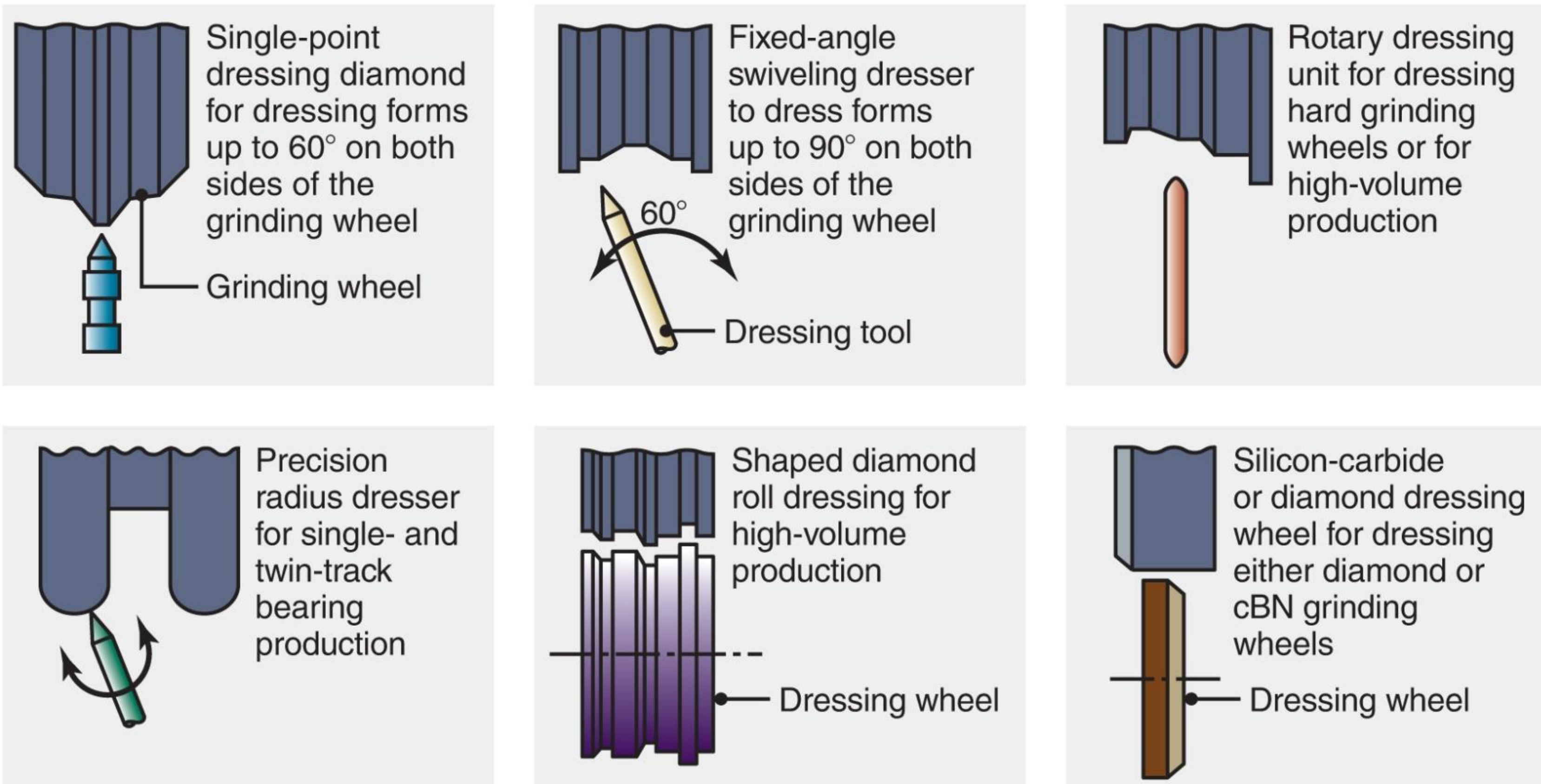
Table 26.2

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

Figure 26.14 (1 of 2)

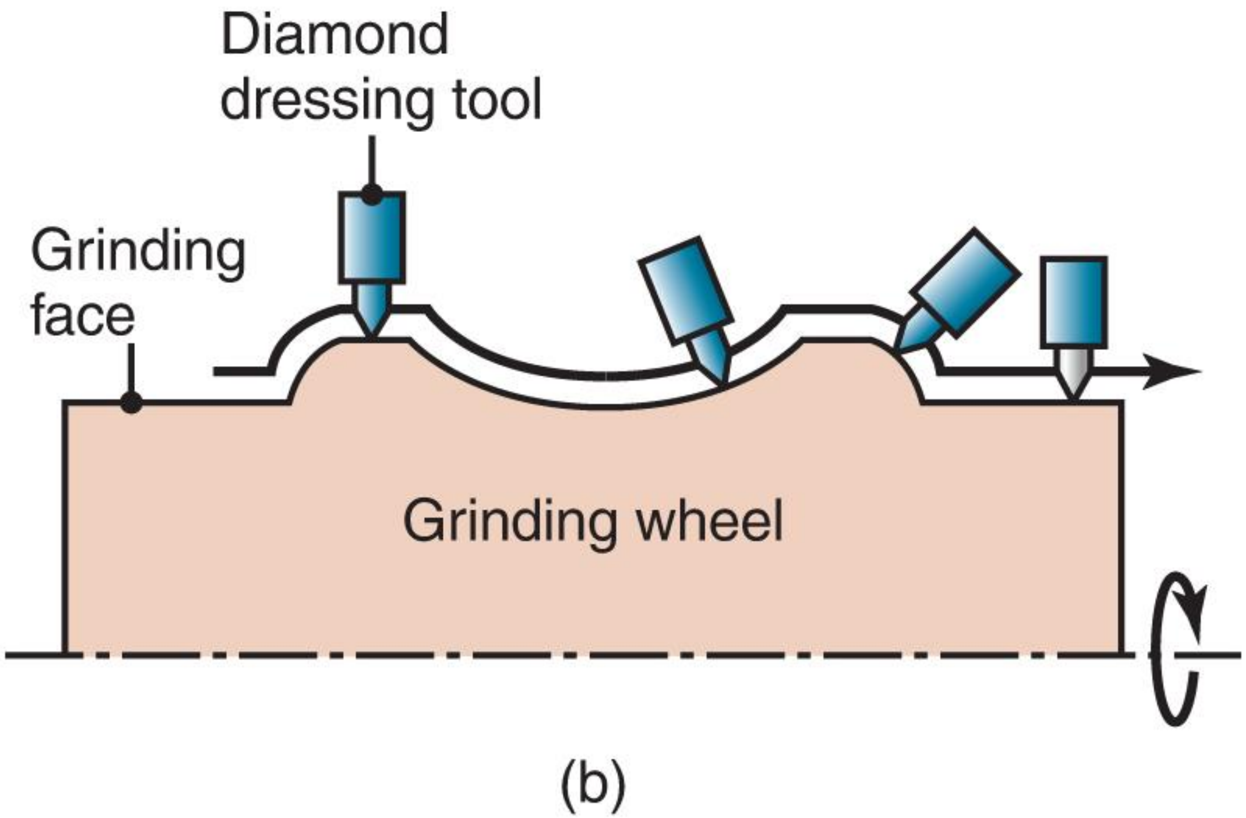
(a) Types of grinding-wheel dressing.



(a)

Figure 26.14 (2 of 2)

(b) Shaping the grinding face of a wheel by dressing it by computer control. Note that the diamond dressing tool is normal to the surface at the point of contact with the wheel.



Source: Courtesy of Okuma Machinery Works, Ltd.

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	—	—

Source: Courtesy of Okuma Machinery Works, Ltd.

Table 26.4

General Characteristics of Abrasive Machining Processes and Machines.

Process	Characteristics	Typical maximum dimensions, length and diameter (m)*
Surface grinding	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 grinding	Round workpieces with stepped diameters; low production rate 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 workpieces; high production rate; low labor skill	Table D: 3.7
Chemical mechanical polishing	Flat surfaces, generally used for semiconductors for microelectronics or MEMS applications; moderate production rate; high labor skill.	D: 0.3
Abrasive flow machining	Used for debarring and finishing of complex geometries; low production rate; low labor skill	D: 0.3
Ultrasonic machining	Holes and cavities with various shapes; suitable for hard and brittle materials; medium labor skill	—

*Larger capacities are available for special applications.

Figure 26.15 (1 of 3)

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, producing a groove in the workpiece, (c) A vertical-spindle rotary-table grinder (also known as the *Blanchard type*).

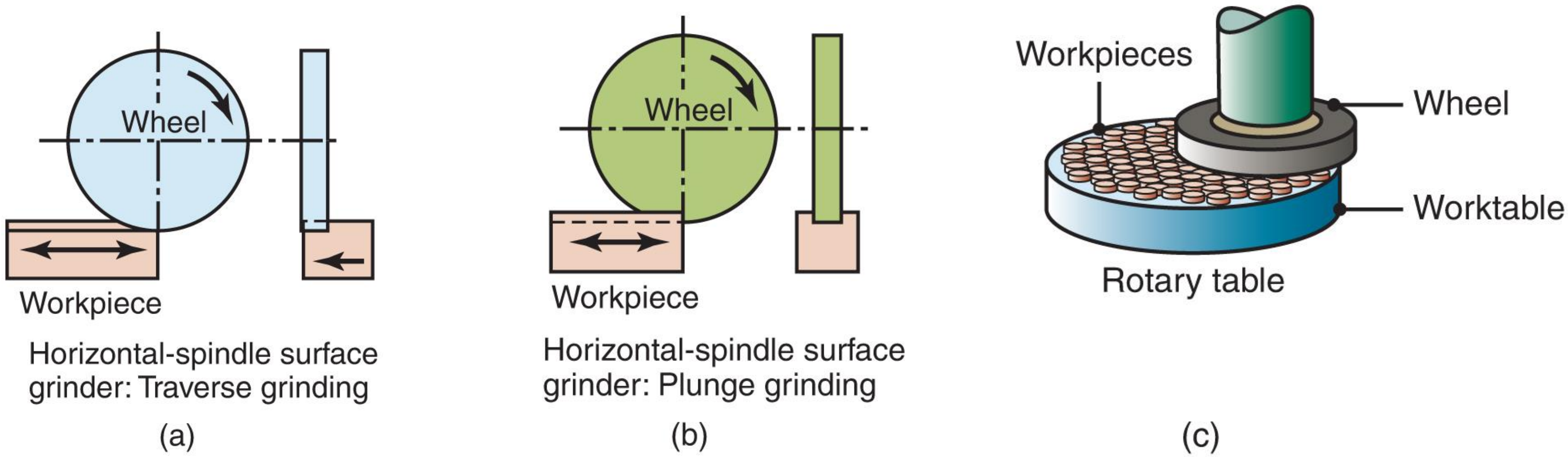


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Figure 26.16

Schematic illustration of a horizontal-spindle surface grinder.

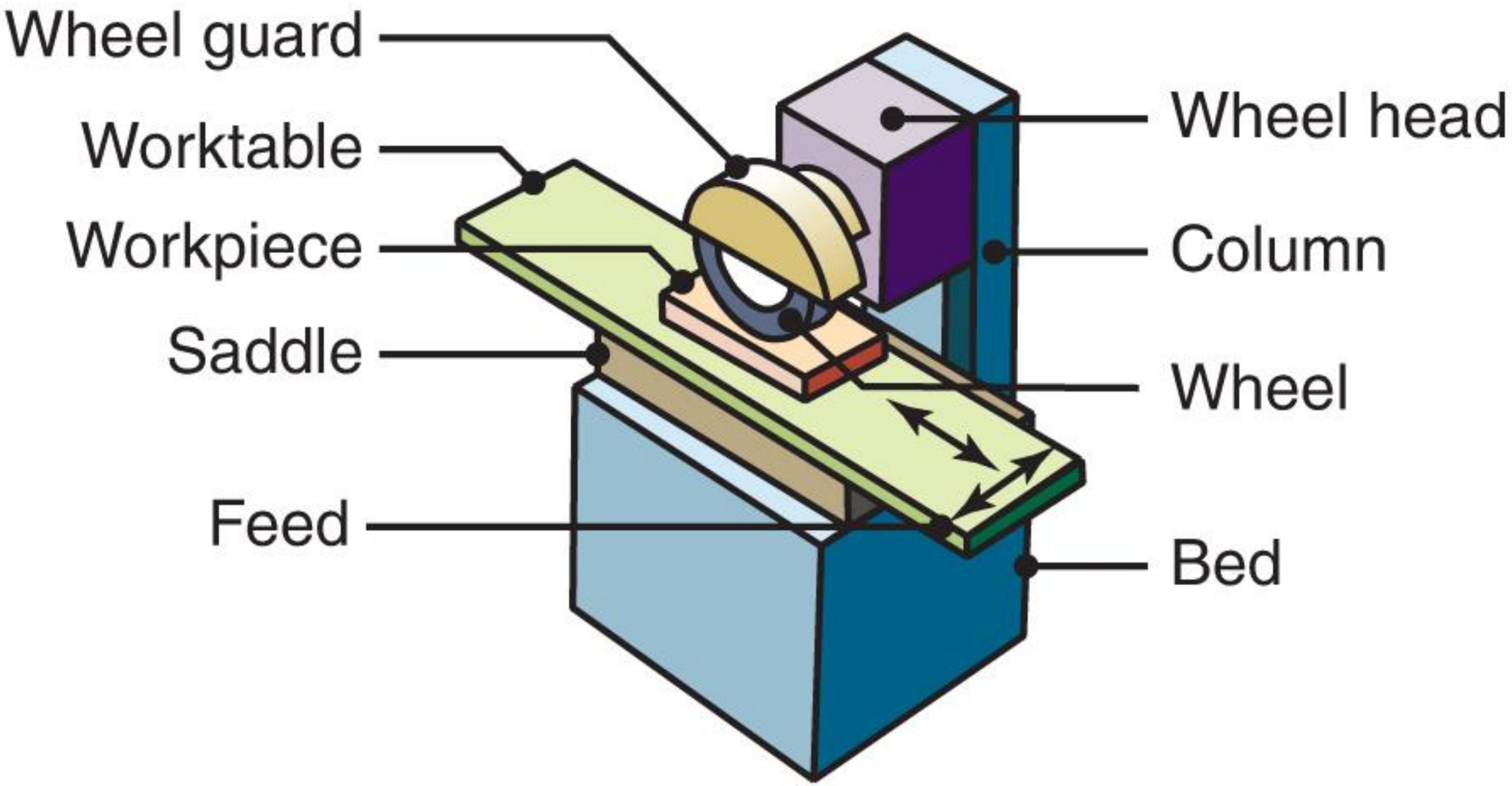


Figure 26.17

(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.

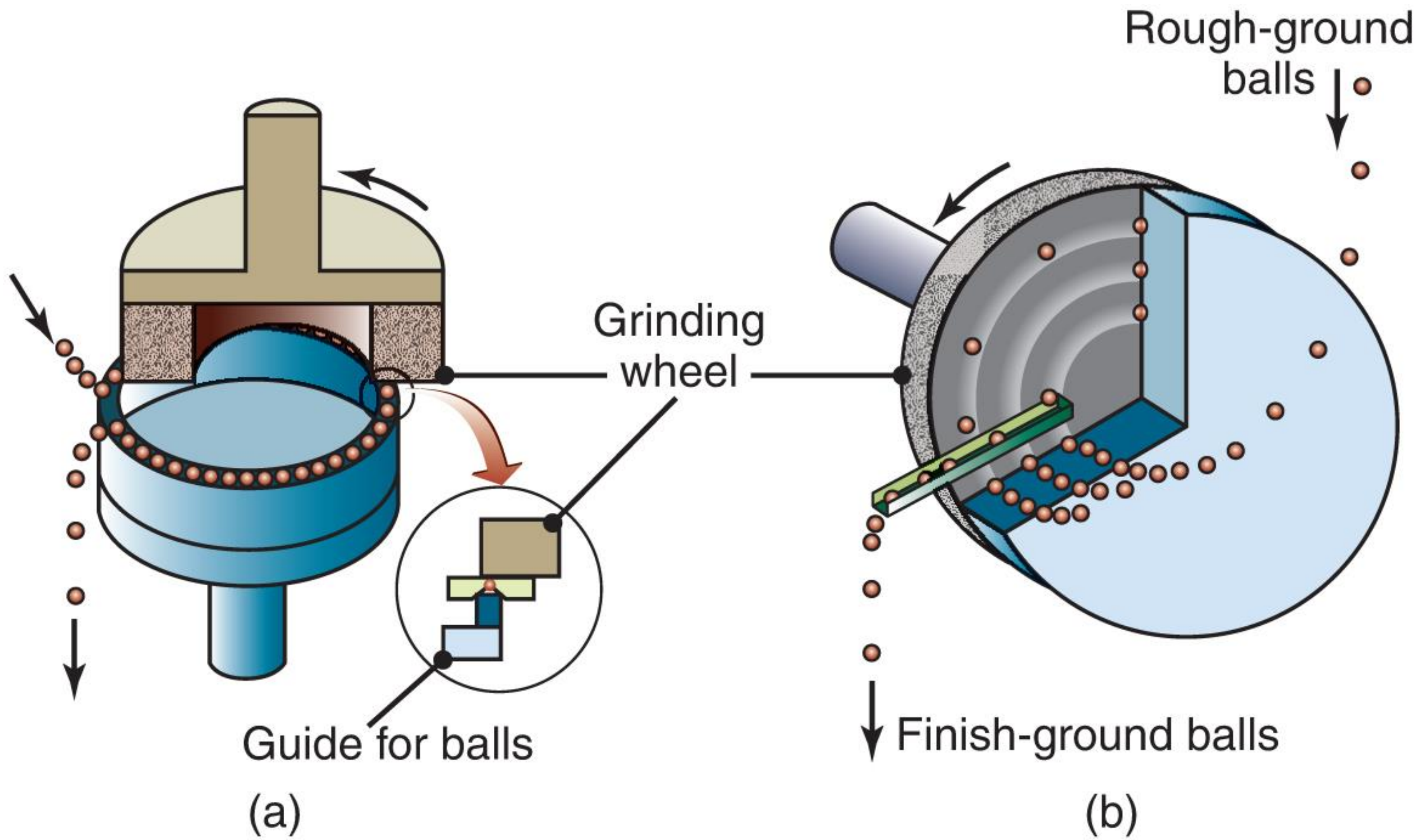
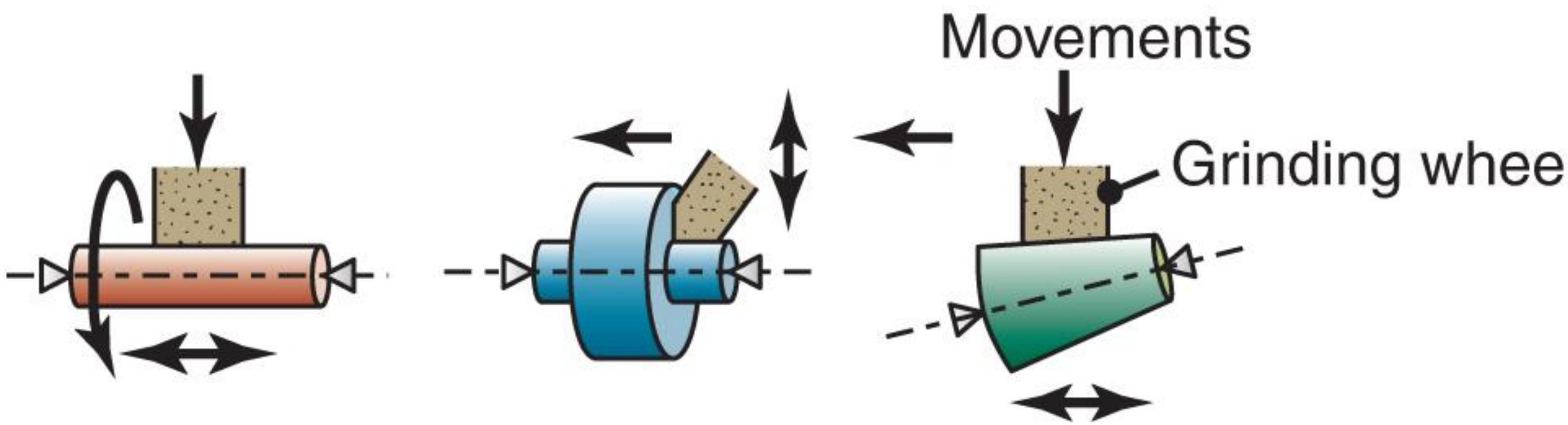


Figure 26.18 (1 of 3)

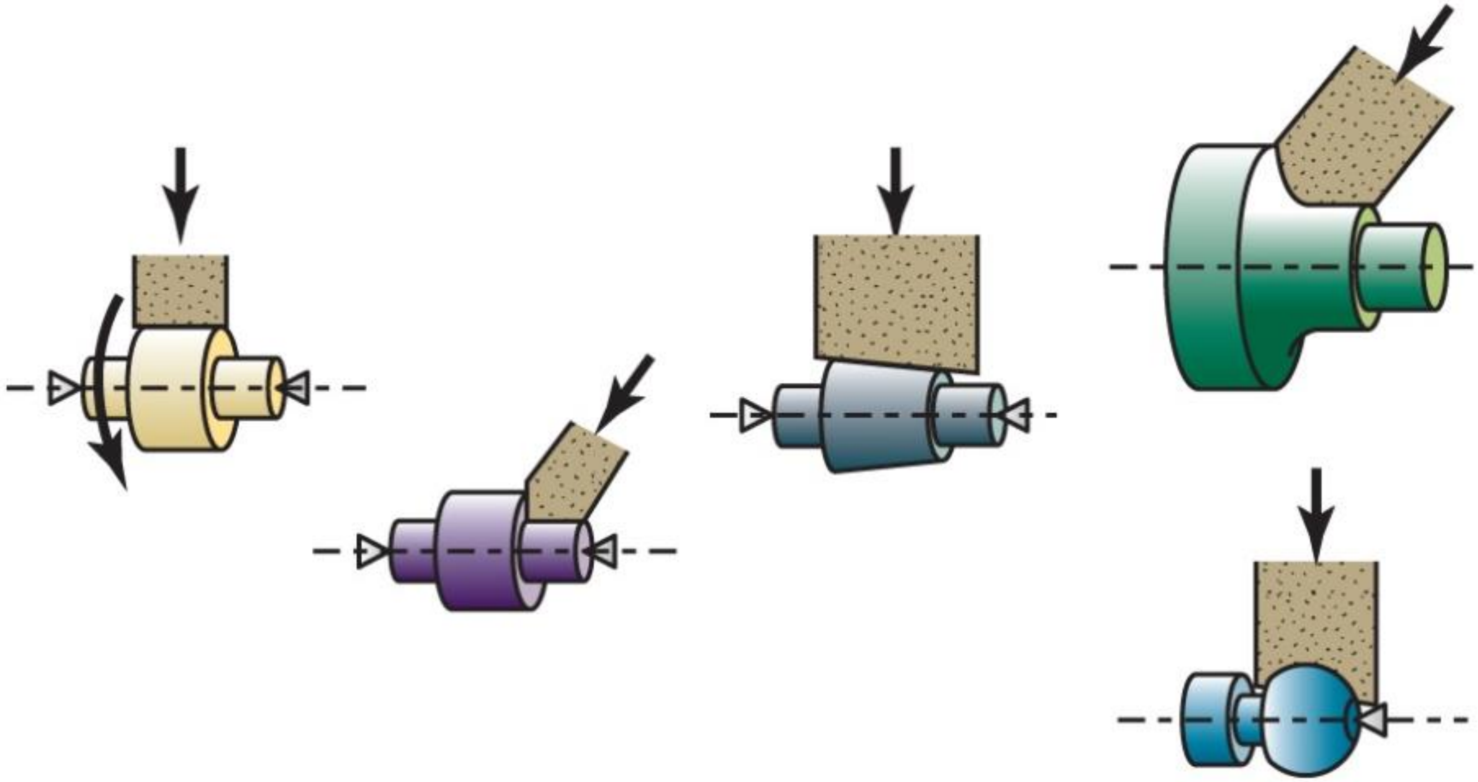
Examples of various cylindrical-grinding operations: (a) traverse grinding.



(a)

Figure 26.18 (2 of 3)

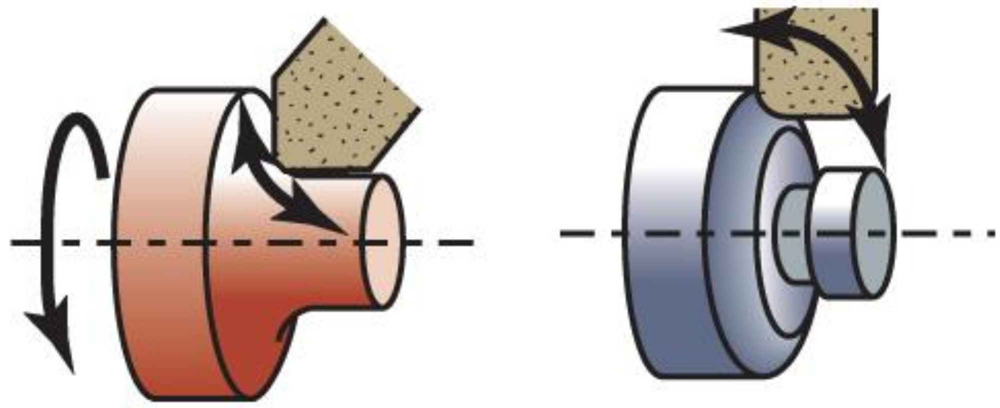
Examples of various cylindrical-grinding operations: (b) plunge grinding.



(b)

Figure 26.18 (3 of 3)

Examples of various cylindrical-grinding operations: (c) profile grinding.



(c)

Source: Courtesy of Okuma Machinery Works, Ltd.

Figure 26.24 (1 of 3)

Schematic illustrations of centerless-grinding operations: (a) through-feed grinding, (b) plunge grinding, (c) internal grinding.

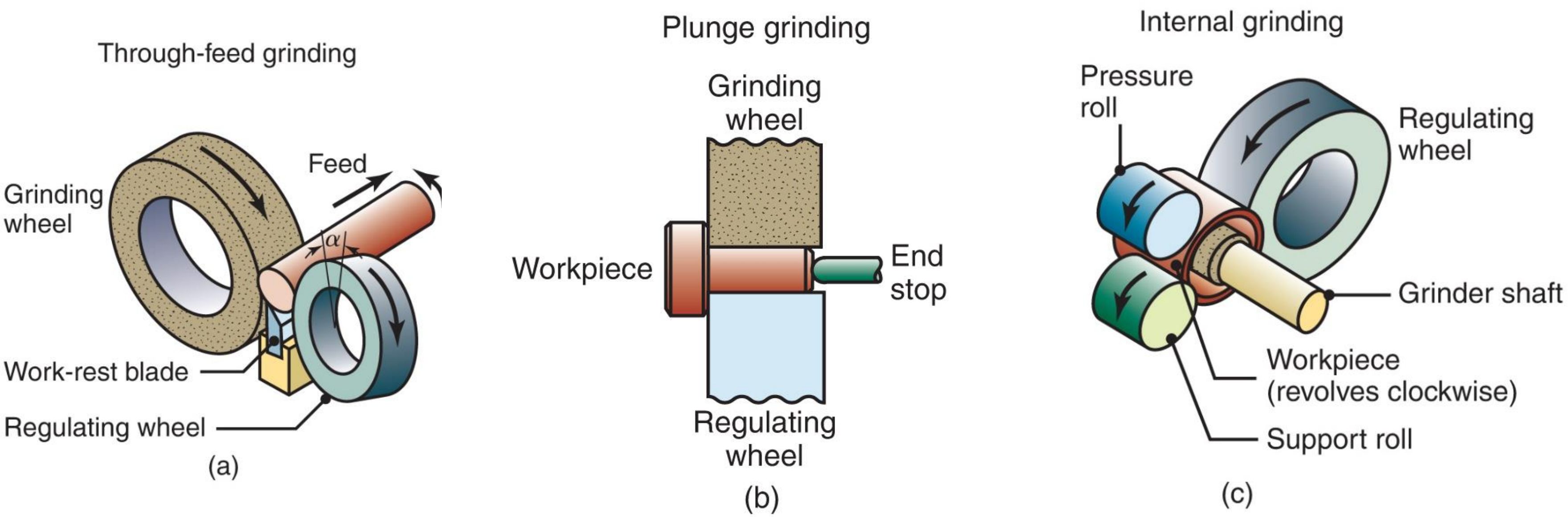


Figure 26.25

(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-feed grinding in one pass. Groove depth is typically on the order of a few mm. This operation also can be performed by some of the processes described in Chapter 27.

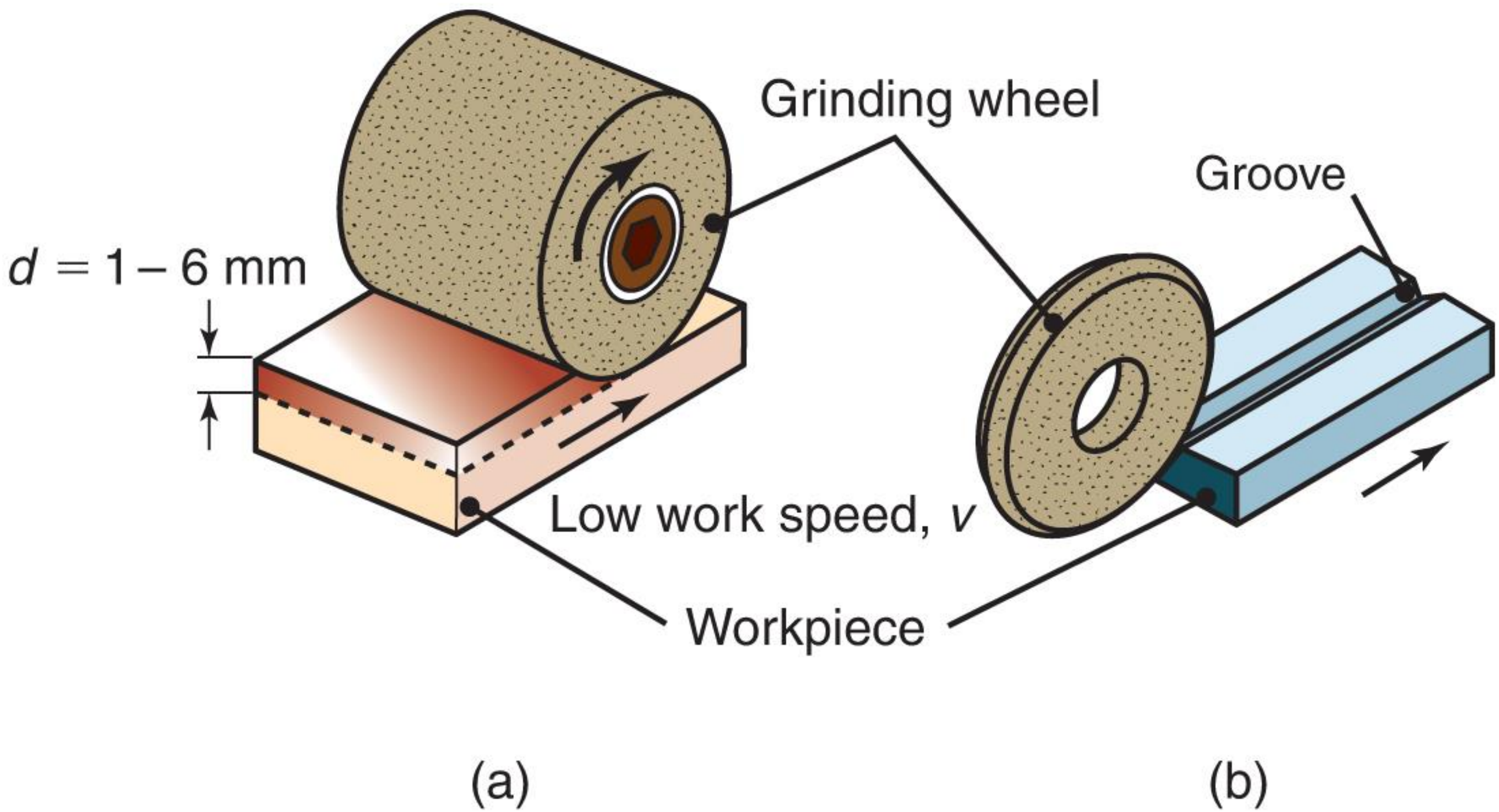


Table 26.5

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 (see also Section 33.7).

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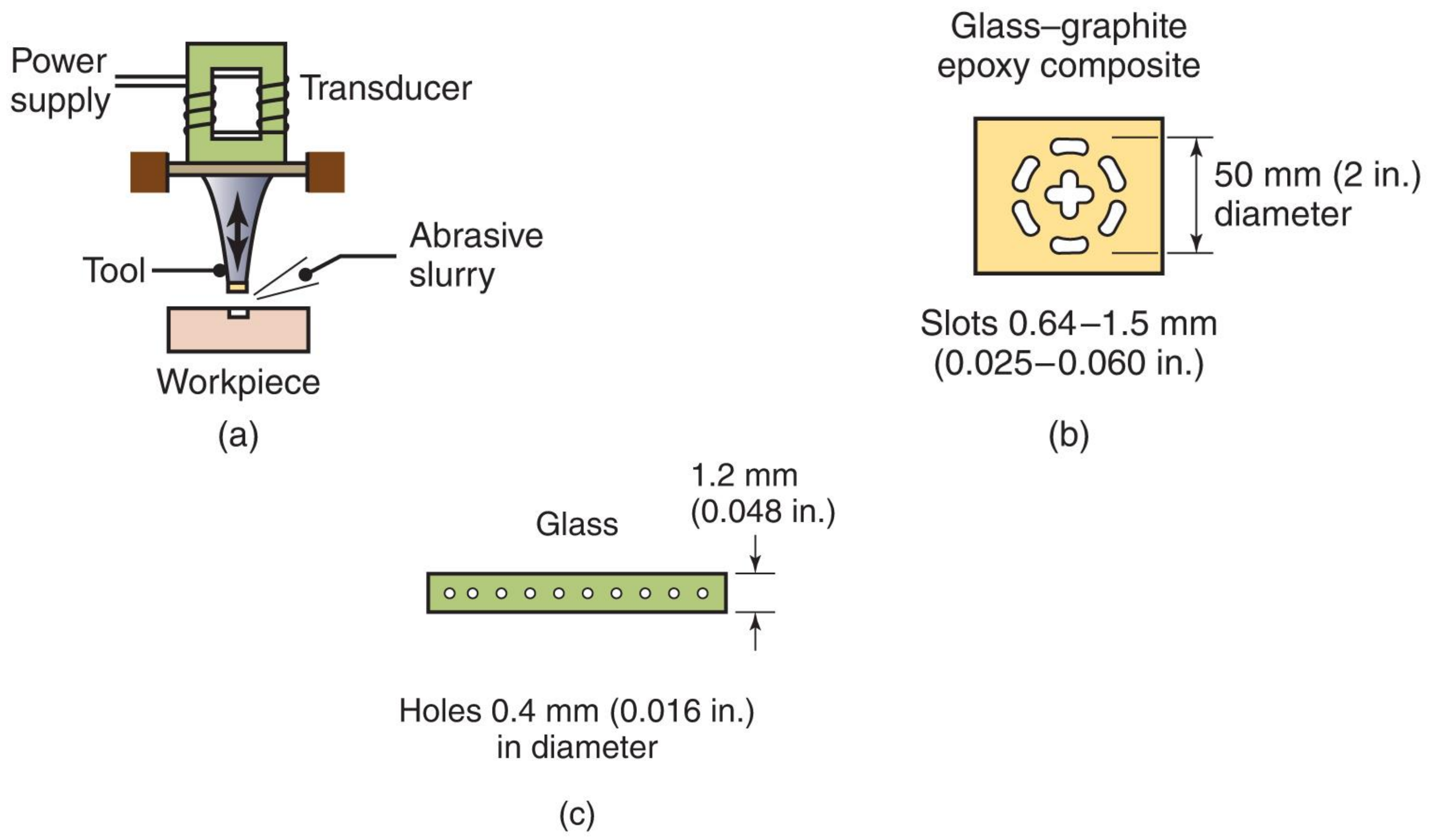
Figure 26.26

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



Ultrasonic Machining

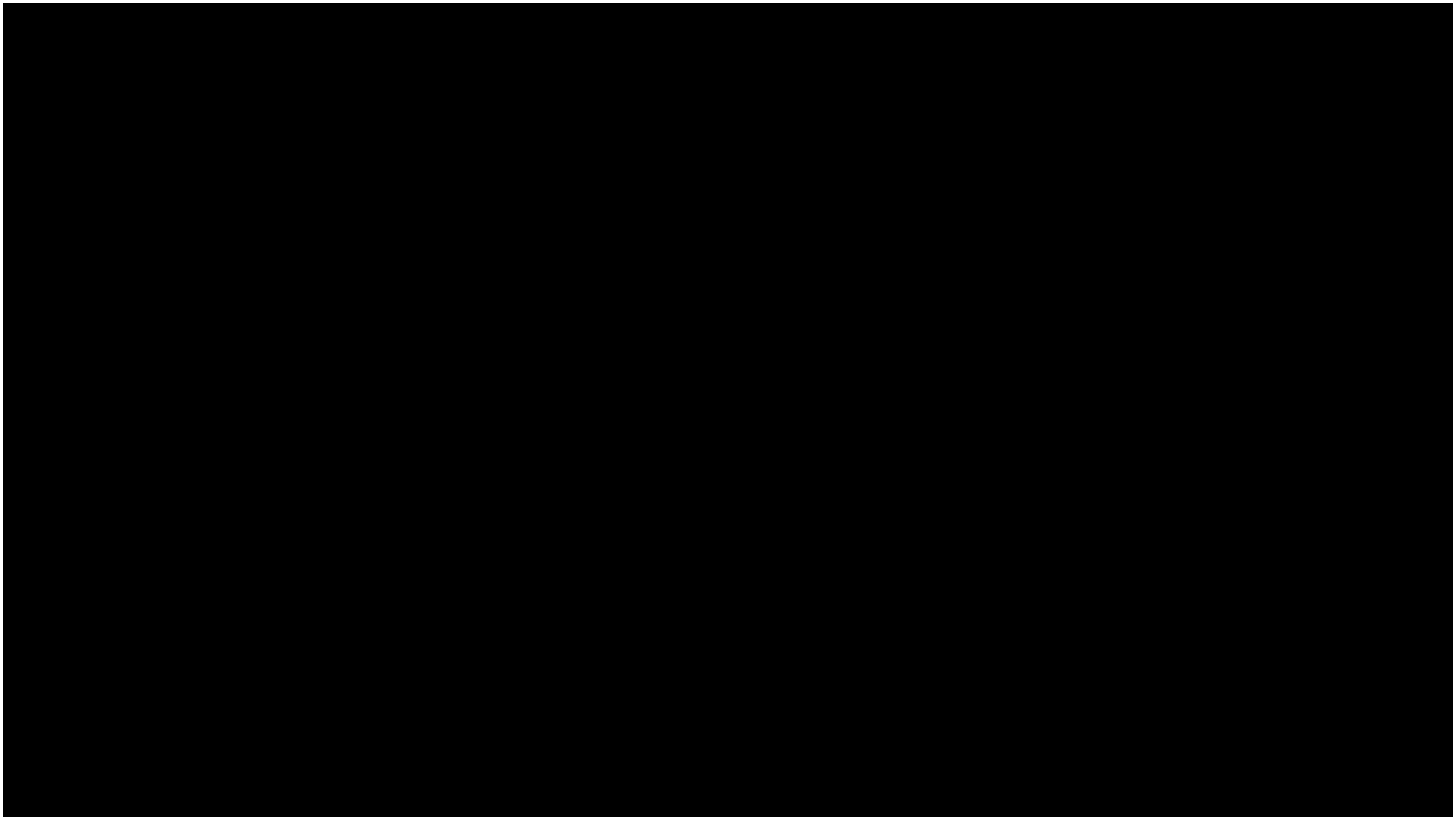


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Figure 26.27

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

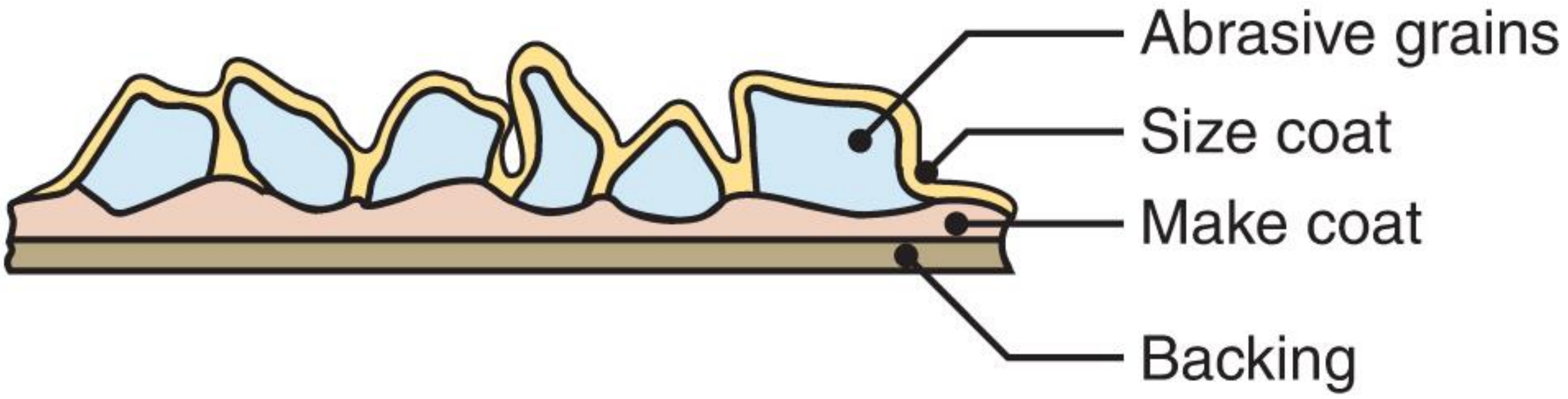

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Figure 26.29

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

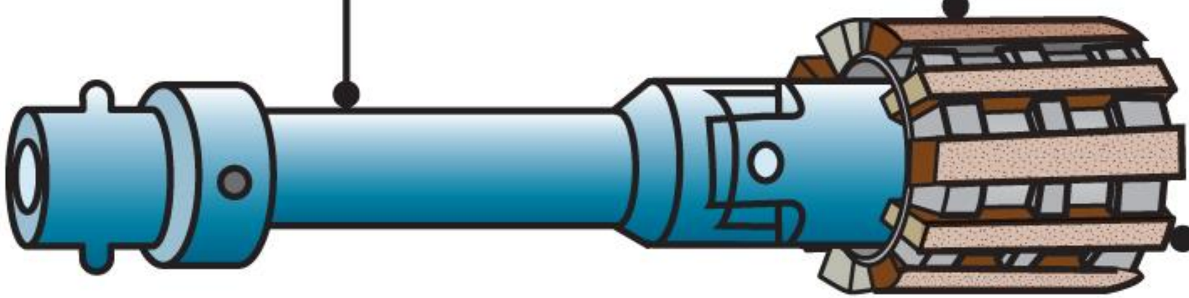


Figure 26.30 (1 of 2)

Schematic illustrations of the superfinishing process for a cylindrical part. (a) Cylindrical microhoning, (b) Centerless microhoning.

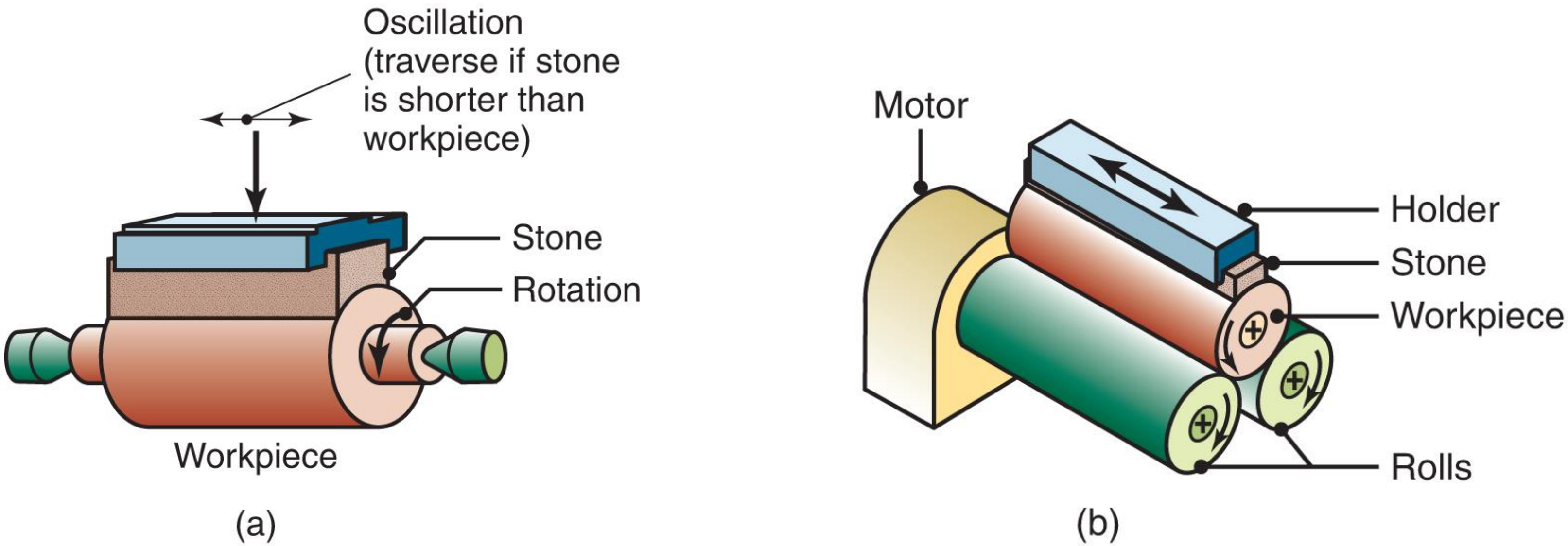


Figure 26.31 (1 of 3)

(a) Schematic illustration of the lapping process.

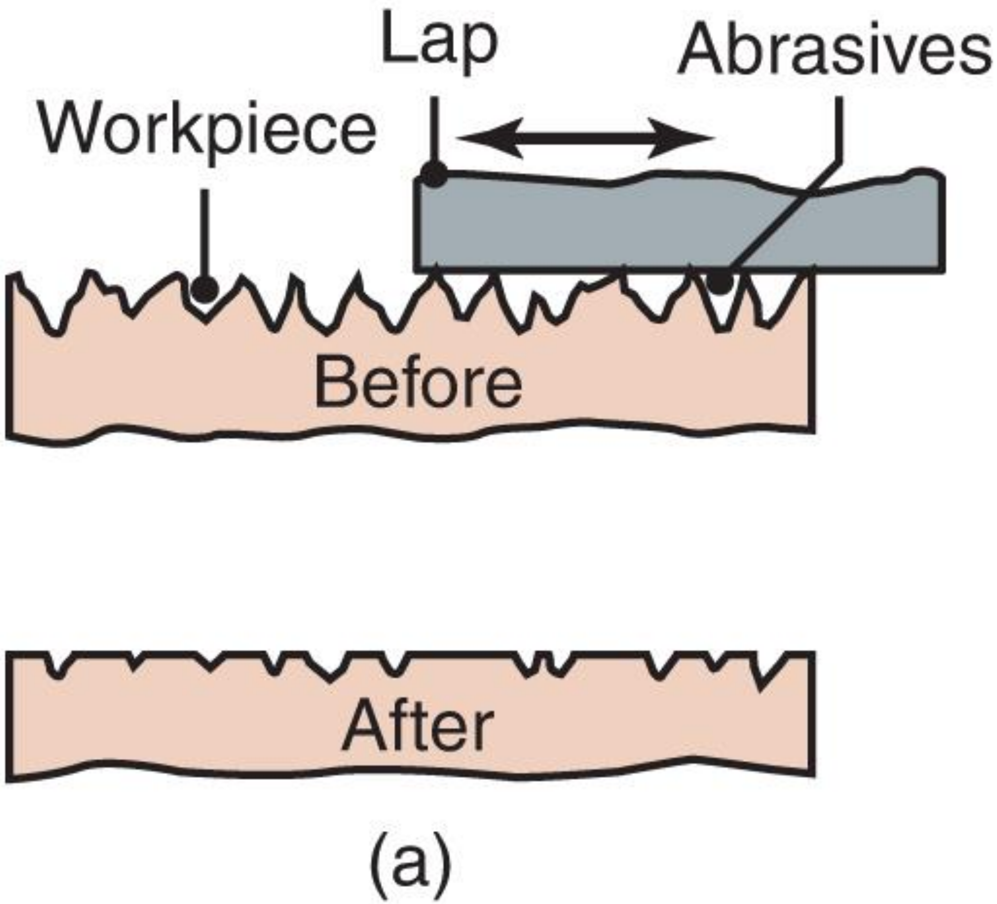
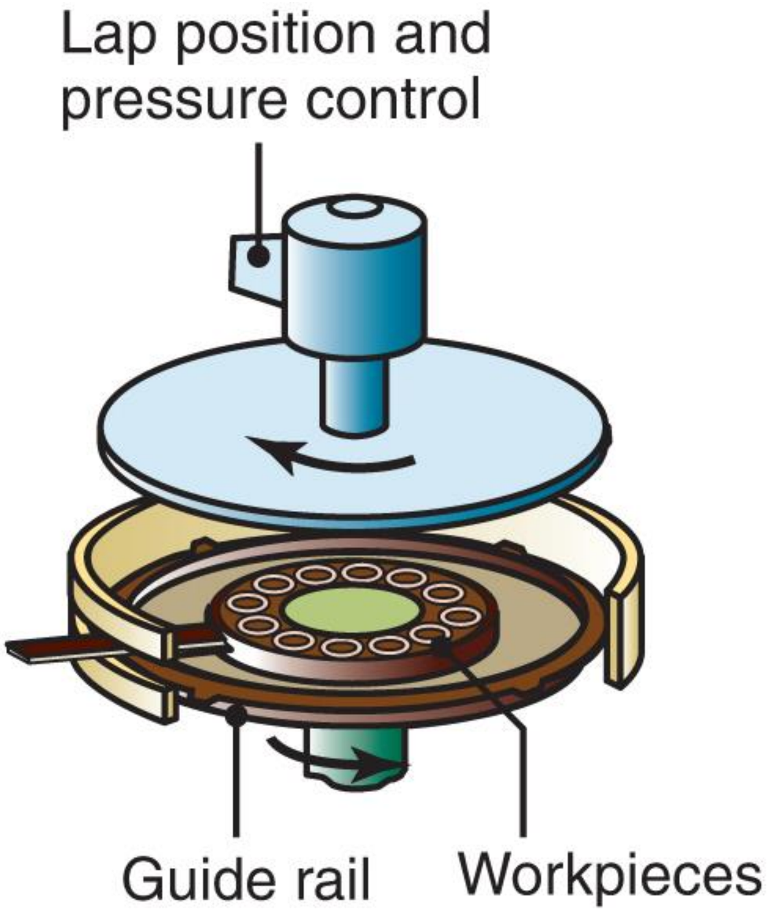


Figure 26.31 (2 of 3)

(b) Production lapping on flat surfaces.



(b)

Figure 26.31 (3 of 3)

(c) Production lapping on cylindrical surfaces.

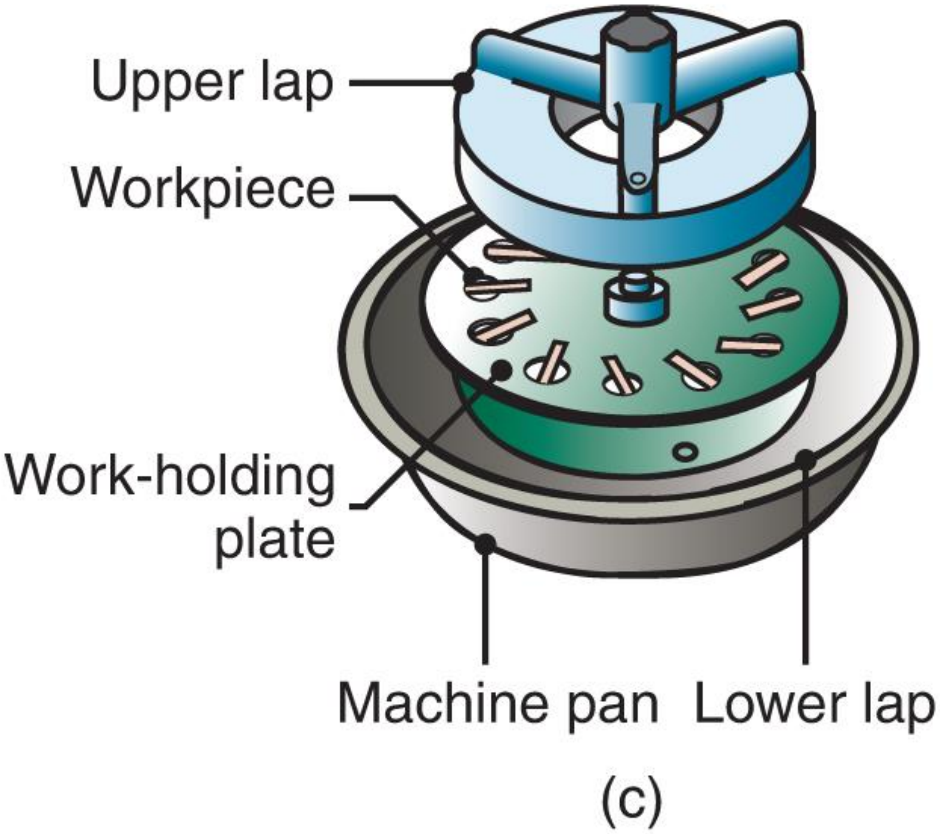
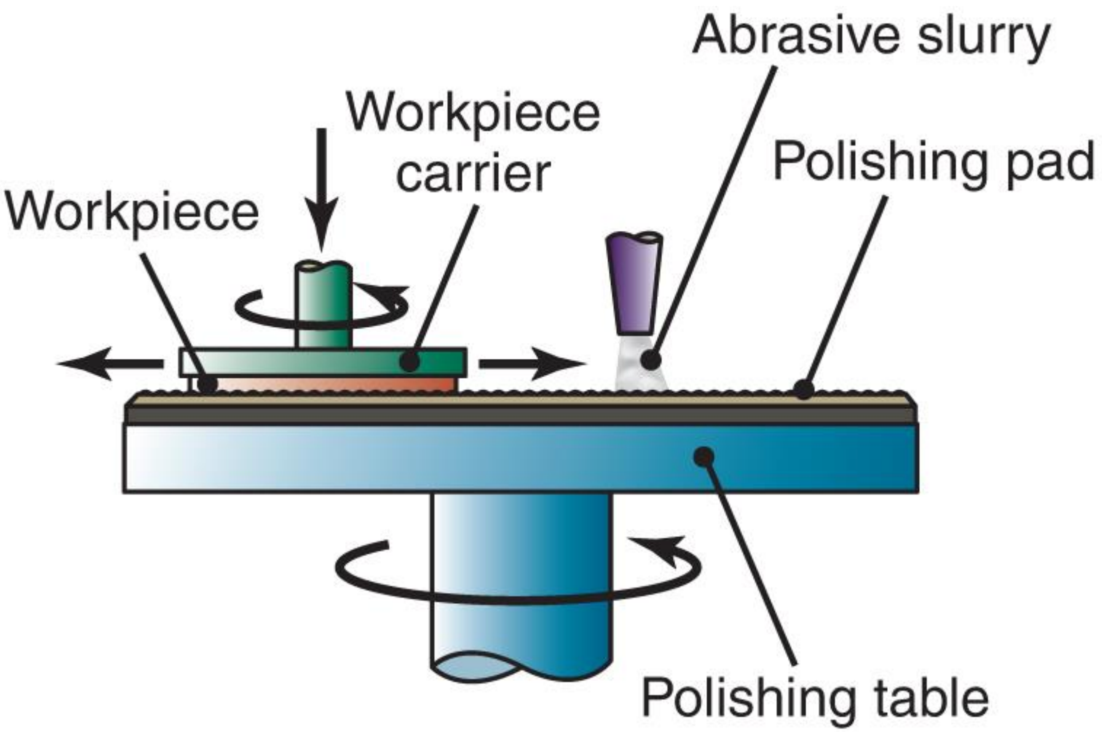


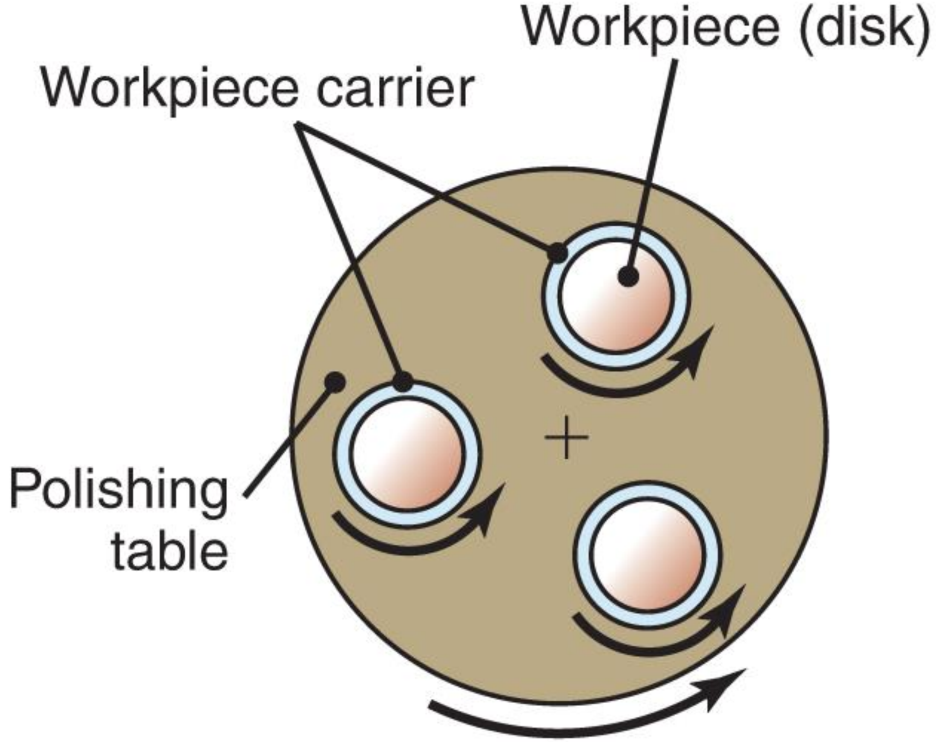
Figure 26.32 (1 of 2)

Schematic illustration of the chemical–mechanical polishing process. This process is used widely in making silicon wafers and integrated circuits and also is known as *chemical–mechanical planarization*. For other materials and applications, more carriers and more disks per carrier are possible.



(a) Side view

Figure 26.32 (2 of 2)



(b) Top view

Lapping

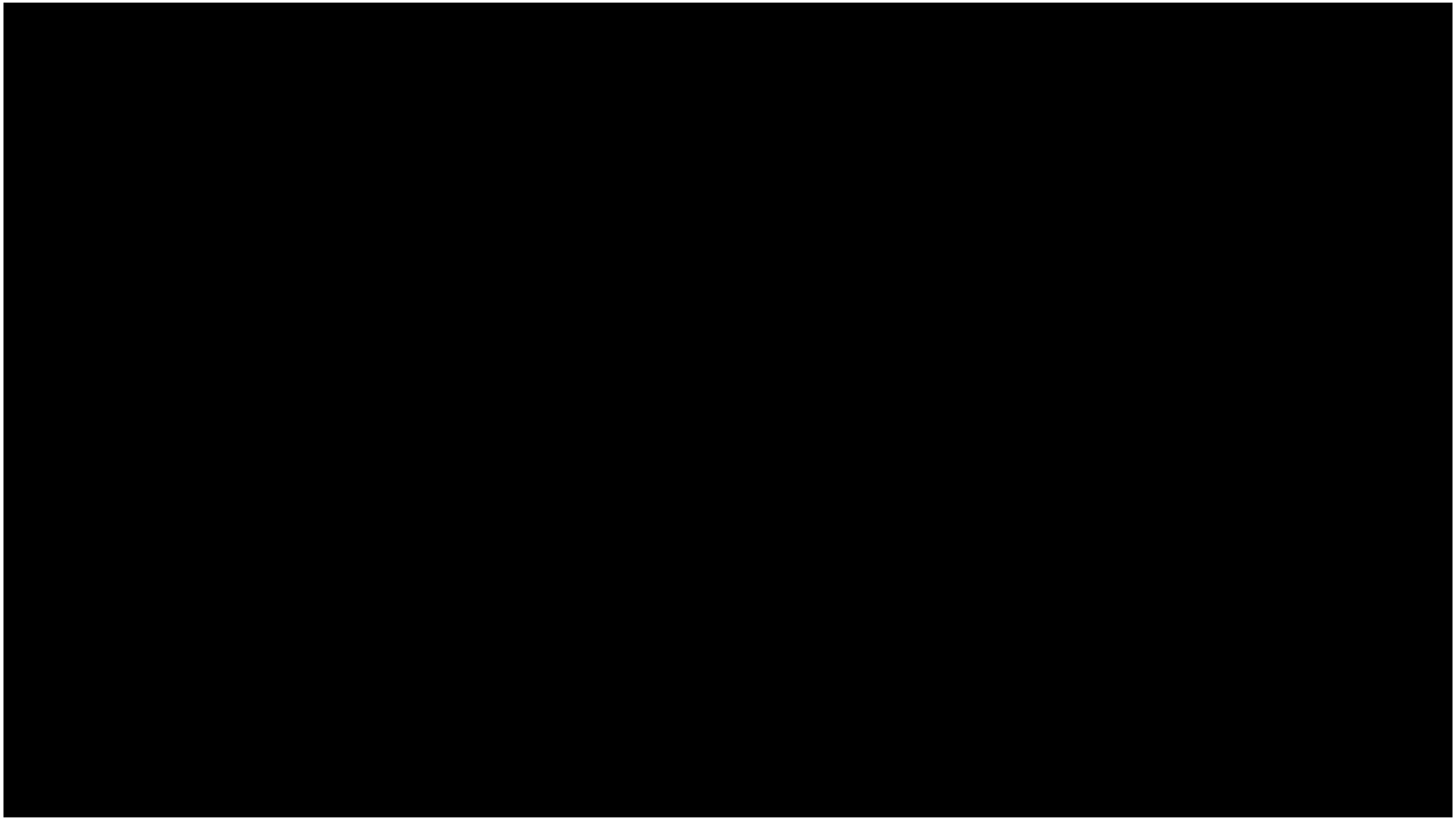


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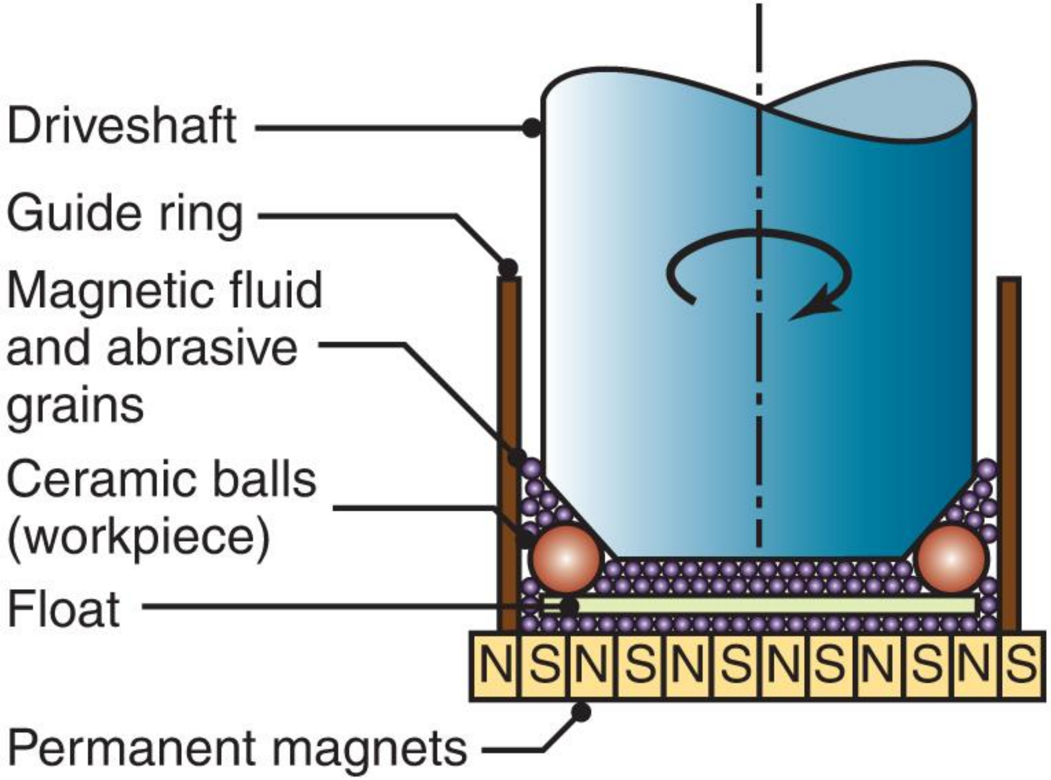
Figure 26.33 (1 of 2)

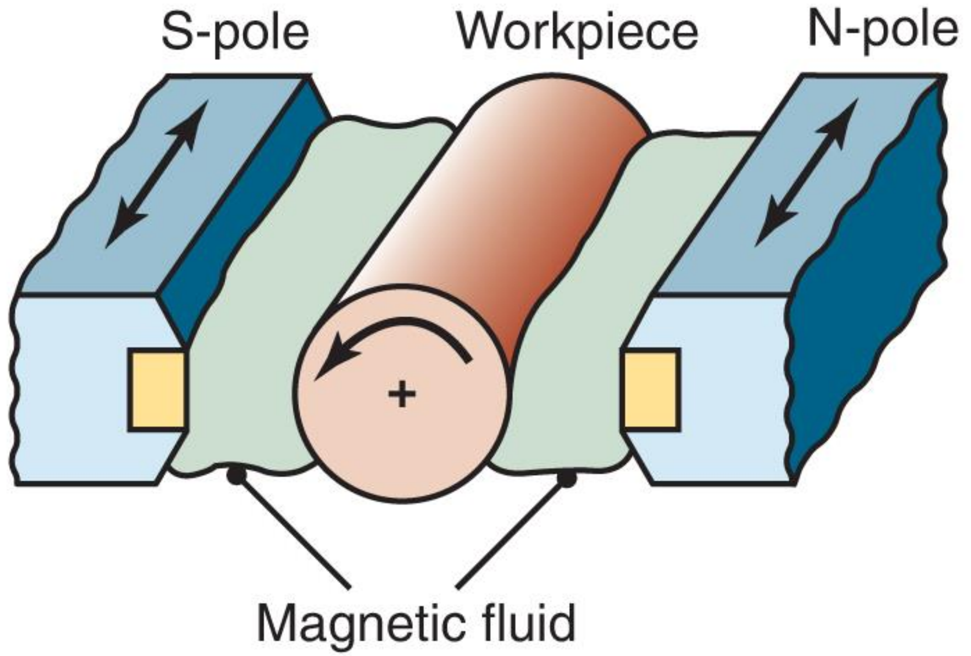
Schematic illustration of polishing of balls and rollers by magnetic fields. (a) Magnetic-float polishing of ceramic balls.



(a)

Figure 26.33 (2 of 2)

Schematic illustration of polishing of balls and rollers by magnetic fields. (b) Magnetic-field-assisted polishing of rollers.

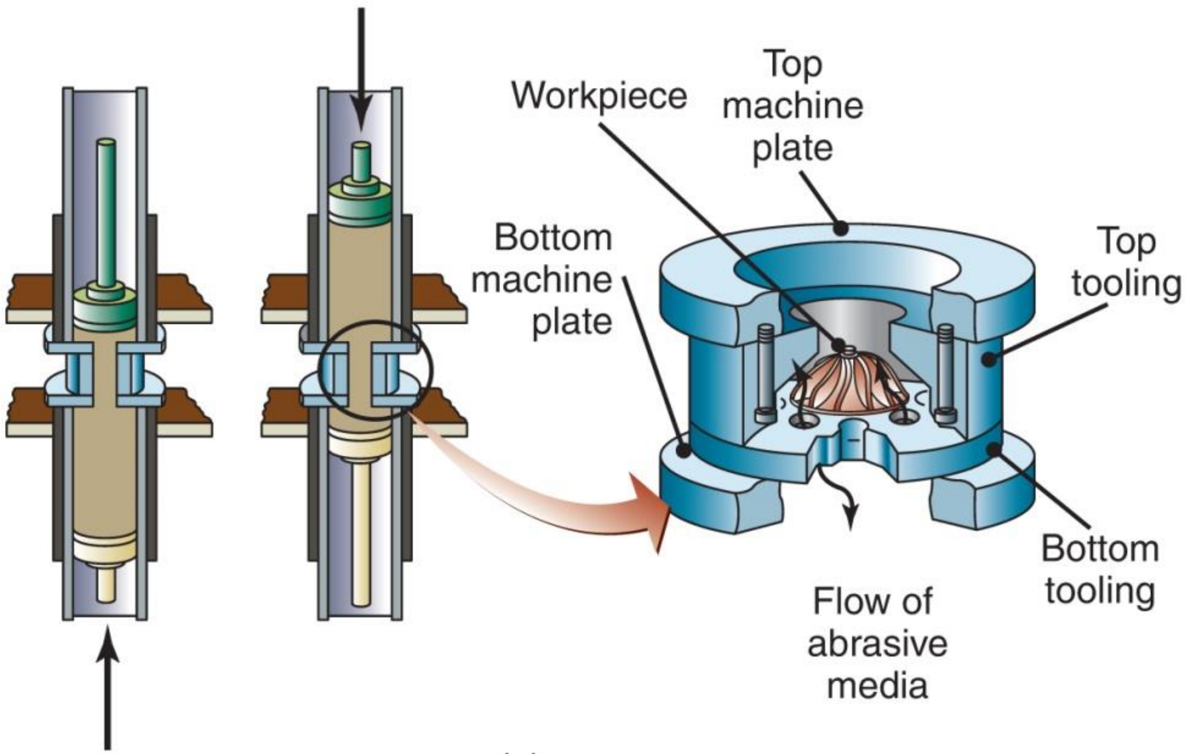


(b)

Source: After R. Komanduri, M. Doc, and M. Fox.

Figure 26.34 (1 of 2)

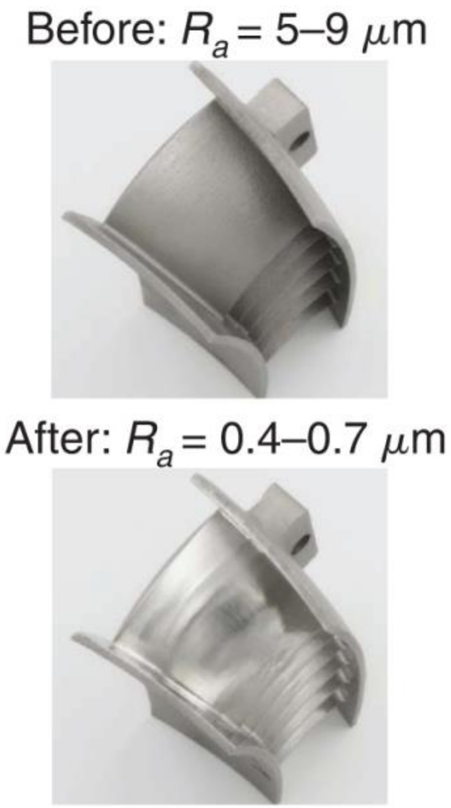
(a) Schematic illustration of abrasive-flow machining to deburr a turbine impeller. The arrows indicate movement of the abrasive media. Note the special fixture, which is usually different for each part design.



(a)

Figure 26.34 (2 of 2)

(b) Valve fittings subjected to abrasive-flow machining to eliminate burrs and improve surface quality.



(b)

Source: Courtesy of Kennametal Extrude Hone.

Abrasive Flow

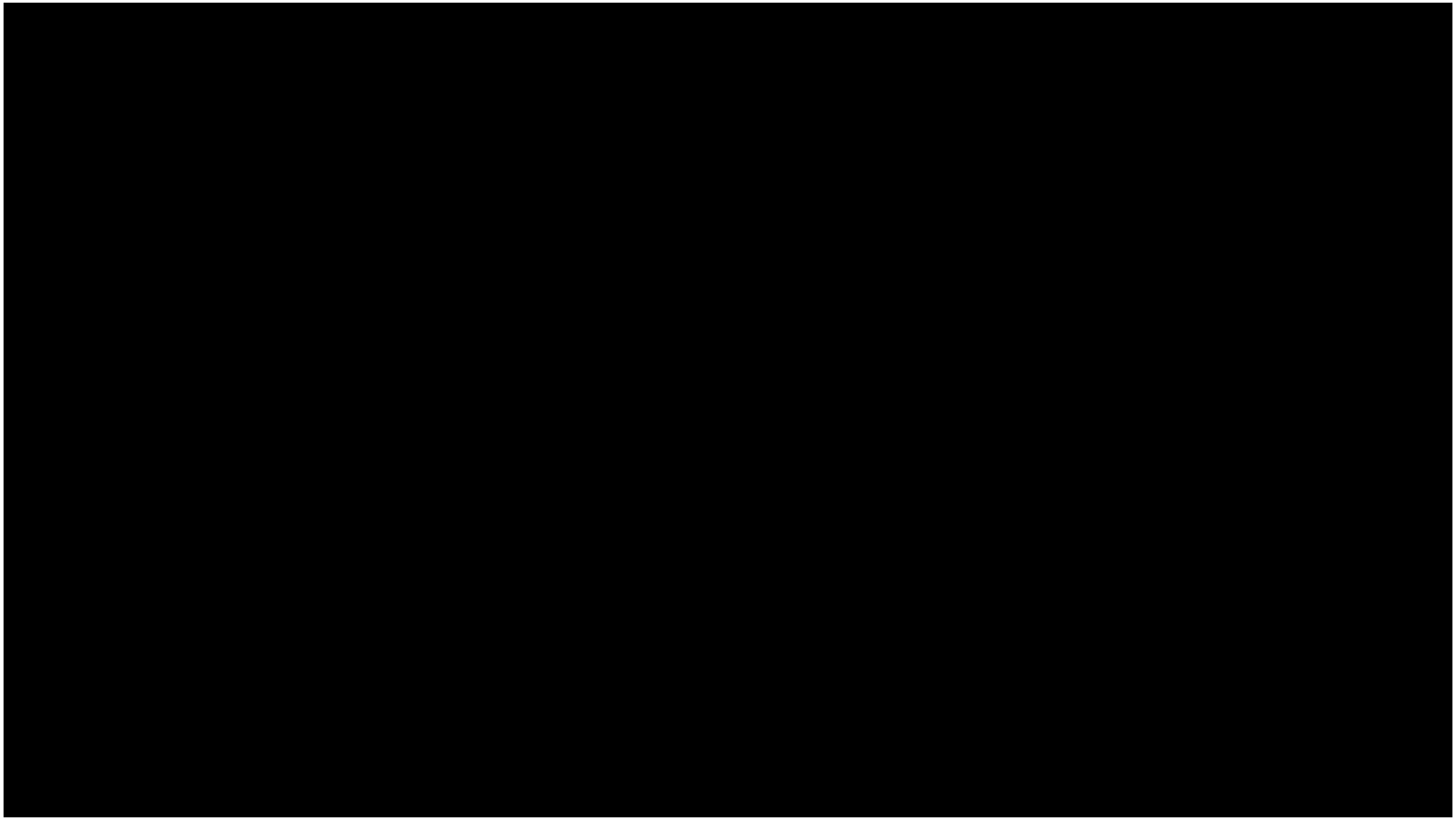


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Figure 26.35

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 is necessary for the part to function properly.

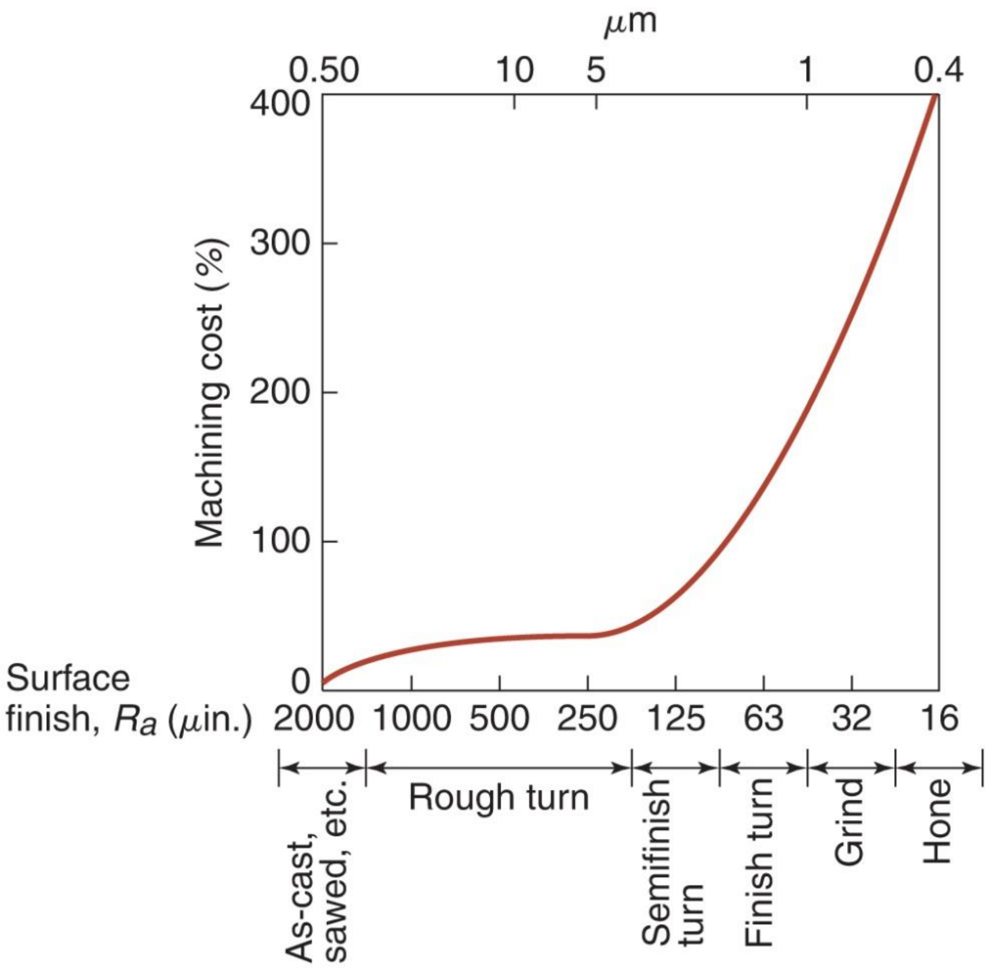


Figure 26.37

Grinding of a 3-m diameter gear.

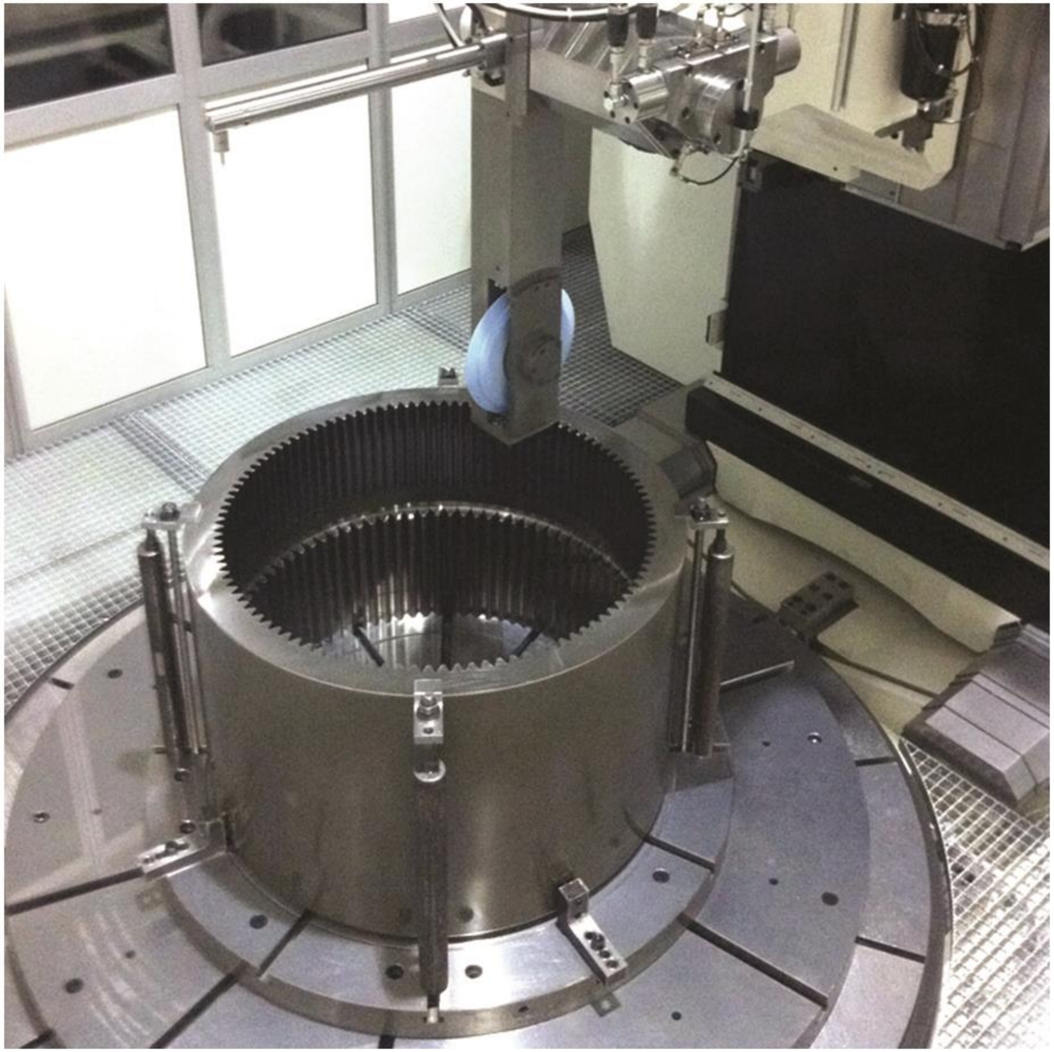
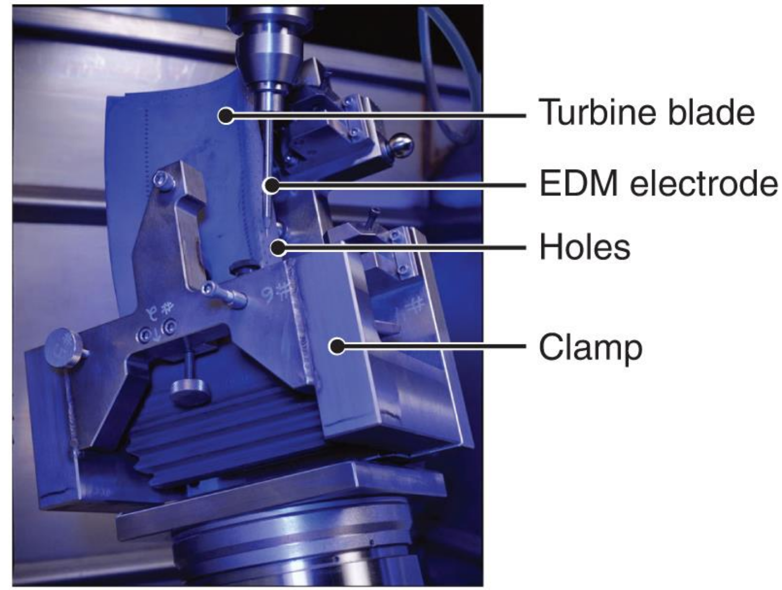


Figure 27.1 (1 of 2)

Examples of parts made by advanced machining processes. (a) Samples of parts produced by water-jet cutting, (b) Turbine blade, produced by plunge electrical-discharge machining, in a fixture to produce forced air cooling channels also by electrical-discharge machining

(a)



(b)

Source: (a) Courtesy of OMAX Corporation.

Table 27.1 (1 of 2)

General Characteristics of Advanced Machining Processes.

Process	Characteristics	Process parameters and typical material-removal rate or cutting speed
Chemical machining (CM)	Shallow removal on large flat or curved surfaces; blanking of thin sheets; low tooling and equipment cost; suitable for low-production runs	0.0025–0.1 mm/min. (0.0001–0.004 in./min)
Electrochemical machining (ECM)	Complex shapes with deep cavities; highest rate of material removal among other nontraditional processes; expensive tooling and equipment; high power consumption; medium-to-high production quantity	V: 5–25 D.C.; A: 1.5-8 A/mm^2; 2.5–12 mm/min (0.1–0.5 in./min), depending on current density
Electrochemical grinding (ECG)	Cutting off and sharpening hard materials, such as tungsten-carbide tools; also used as a honing process; higher removal rate than grinding	A: 1–3 A/mm^2; typically 25 mm^3/s (0.0016 in^3/s) per 1000 A
Electrical-discharge machining (EDM)	Shaping and cutting complex parts made of hard materials; some surface damage may result; also used as a grinding and cutting process; expensive tooling and equipment	V: 50–380; A: 0.1–500; typically 300 mm^3/min (0.02 in^3/min)

Table 27.1 (2 of 2)

General Characteristics of Advanced Machining Processes.

Wire electrical-discharge machining	Contour cutting of flat or curved surfaces; expensive equipment	Varies with material and thickness
Laser-beam machining (LBM)	Cutting and hole making on thin materials; heat-affected zone; does not require a vacuum; expensive equipment; consumes much energy	0.50–7.5 m/min (1.67–25 ft/min)
Laser microjet	Water-jet guided laser uses a 25–100 μm diameter stream to mill or cut; large depth of field; little thermal damage from laser machining	Varies with material; up to 20 mm in silicon, 2 mm in stainless steel; up to 300 mm/s in 50 μm thick silicon.
Electron-beam machining (EBM)	Cutting and hole making on thin materials; very small holes and slots; heat-affected zone; requires a vacuum; expensive equipment	1–2 mm^3/min (0.004–0.008 in^3/hr)
Water-jet machining (WJM)	Cutting all types of nonmetallic materials; suitable for contour cutting of flexible materials; no thermal damage; noisy	Varies considerably with material
Abrasive water-jet machining (AWJM)	Single-layer or multilayer cutting of metallic and nonmetallic materials	Up to 7.5 m/min (25 ft/min)
Abrasive-jet machining (AJM)	Cutting, slotting, deburring, etching, and cleaning of metallic and nonmetallic materials; tends to round off sharp edges; can be hazardous	Varies considerably with material

Figure 27.2 (1 of 2)

(a) Missile skin-panel section contoured by chemical milling to improve the stiffness-to-weight ratio of the part, (b) Weight reduction of space-launch vehicles by the chemical milling of aluminum-alloy plates. The plates are chemically milled after they have been formed into shape by a process such as roll forming or stretch forming. The design of the chemically machined rib patterns can readily be modified at minimal cost.

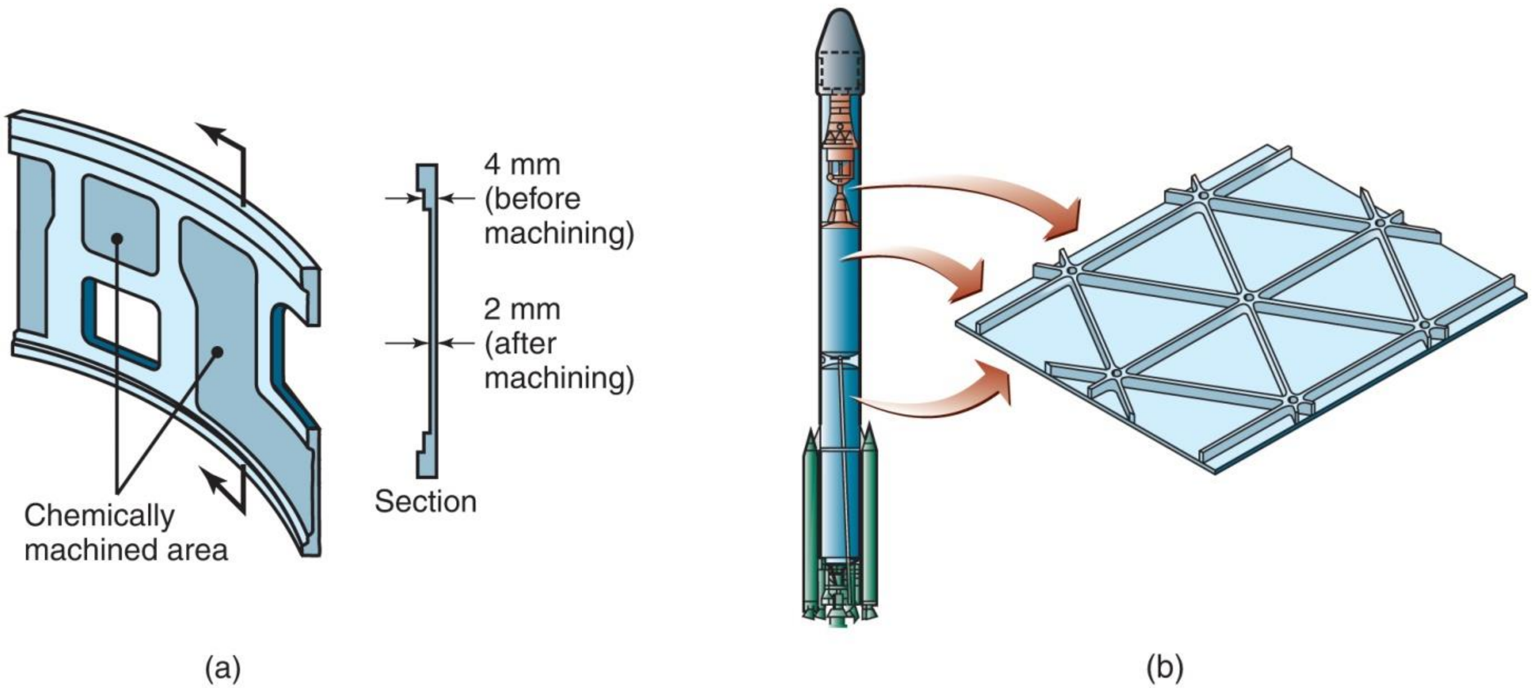


Figure 27.3

(a) Schematic illustration of the chemical-machining process; note that no forces or machine tools are involved in this process, (b) Stages in producing a profiled cavity by chemical machining; note the undercut.

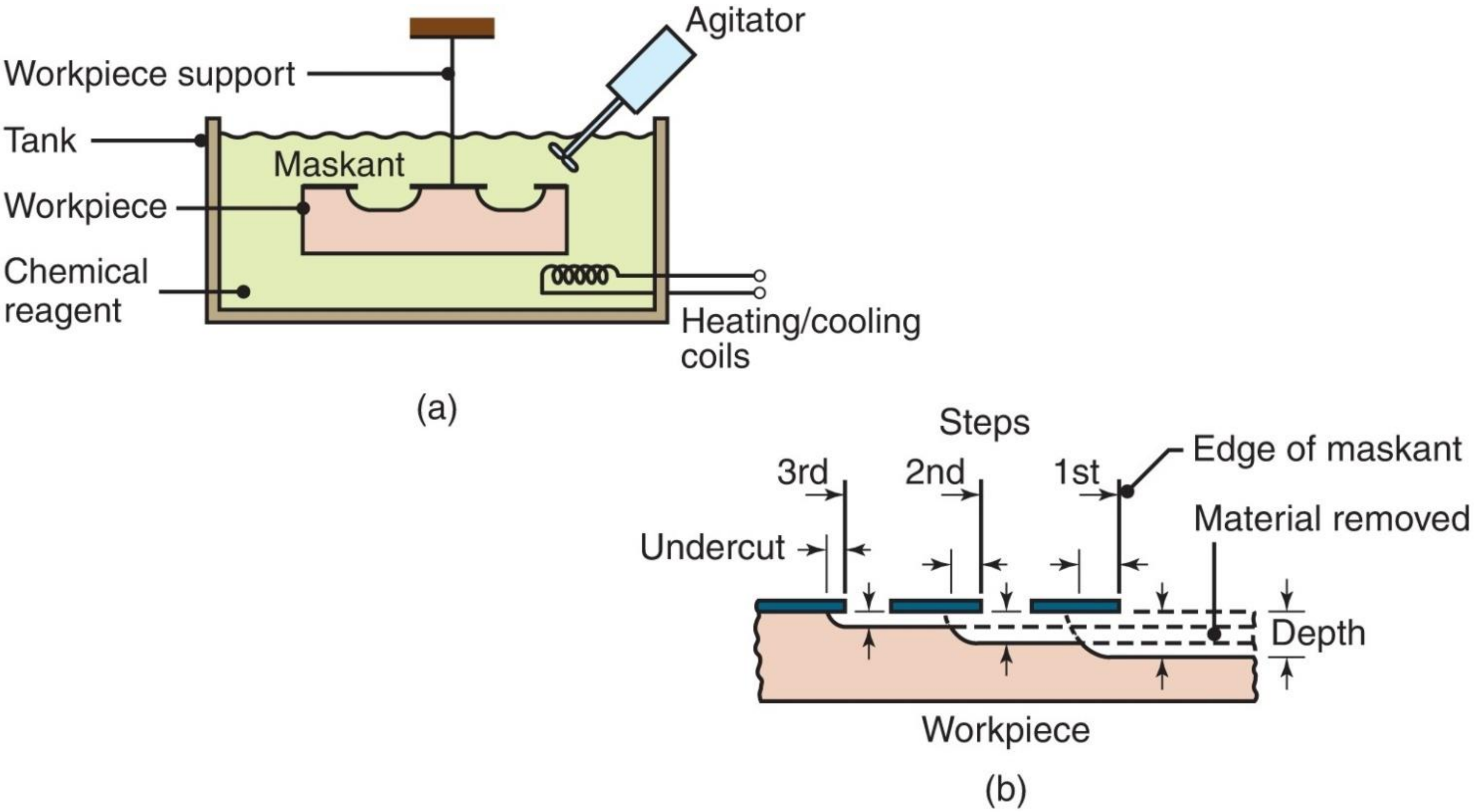


Figure 27.4

Schematic illustration of the electrochemical machining process.

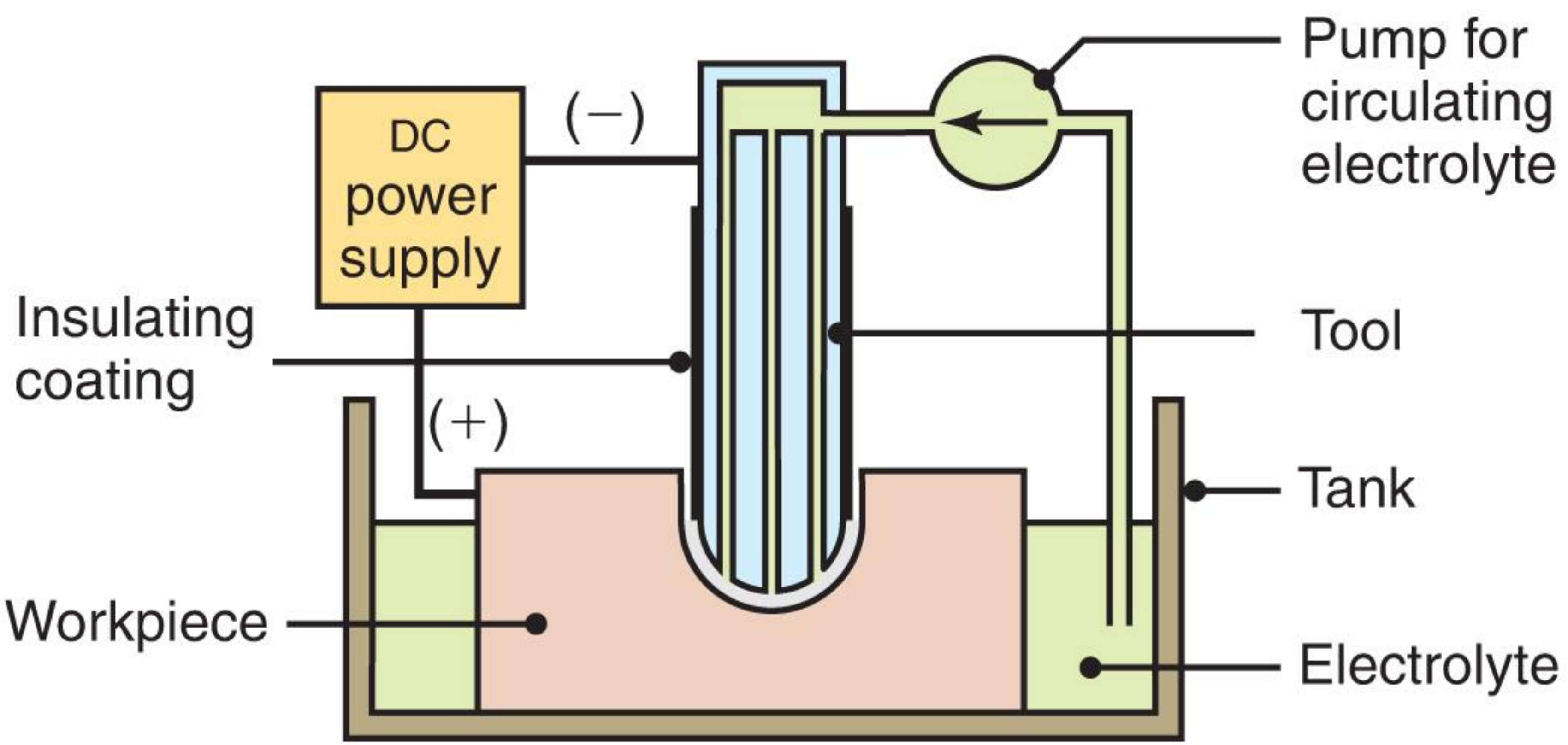
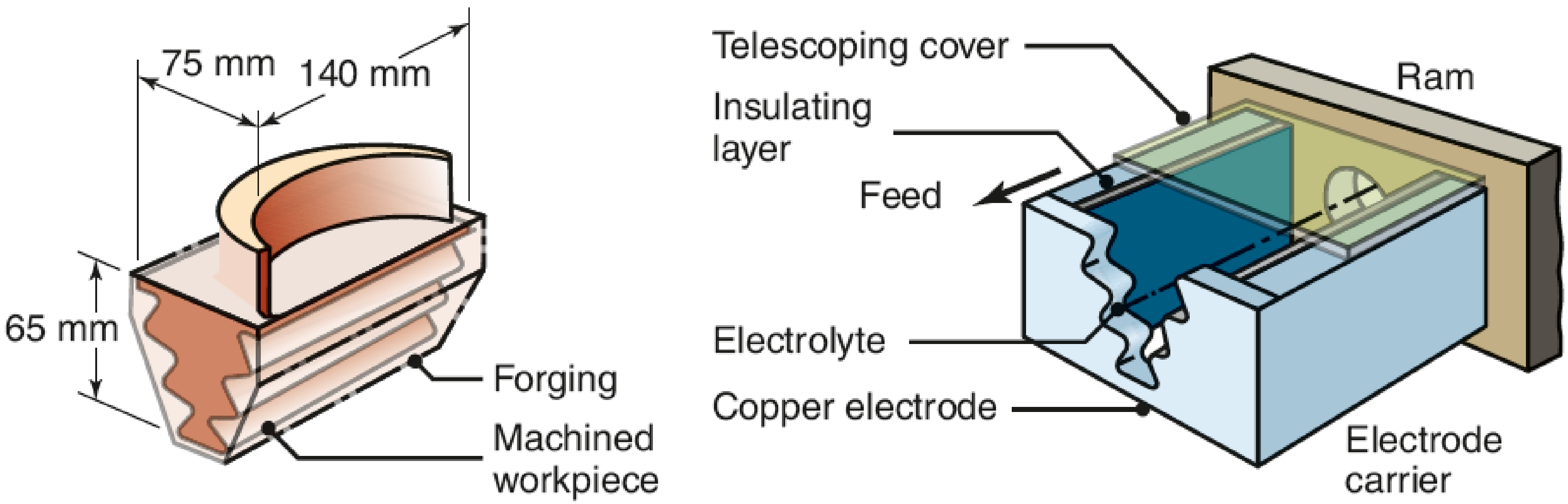


Figure 27.5 (1 of 3)

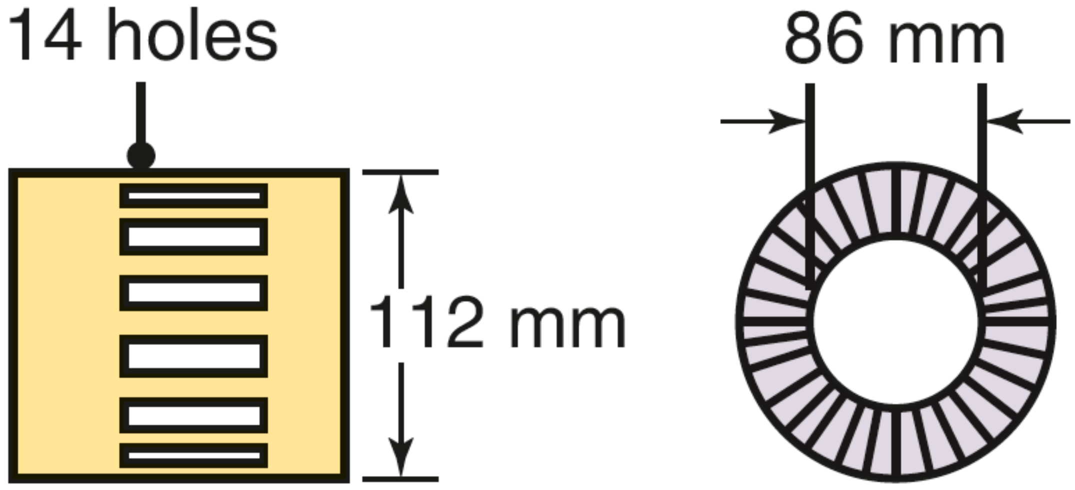
Typical parts made by electrochemical machining. (a) Turbine blade made of a nickel alloy of 360 HB; note the shape of the electrode on the right.



(a)

Figure 27.5 (2 of 3)

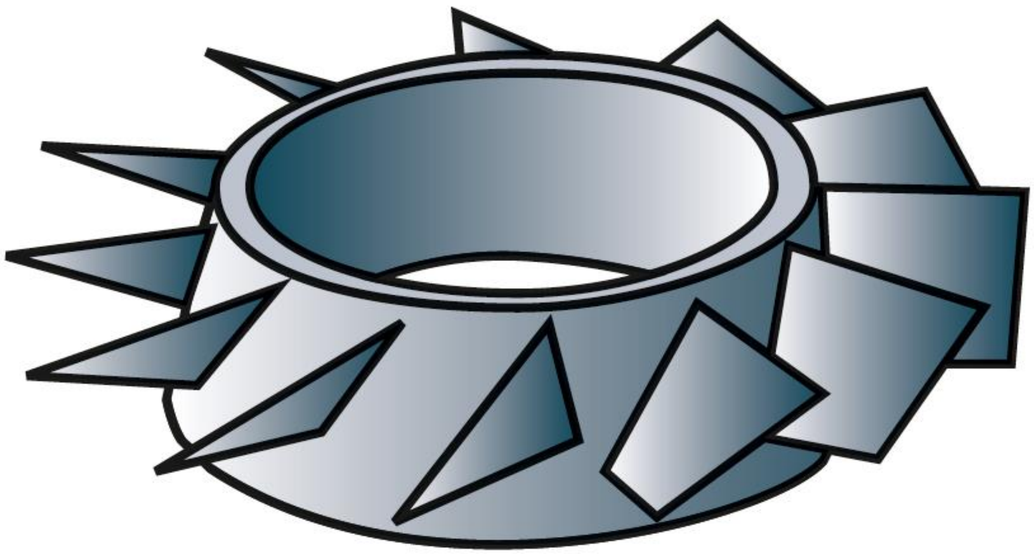
Typical parts made by electrochemical machining. (b) Thin slots on a 4340-steel roller-bearing cage.



(b)

Figure 27.5 (3 of 3)

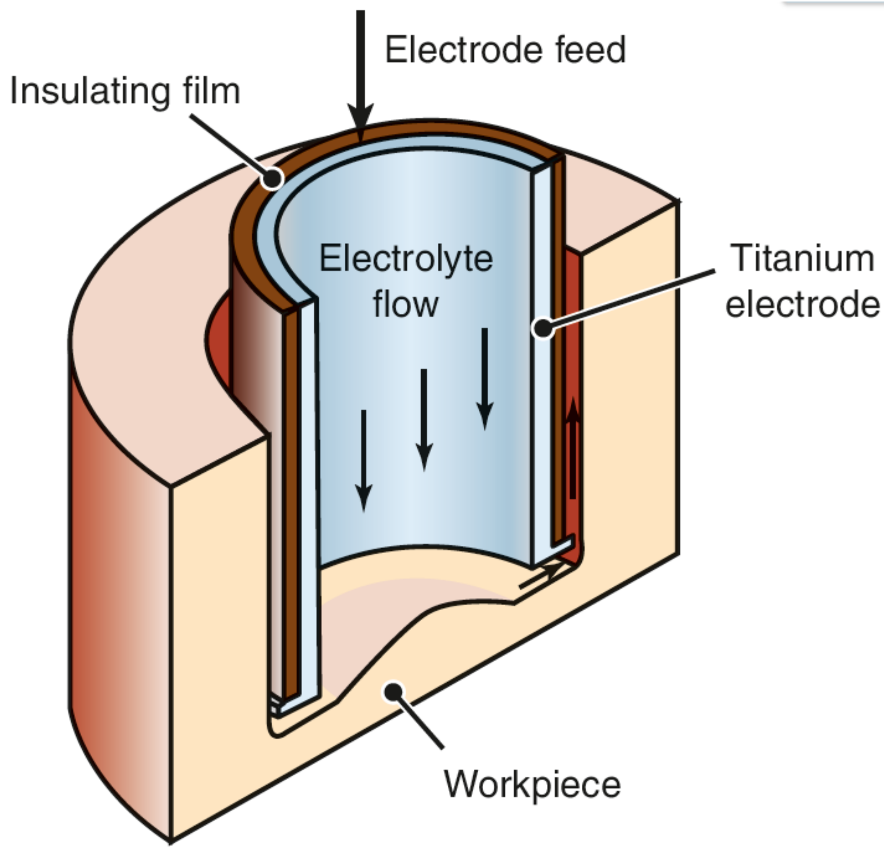
Typical parts made by electrochemical machining. (c) Integral airfoils on a compressor disk.



(c)

Figure 27.6 (1 of 2)

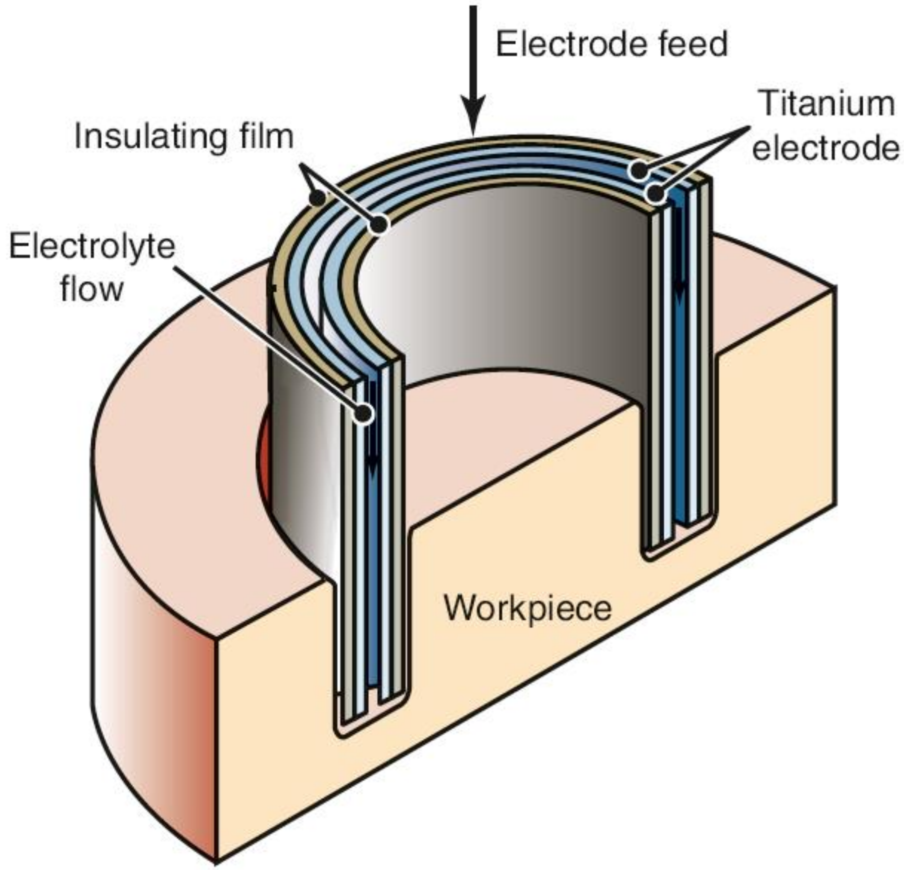
Shaped electrolytic machining operations. (a) Shaped-tube electrolytic machining, used to make small holes with aspect ratios as large as 300:1.



(a)

Figure 27.6 (2 of 2)

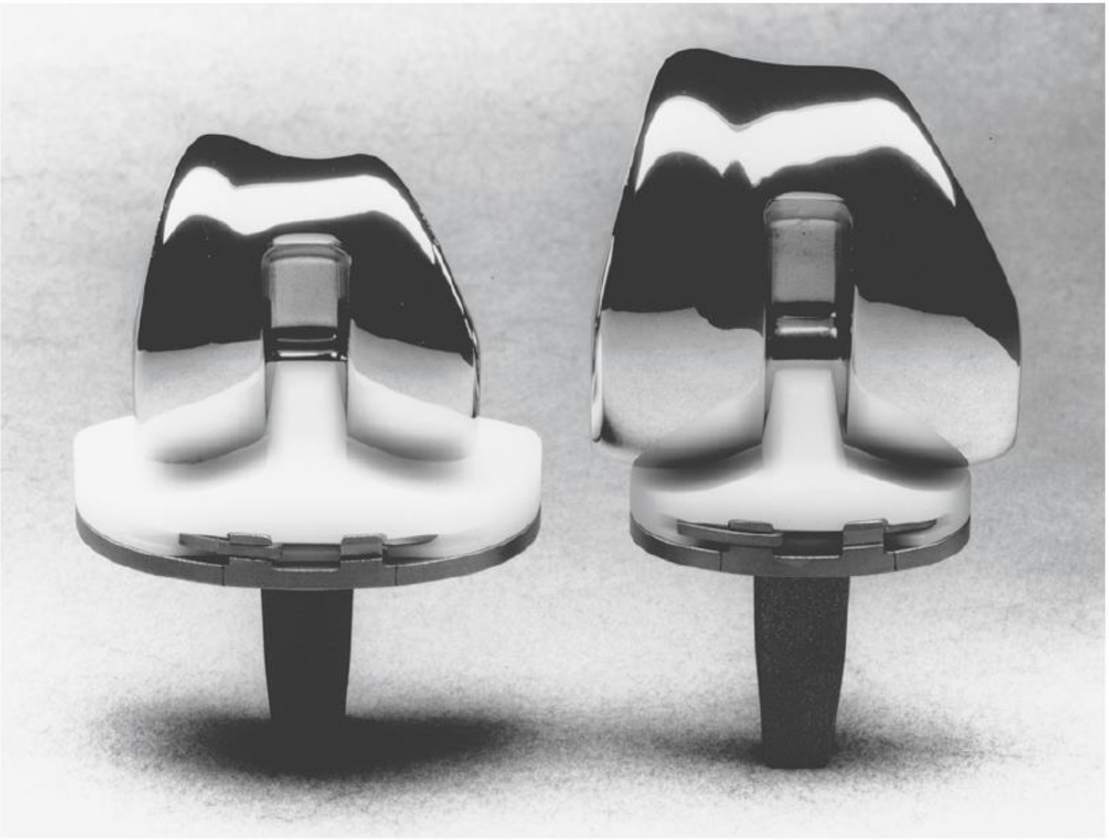
Shaped electrolytic machining operations. (b) electrolytic trepanning, used for larger diameter holes.



(b)

Figure 27.7 (1 of 2)

(a) Two total knee-replacement systems, showing metal implants (top pieces) with an ultrahigh-molecular-weight polyethylene insert (bottom pieces).

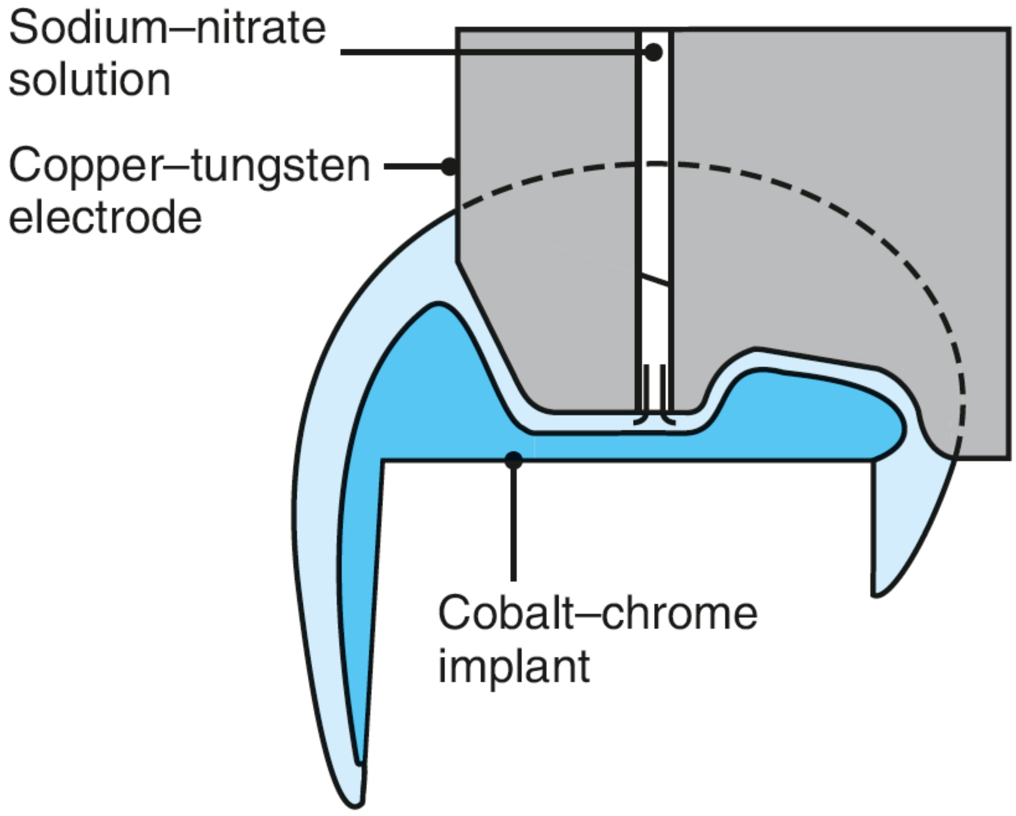


(a)

Pearson

Figure 27.7 (2 of 2)

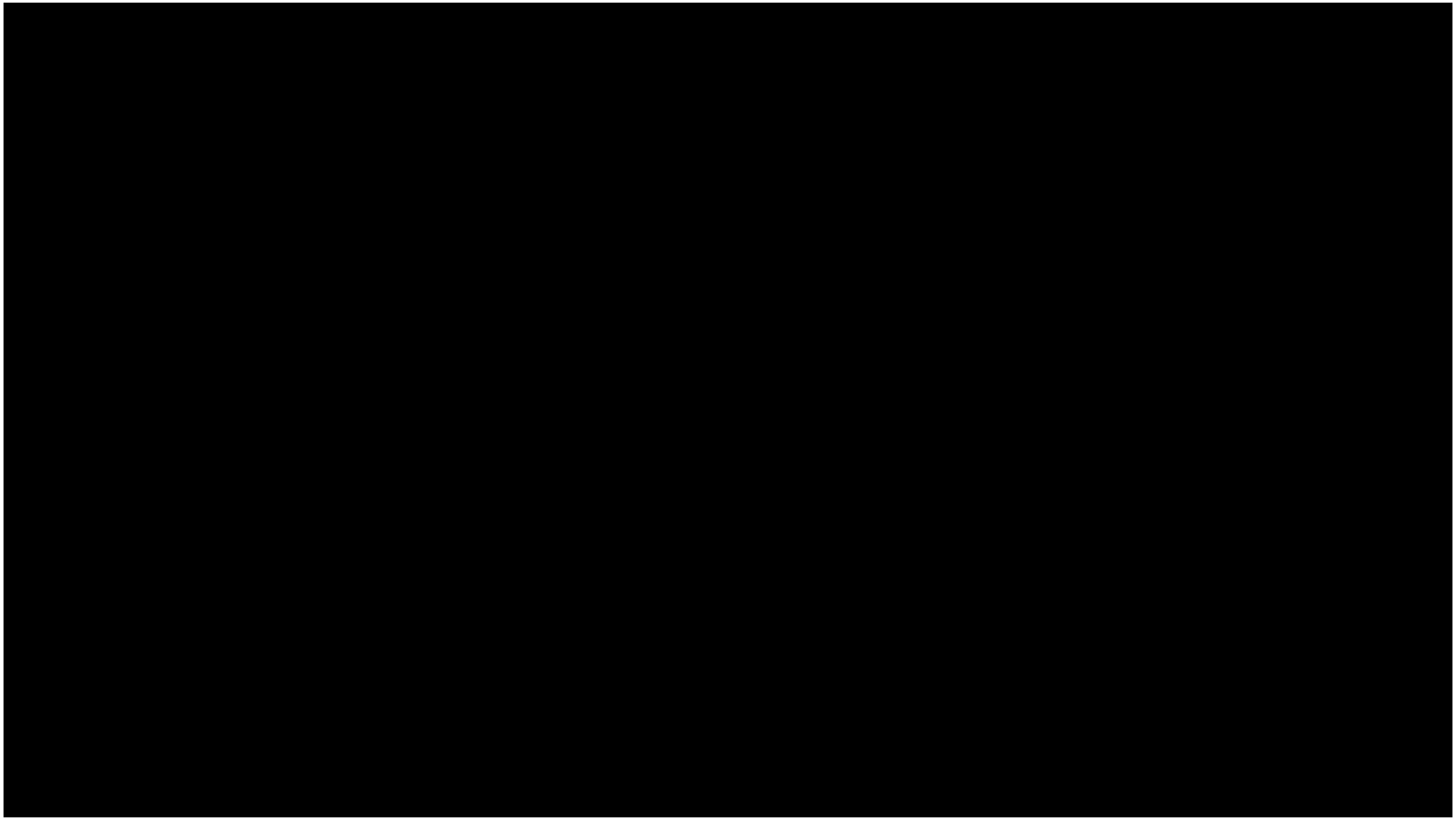
(b) Cross section of the ECM process, as applied to the metal implant.



(b)

Source: Courtesy of Zimmer Biomet, Inc.

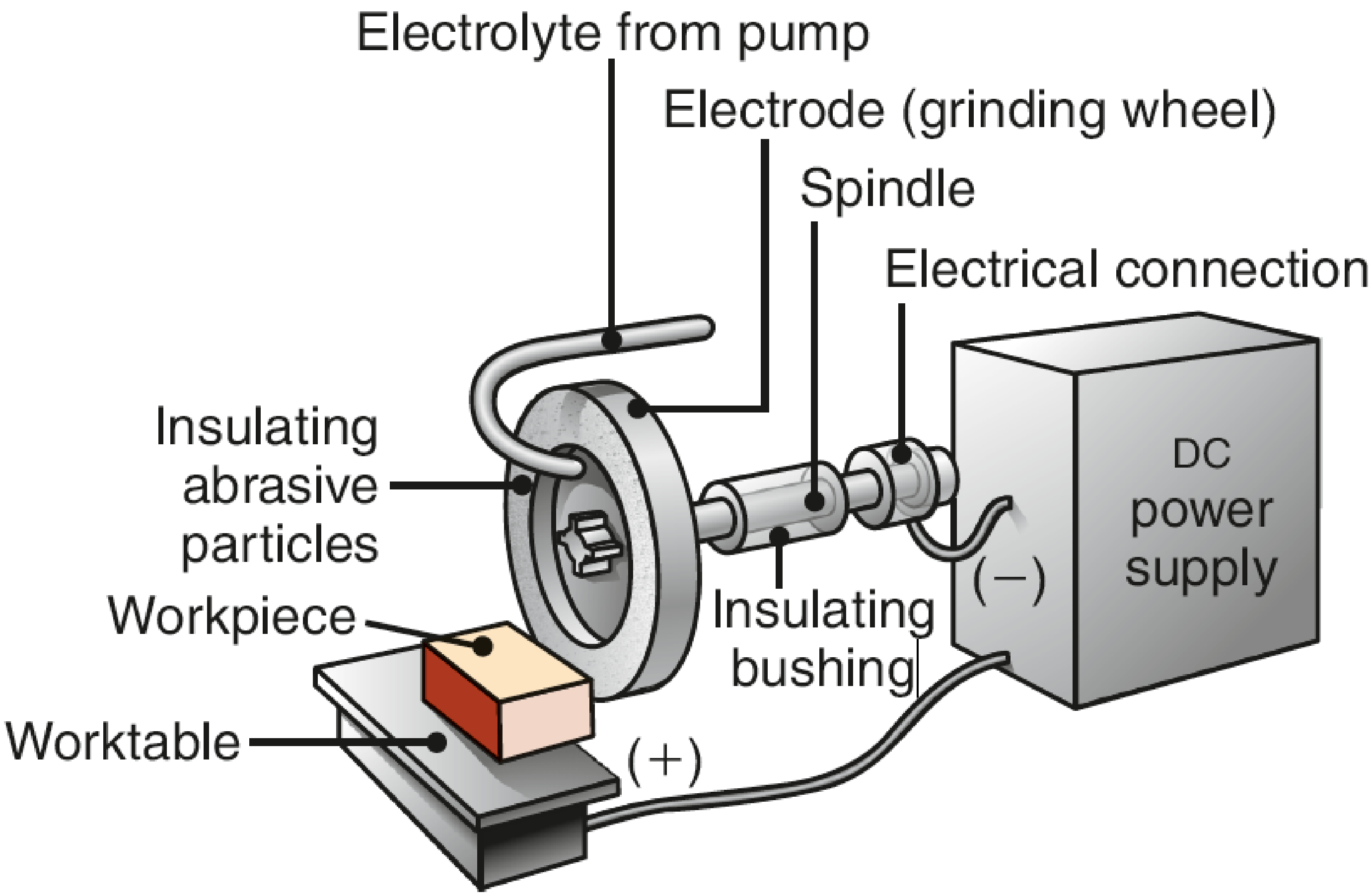
Chemical Machining



https://youtu.be/yG_ZeAEiZ_g

Figure 27.8 (1 of 2)

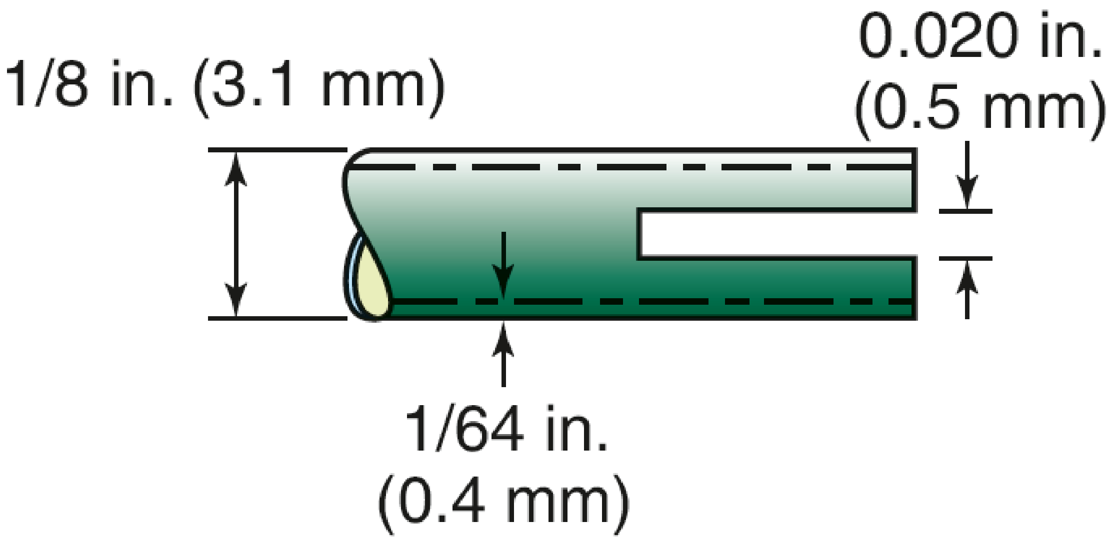
(a) Schematic illustration of the electrochemical-grinding process.



(a)

Figure 27.8 (2 of 2)

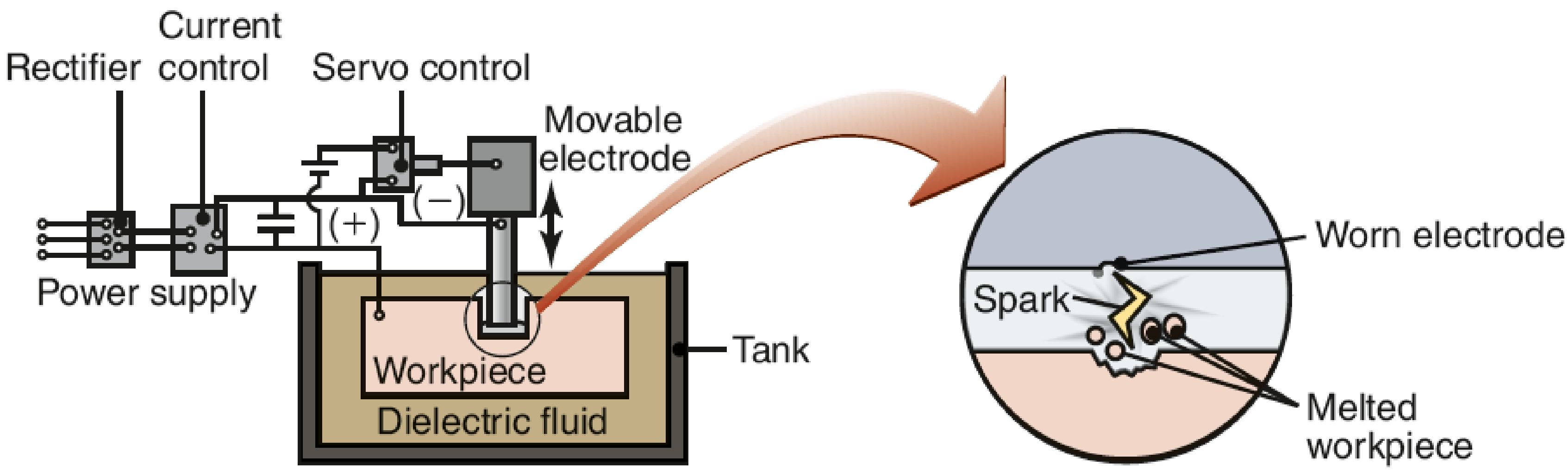
(b) Thin slot produced on a round nickel-alloy (Inconel) tube by this process.



(b)

Figure 27.9 (1 of 4)

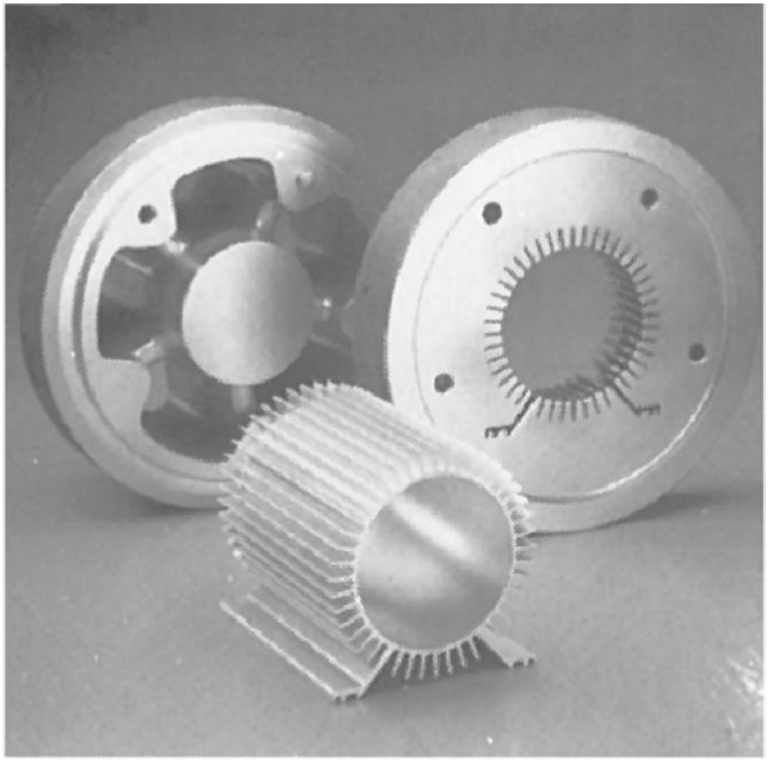
(a) Schematic illustration of the electrical-discharge machining process; this is one of the most widely used machining processes, particularly for die-sinking applications.



(a)

Figure 27.9 (2 of 4)

(b) Examples of cavities produced by EDM, using shaped electrodes. The two round parts (rear) are the set of dies used in extruding the aluminum piece shown in front (see also Fig. 15.9b).

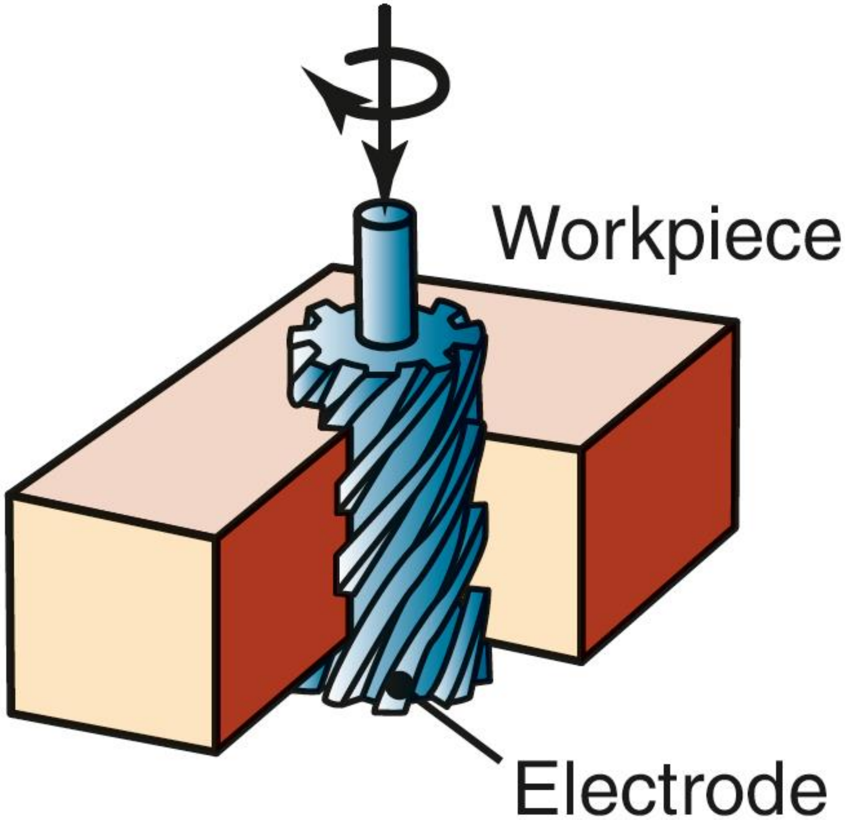


(b)

Source: (b) Courtesy of AGIE USA, Ltd.

Figure 27.9 (3 of 4)

(c) A spiral cavity produced by EDM using a slowly rotating electrode similar to a screw thread.

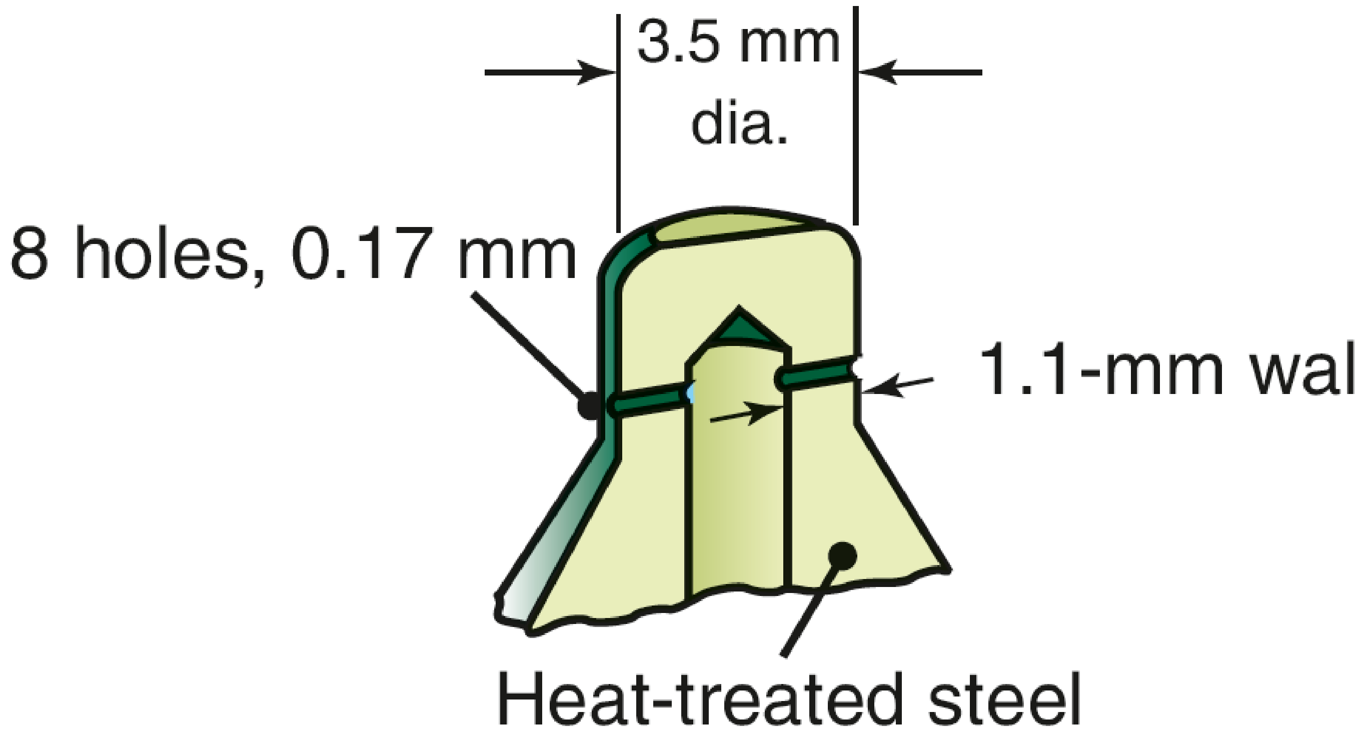


(c)

Pearson

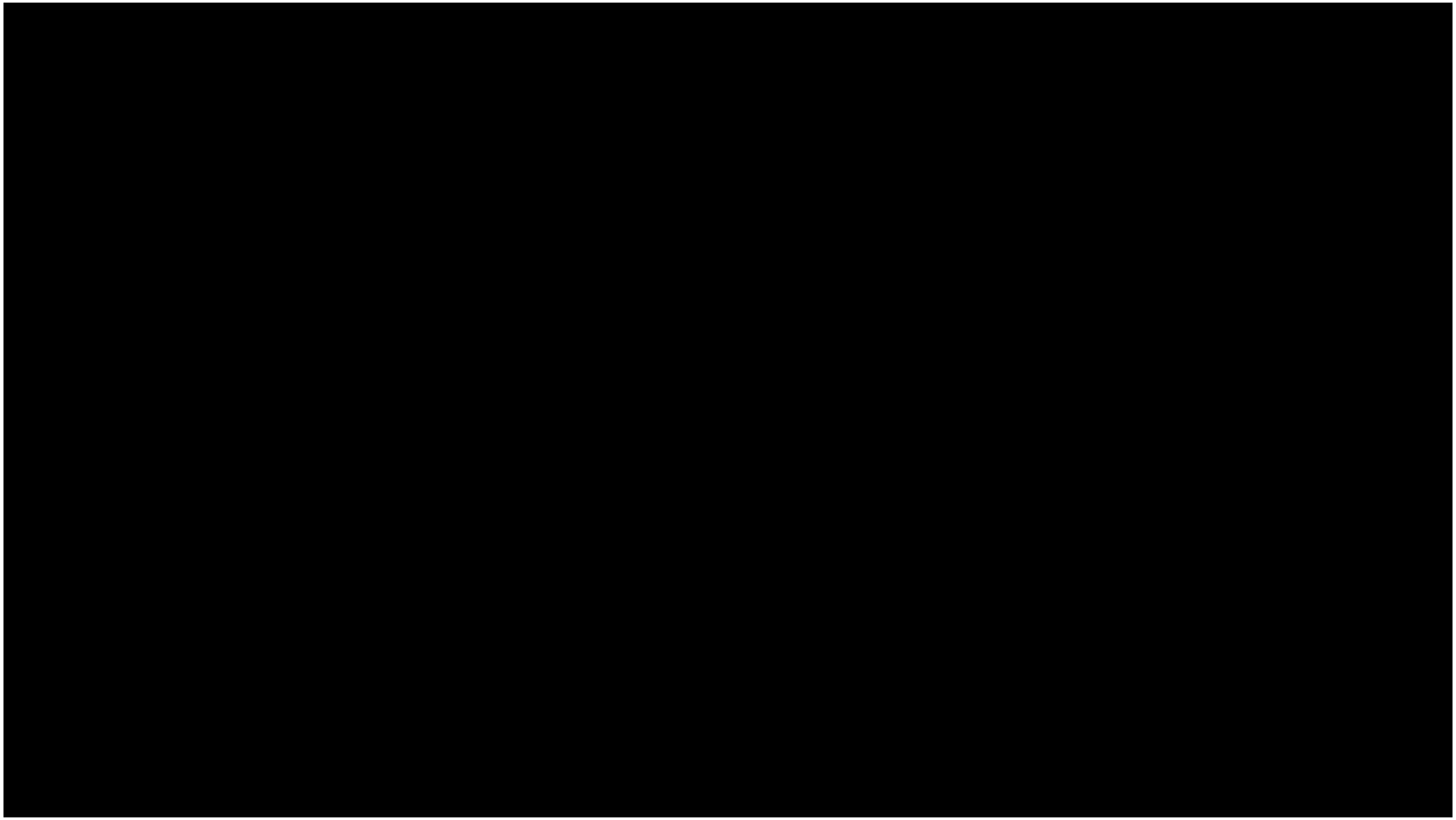
Figure 27.9 (4 of 4)

(d) Holes in a fuel-injection nozzle made by EDM; the material is heat-treated steel.



(d)

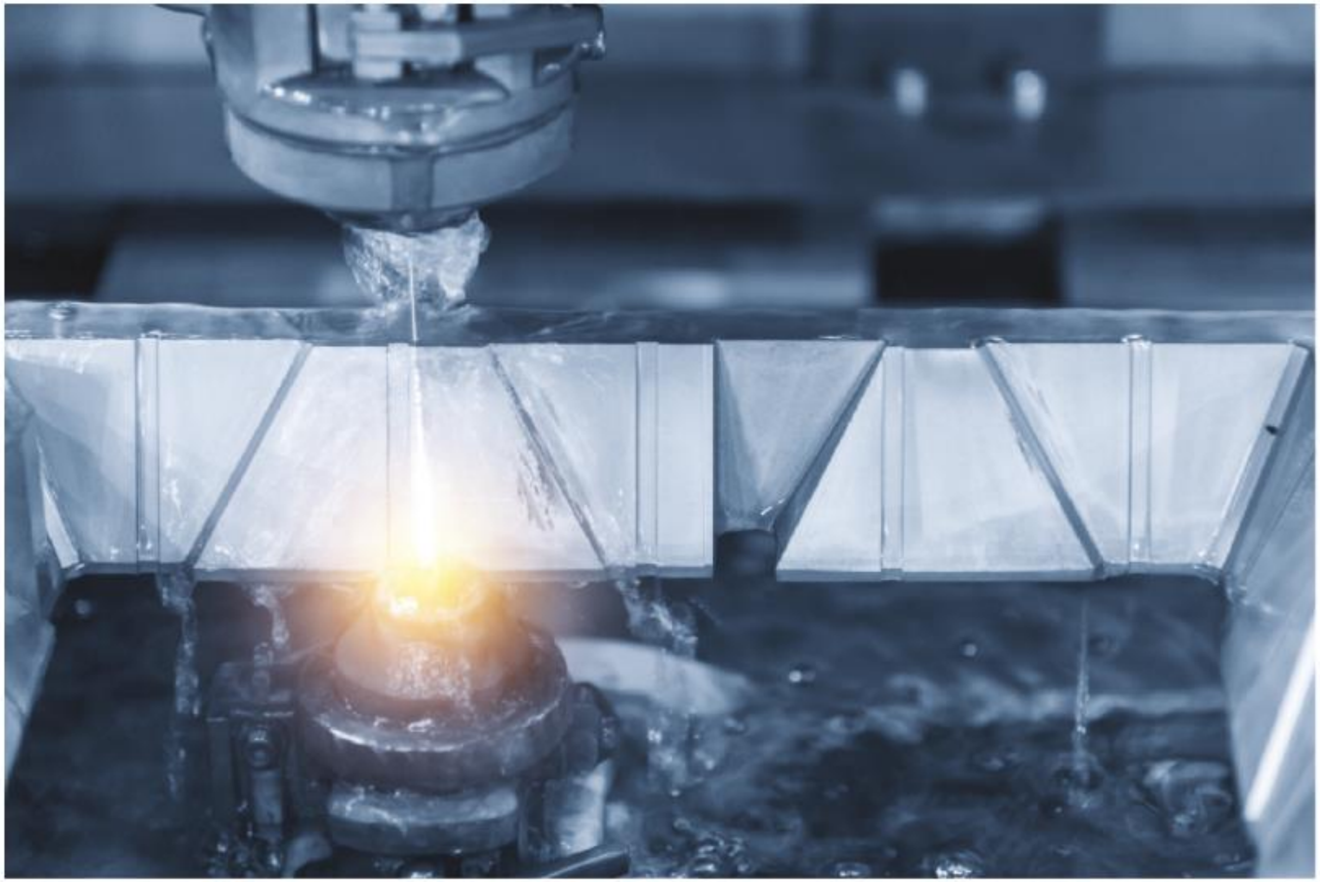
Electro-Discharge Machining



https://youtu.be/L1D5DLWWMp8

Figure 27.10 (1 of 2)

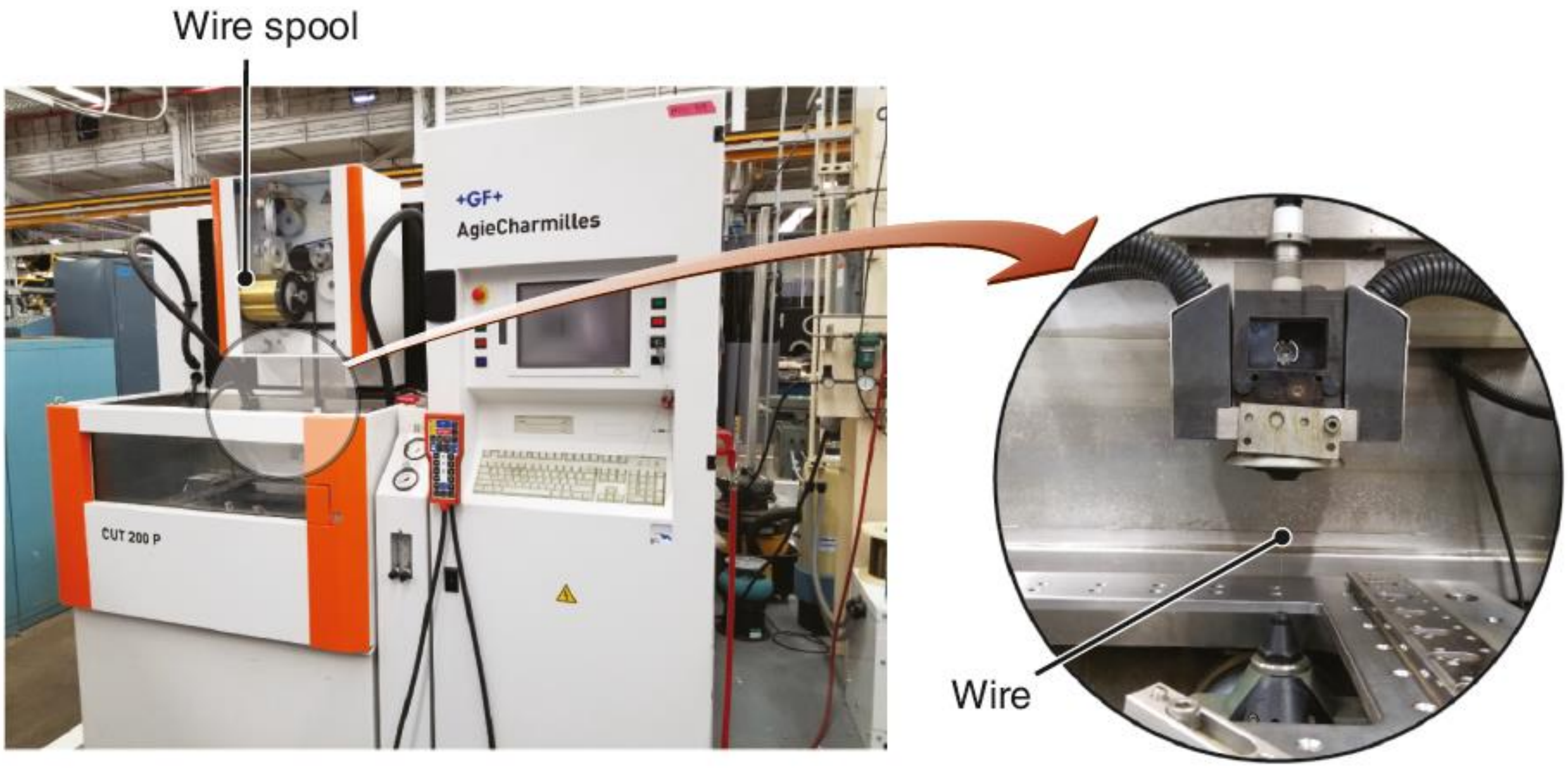
(a) Cutting a thick plate with wire EDM.



(a)

Figure 27.10 (2 of 2)

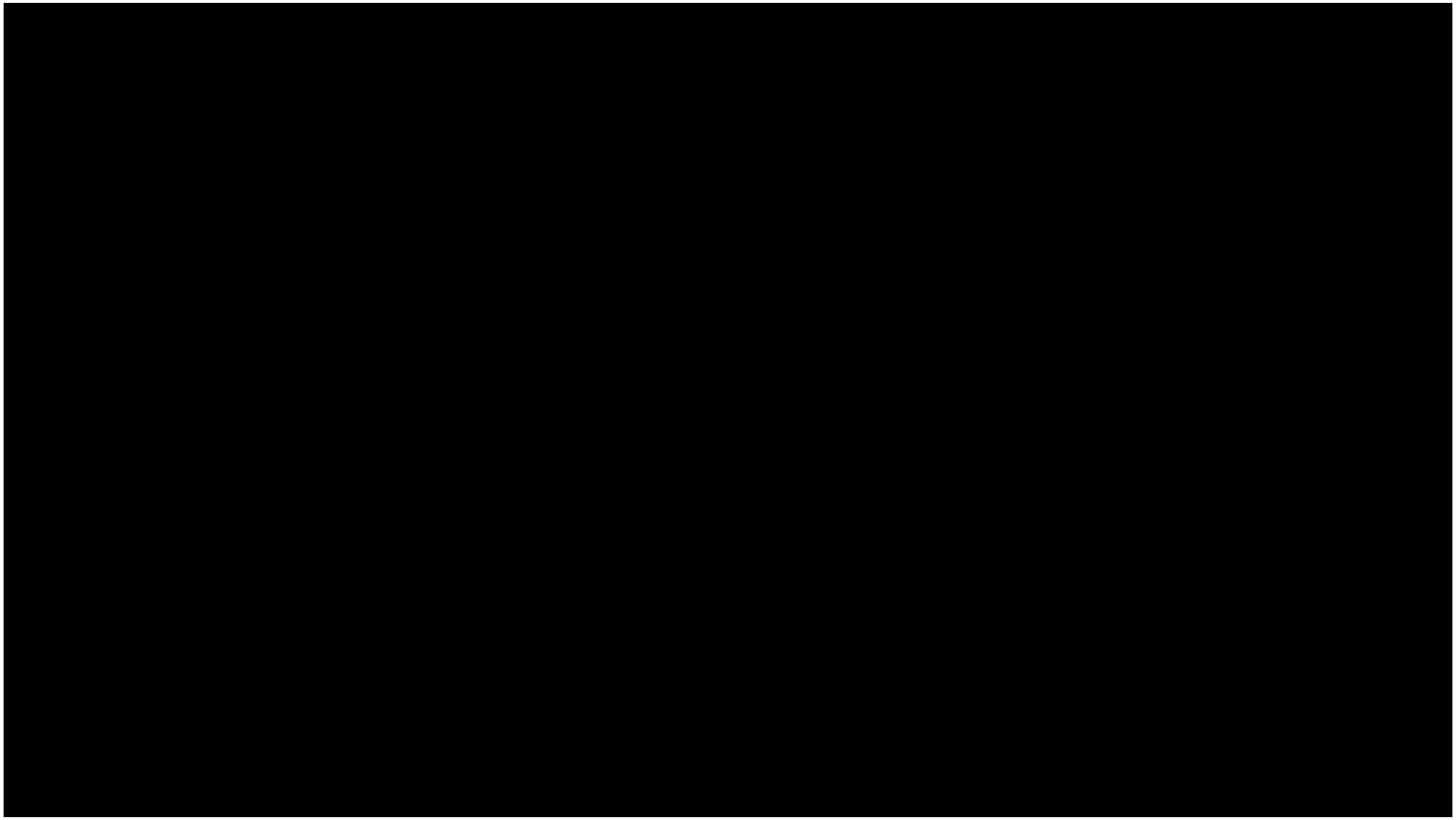
(b) A computer-controlled wire EDM machine.



(b)

Source: Courtesy of L. Love, Oak Ridge National Laboratory.

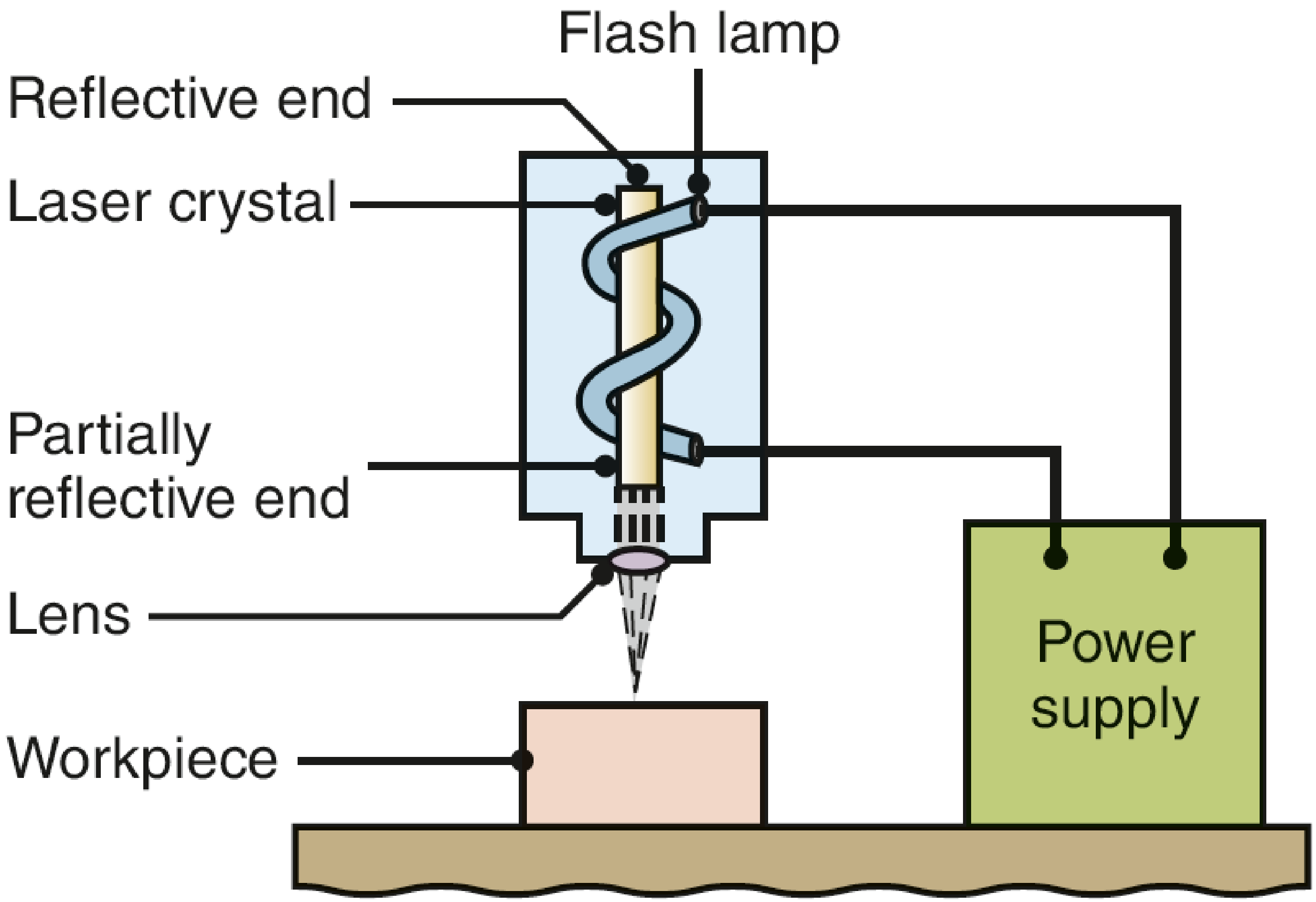
Wire EDM



https://youtu.be/pBueWfzb7P0

Figure 27.11 (1 of 4)

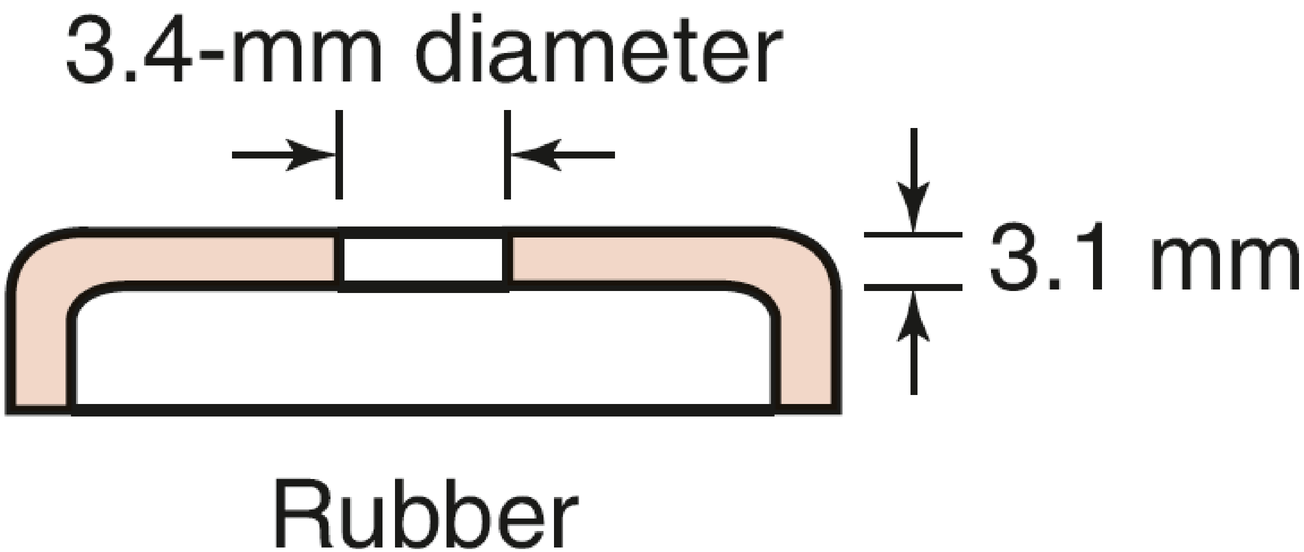
(a) Schematic illustration of the laser-beam machining process.



(a)

Figure 27.11 (2 of 4)

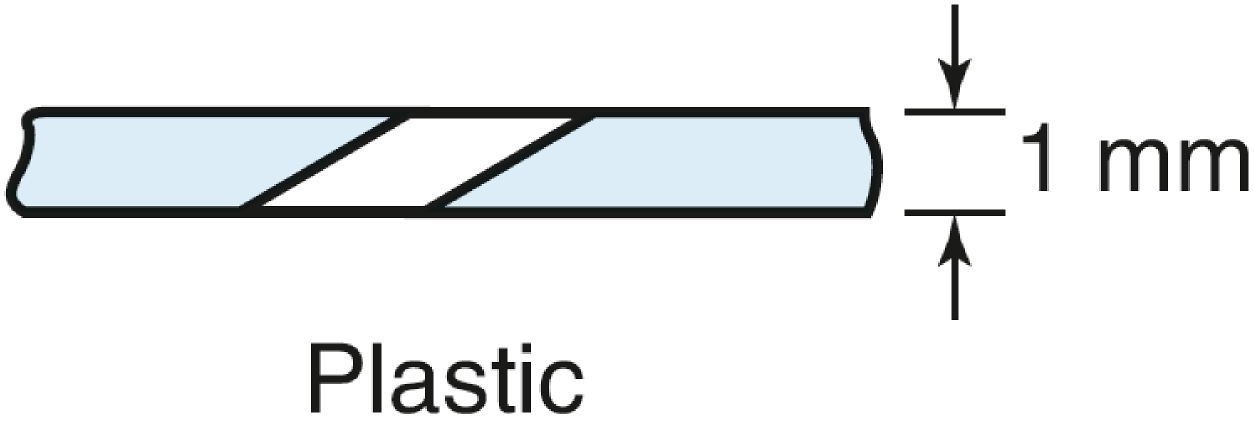
(b) Examples of holes produced in nonmetallic parts by LBM.



(b)

Figure 27.11 (3 of 4)

(c) Examples of holes produced in nonmetallic parts by LBM.

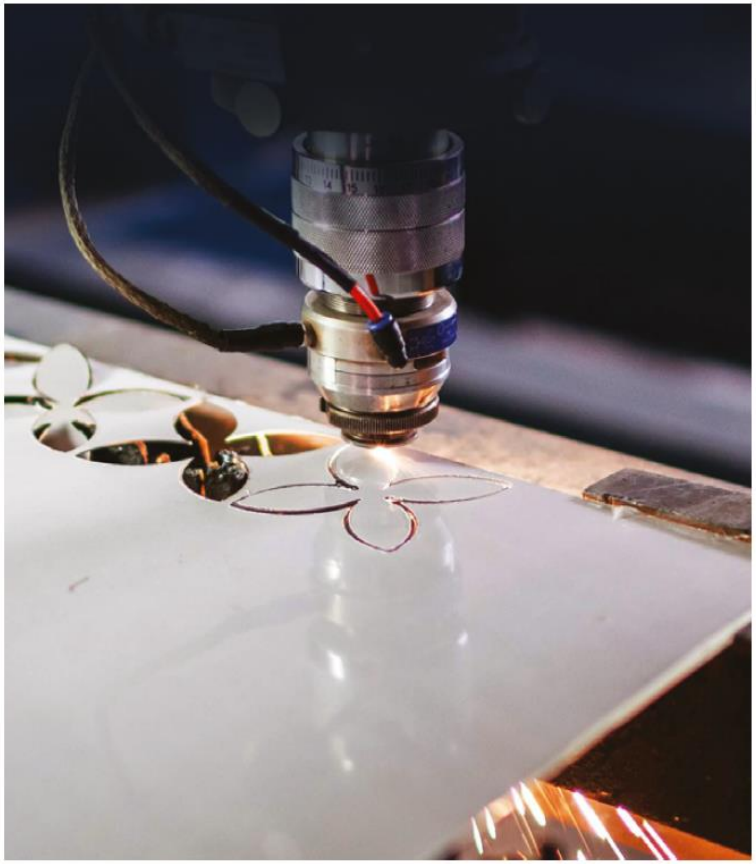


(c)

Pearson

Figure 27.11 (4 of 4)

(d) Cutting sheet metal with a laser beam.



(d)

Source: (d) Courtesy of SPI Lasers UK Ltd.

Table 27.2

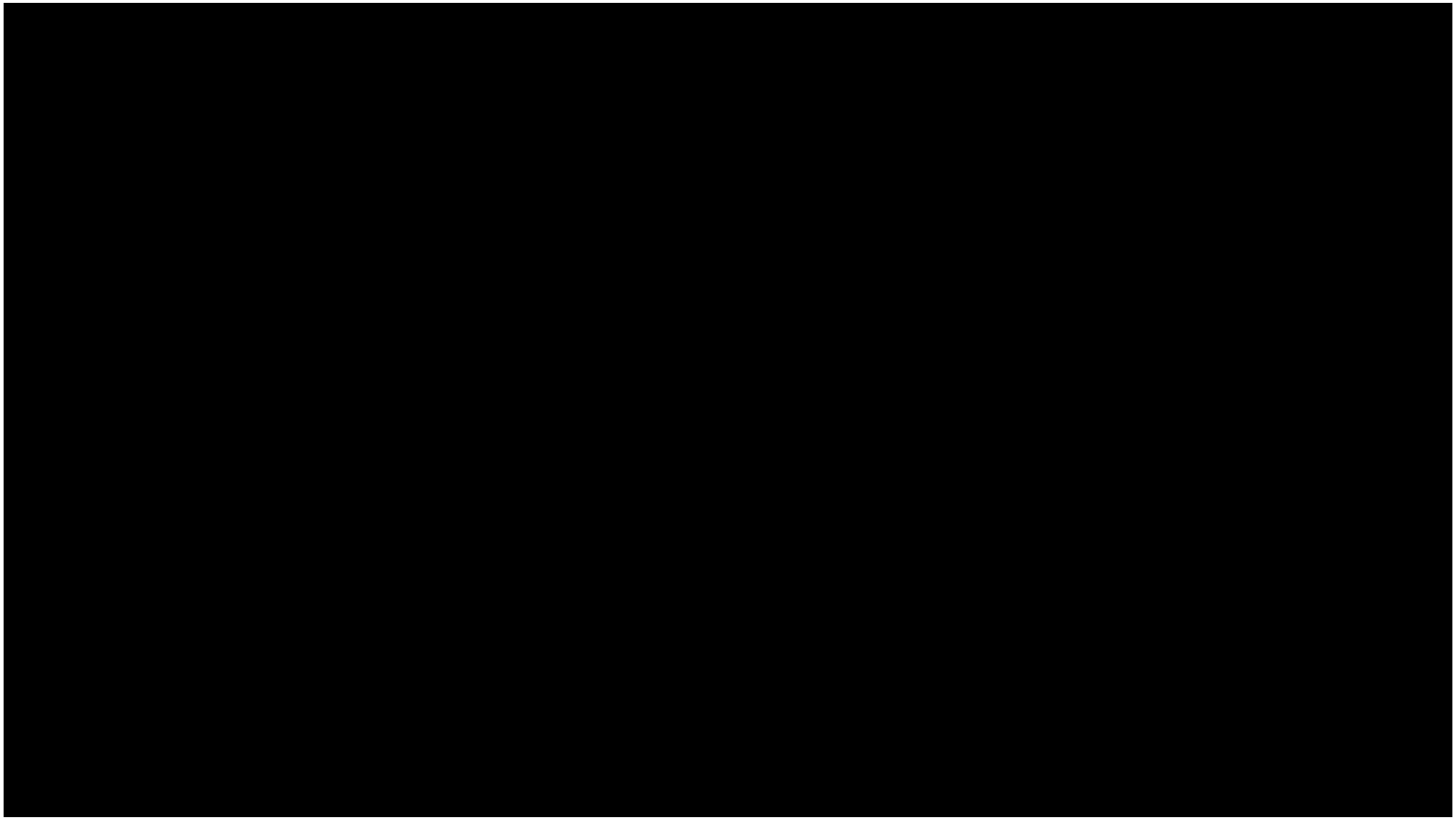
General Applications of Lasers in Manufacturing.

Application	Laser type
Cutting	
Metals	PCO_2, $CWCO_2$, Nd:YAG, ruby
Plastics	$CWCO_2$
Ceramics	PCO_2
Drilling	
Metals	PCO_2, Nd:YAG, Nd:glass, ruby
Plastics	Excimer
Marking	
Metals	PCO_2, Nd:YAG
Plastics	Excimer
Ceramics	Excimer
Surface treatment	$CWCO_2$
Welding	
Metals	PCO_2, $CWCO_2$, Nd:YAG, Nd:glass, ruby, diode
Plastics	Diode, Nd:YAG
Lithography	Excimer

Note: P = pulsed, CW = continuous wave,
Nd:YAG = neodynmium: yttrium–aluminum–garnet.

Pearson

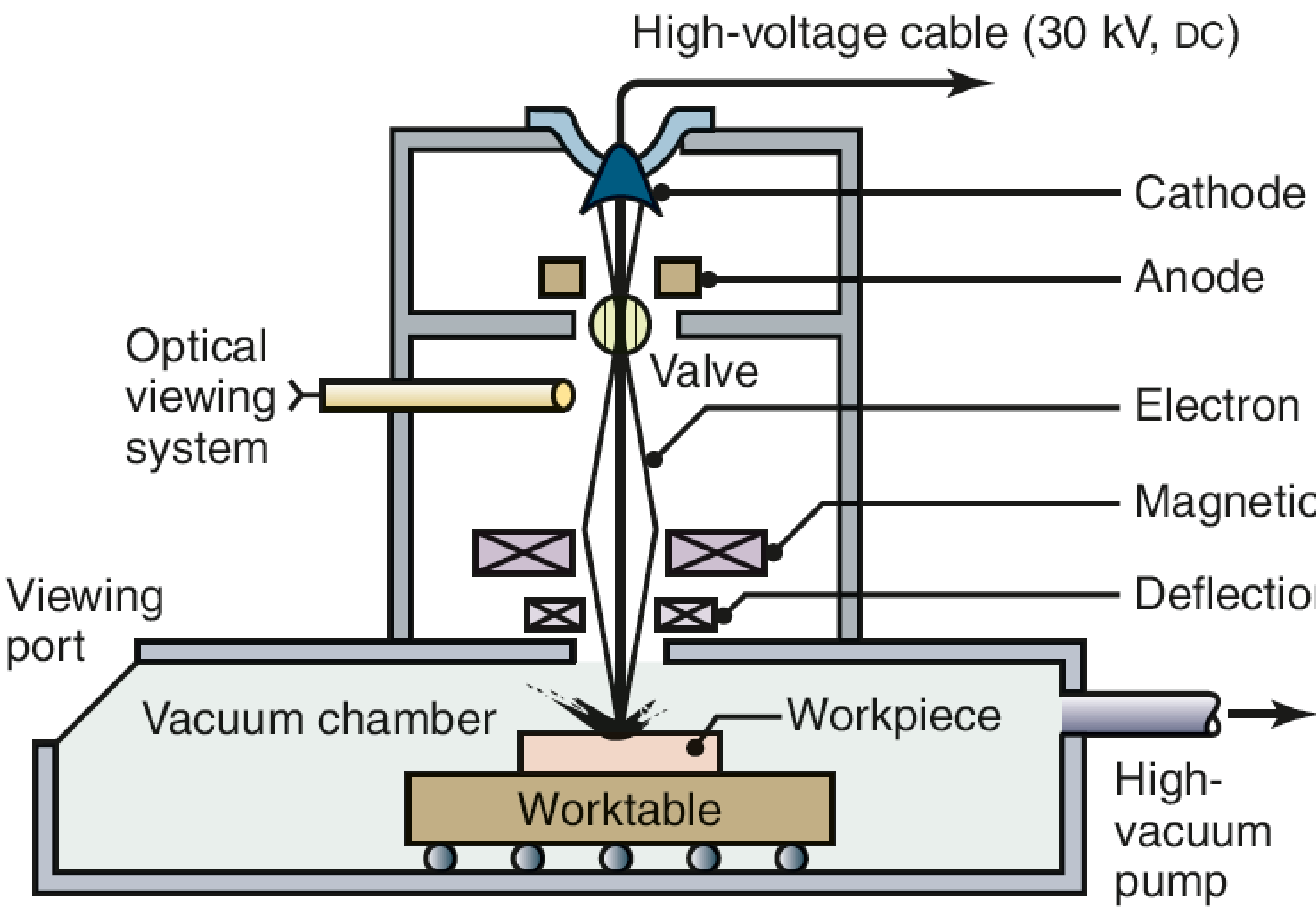
Laser Beam Machining



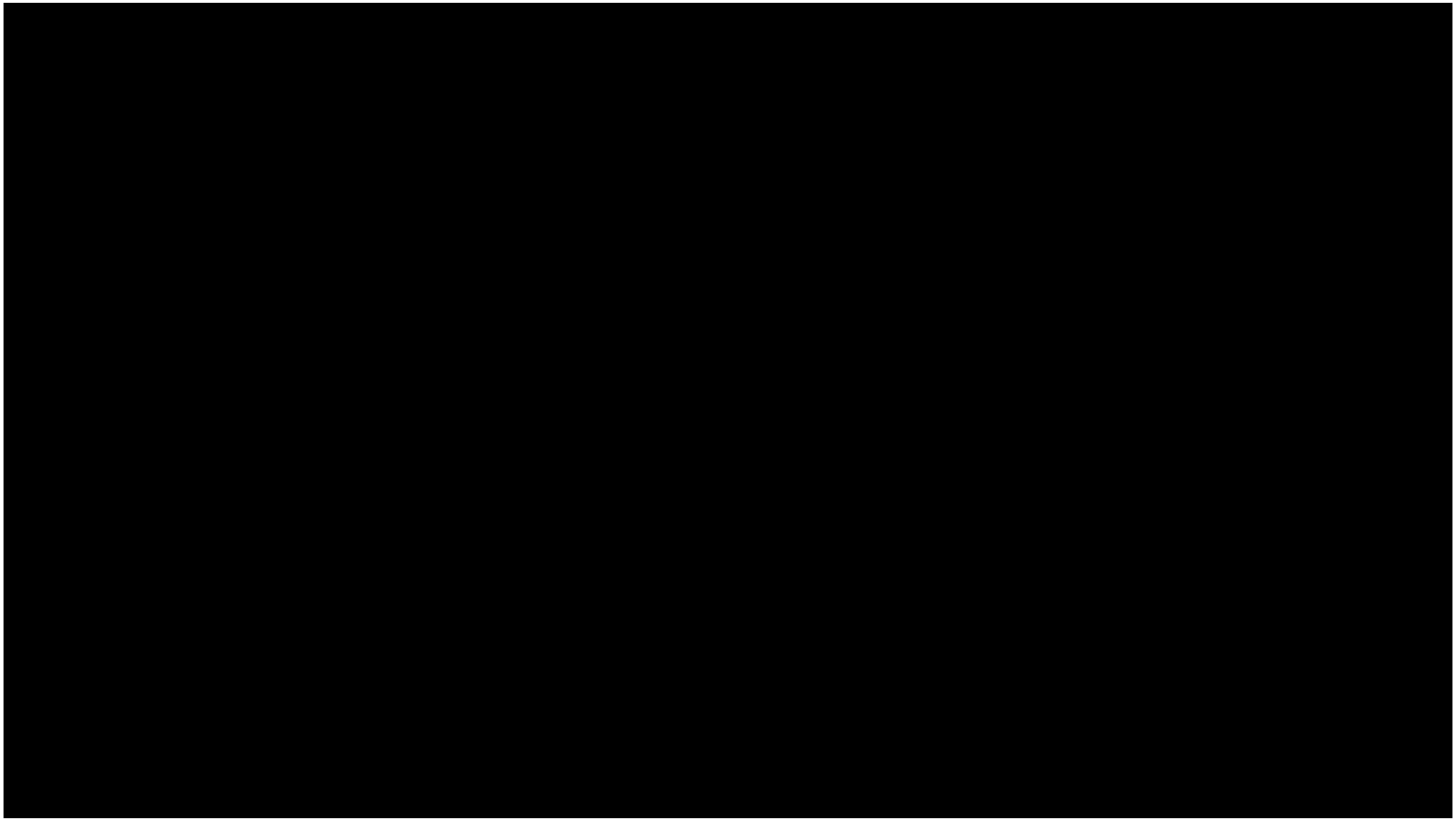
https://youtu.be/ptEmX9O4nDw

Figure 27.13

Schematic illustration of the electron-beam machining process. Unlike LBM, this process requires a vacuum, so the workpiece size is limited to the size of the vacuum chamber.



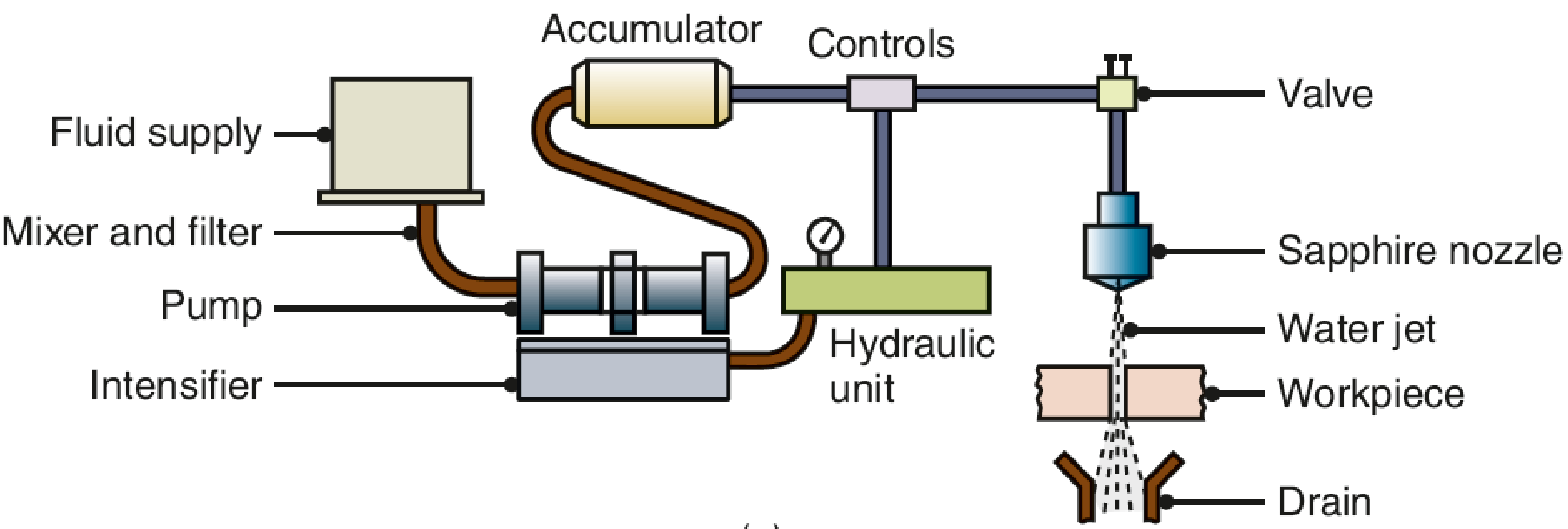
Electron Beam Machining



https://youtu.be/jbY-tOcI2tM

Figure 27.14 (1 of 3)

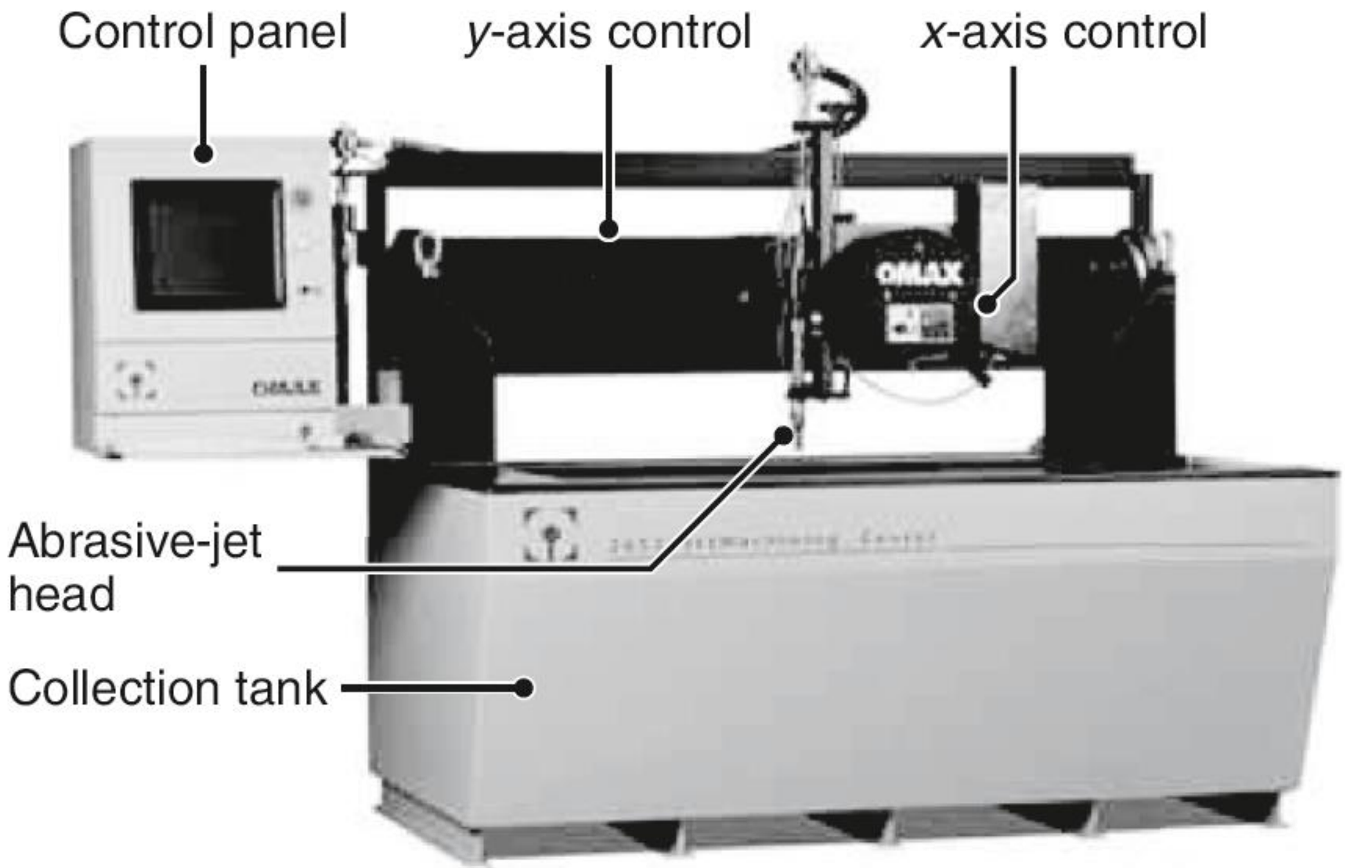
(a) Schematic illustration of the water-jet machining process.



(a)

Figure 27.14 (2 of 3)

(b) A computer-controlled water-jet cutting machine.



(b)

Figure 27.14 (3 of 3)

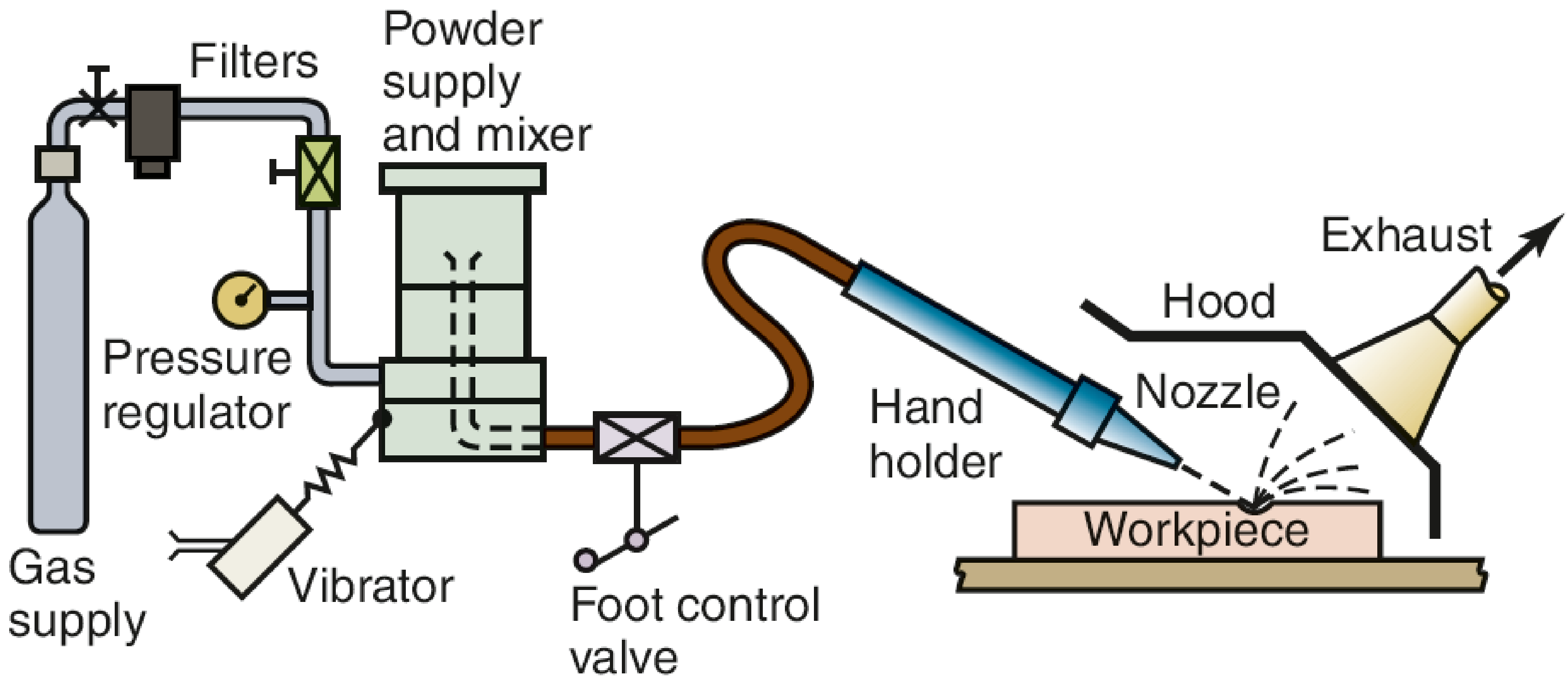
(c) Examples of various nonmetallic parts produced by the water-jet cutting process.

(c)

Source: Courtesy of OMAX Corporation.

Figure 27.15 (1 of 2)

(a) Schematic illustration of the abrasive-jet machining process.



(a)

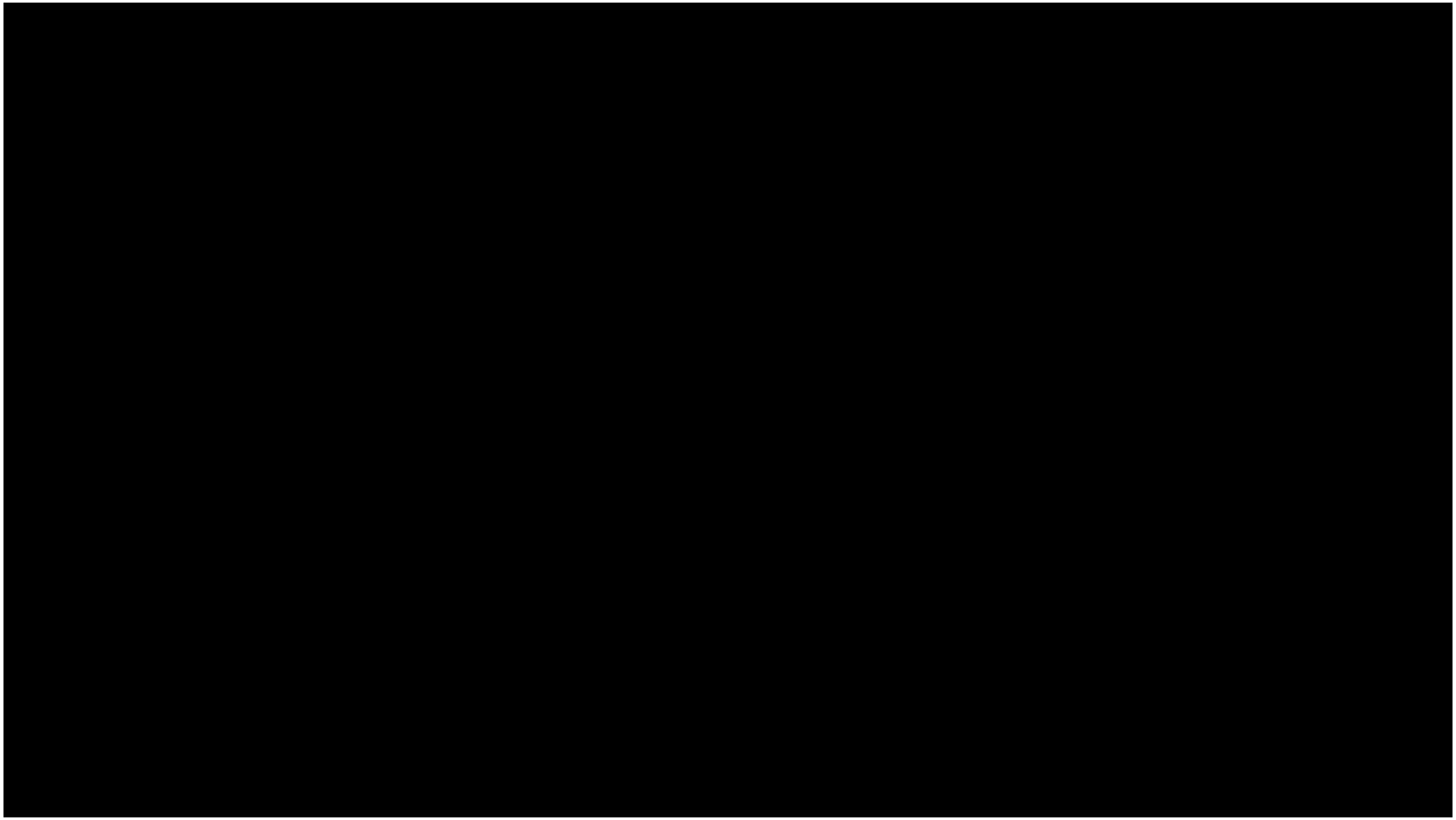
Figure 27.15 (2 of 2)

(b) Examples of parts made by abrasive-jet machining, produced in 50-mm (2-in.) thick 304 stainless steel.

(b)

Source: Courtesy of OMAX Corporation.

Water Jet/ Abrasive Water Jet Cutting



https://youtu.be/_FIsrYzyvlg