Abrasive Machining and Finishing

Manufacturing

Processes

Outline

- Units
- Abrasives
- Grinding
  - Grinding Wheels
  - Grinding Process
- Coated Abrasives
  - Belt Grinding
- Honing
- Lapping
- Other Finishing Operations
- Deburring Processes

Abrasive Machining

Abrasive Machining

Why a smooth surface?

Abrasive Machining

Why a smooth surface?

Reduction in Friction

Heat - Bearings

Reduction in Wear

Bushings/Bearings

Appearance

Car Body, Furniture

Clearance

Disk Head

Sharpness

Cutting Tools

Abrasive Machining

How do we get a smooth surface?

Abrasive Machining

How do we get a smooth surface?

Remove Material

Abrasive Machining

Flatten

Burnishing

Fill in Voids

Add material

Paint

Finish

Wax

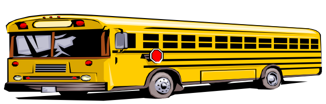
Units

Meter (m)		
Centimeter (cm) =	.01 m	
Millimeter (mm) =	.001 m	
Micrometer (µm)	=	10^{-6} m
Nanometer (nm)	=	10^{-9} m
Angstrom (Ǻ)	=	10^{-10} m

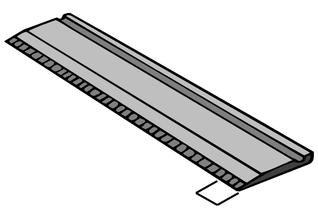
Units

12872000 m meter

10^{-2} centimeter



10^{-6} micrometer



10^{-9} nanometer

10^{-10} angstrom

Abrasives

Abrasives

- Small, hard nonmetallic particles with sharp edges and irregular shapes

- Can remove small amounts of material, producing tiny chips

- Abrasive processes can produce fine surface finishes and accurate dimensional tolerances

Types of Abrasives

Conventional Abrasives

a. Aluminum oxide (Al_2O_3)

b. Silicon carbide (SiC)

Superabrasives

c. Cubic Boron Nitride (cBN)

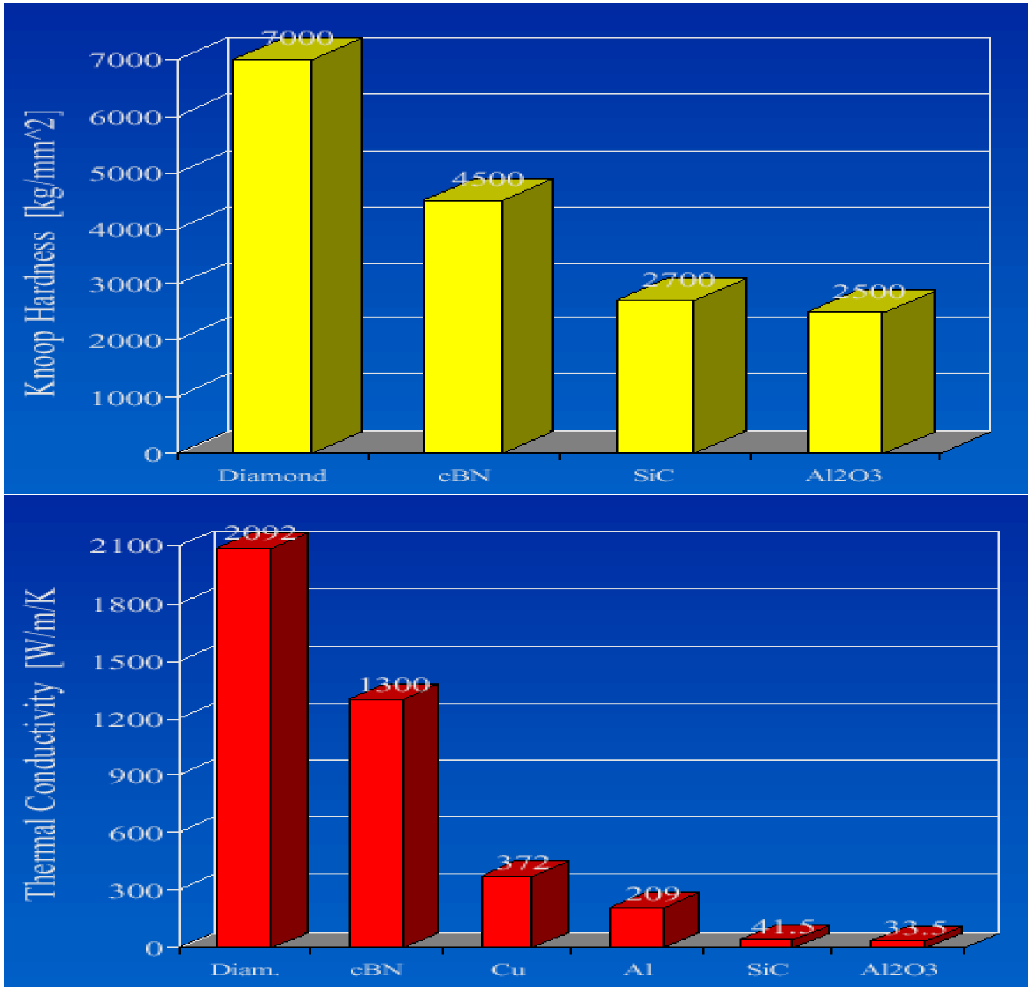
d. Diamond

Abrasives are harder than conventional tool materials

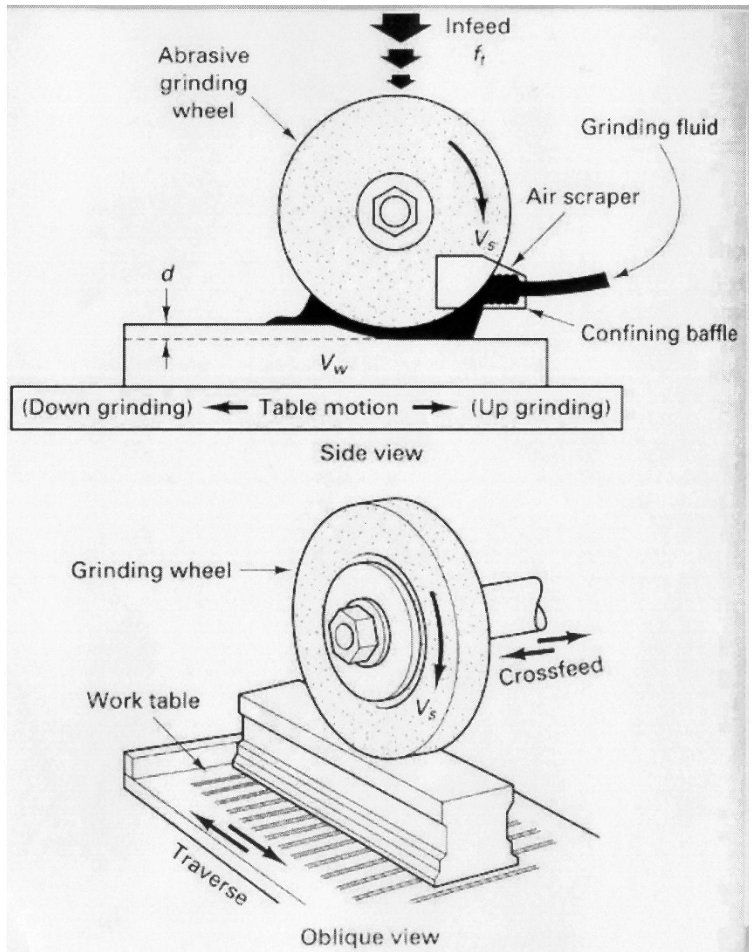
Abrasive Factors

- Grain size
- Grain shape
- Hardness
- Friability (tendency to fracture)

Abrasive Hardness and Thermal Conductivity

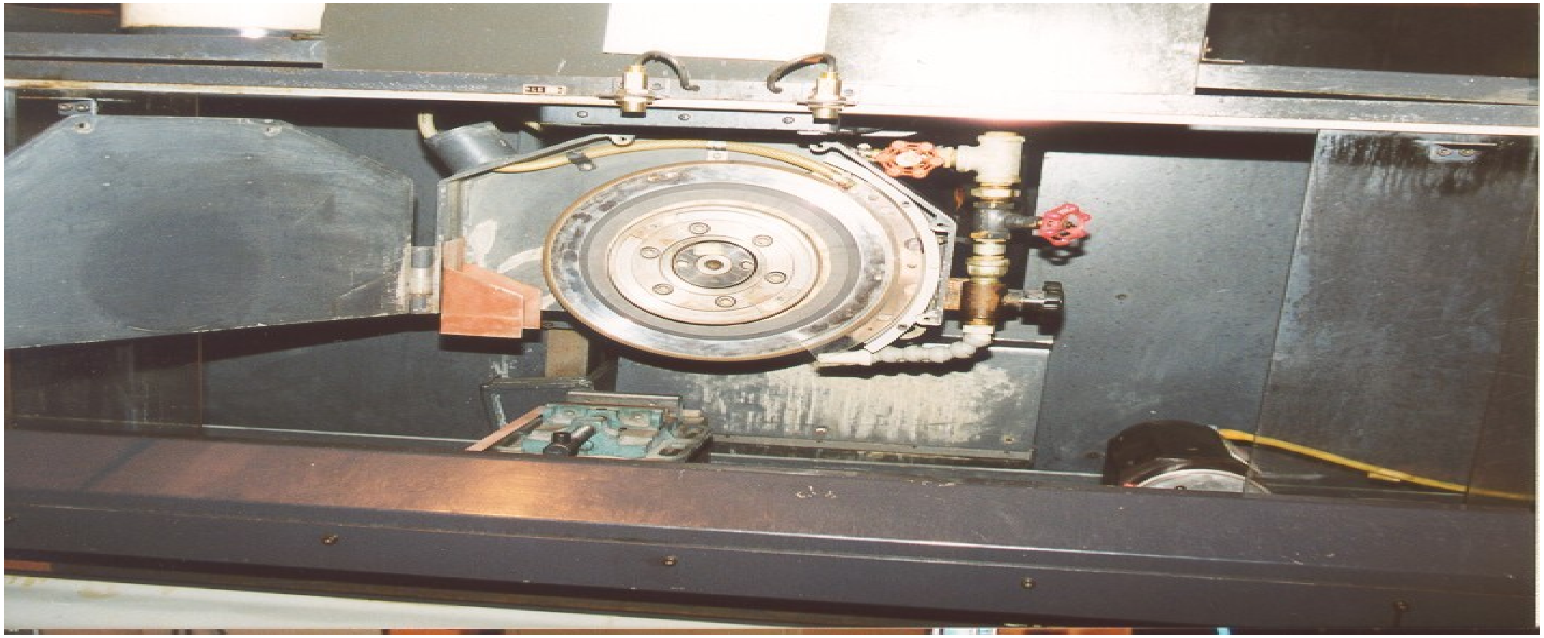


Grinding



Infeed
f_t
Abrasive grinding wheel
Grinding fluid
Air scraper
V_s
d
Confining baffle
V_w
(Down grinding) ← Table motion → (Up grinding)
Side view
Grinding wheel
Crossfeed
V_s
Work table
Traverse
Oblique view

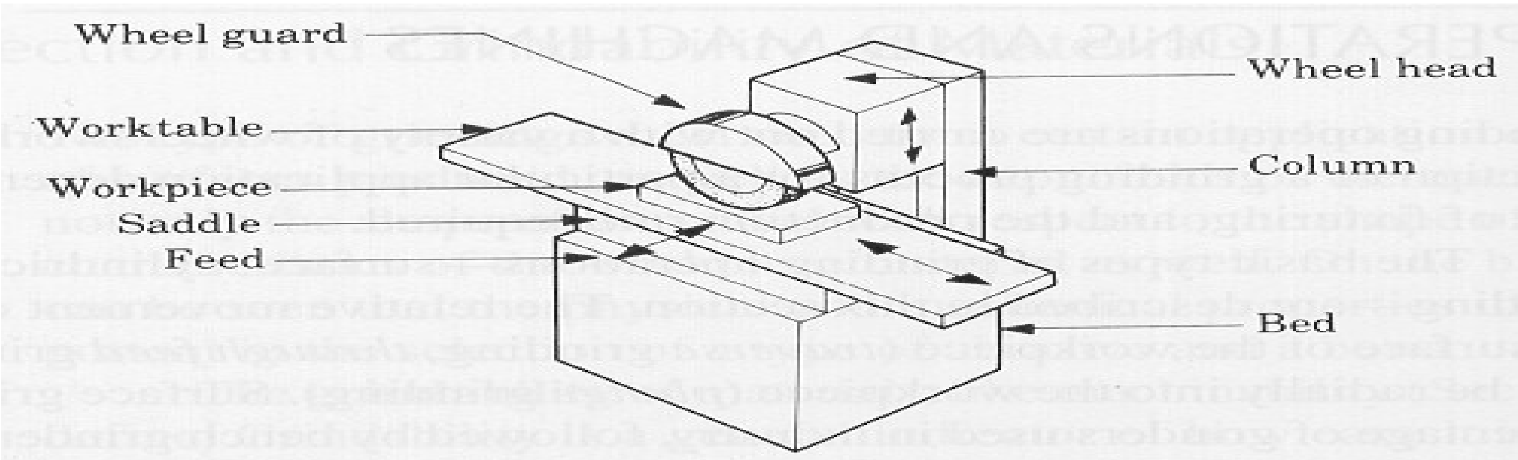
Example of a Grinding Machine



Types of Grinding

- Surface Grinding
- Cylindrical Grinding
- Internal Grinding
- Centerless Grinding
- Others
  - Tool and cutter grinders
  - Tool-post grinding
  - Swing-frame grinders
  - Bench grinders
- Creep-Feed Grinding

Surface Grinding



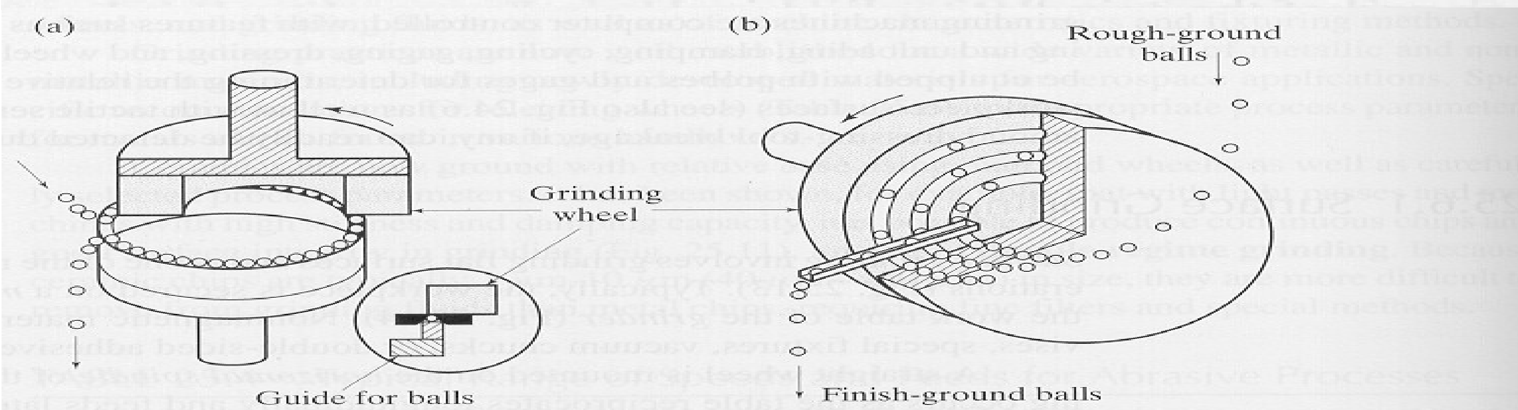
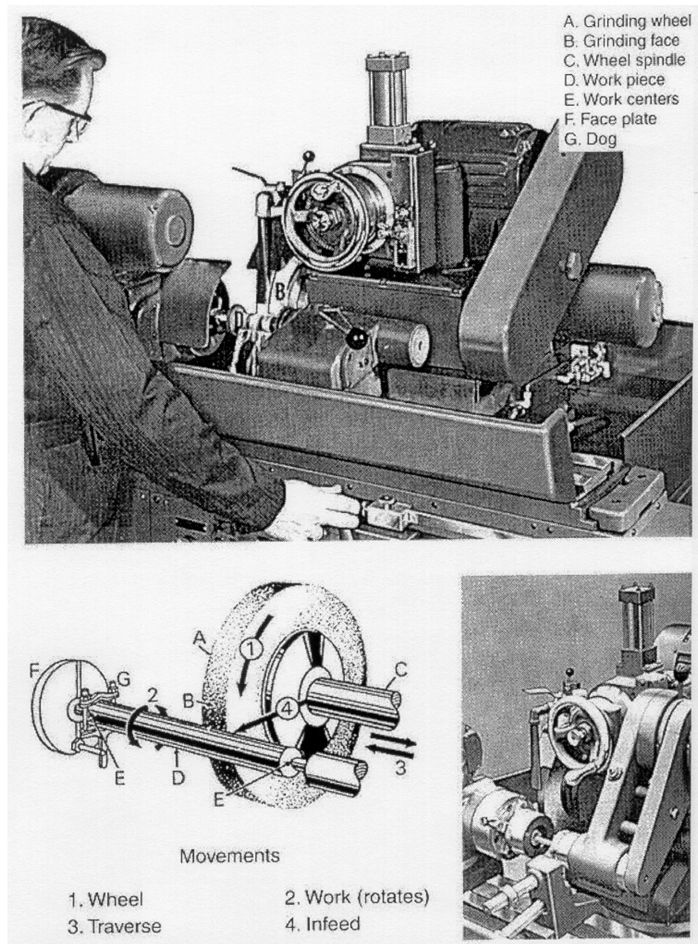


FIGURE 25.15 (a) Rough grinding of steel balls on a vertical-spindle grinder; the balls are guided by a special rotary fixture. (b) Finish grinding of balls in a multiple-groove fixture. The balls are ground to within 0.013 mm (0.0005 in.) of their final size. *Source: American Machinist.*

Cylindrical Grinding



Cylindrical Grinding

Cylindrical Grinding

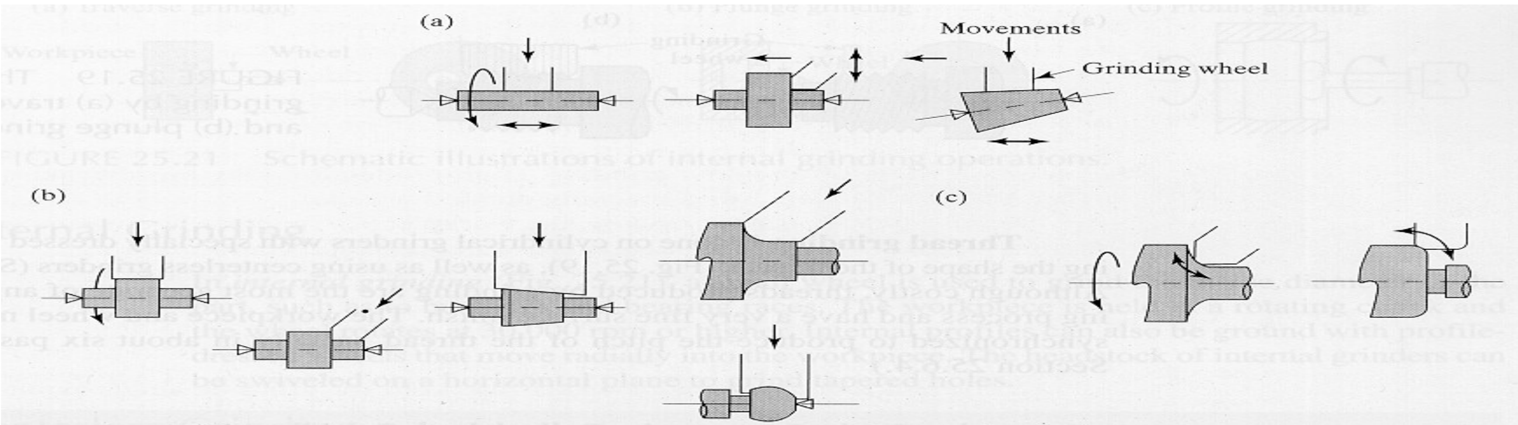


FIGURE 25.16 Examples of various cylindrical grinding operations. (a) Traverse grinding, (b) plunge grinding, and (c) profile grinding. *Source*: Okuma Machinery Works Ltd.

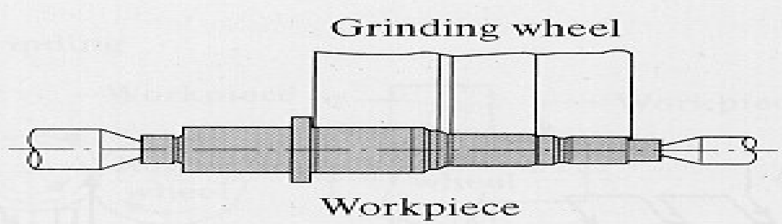
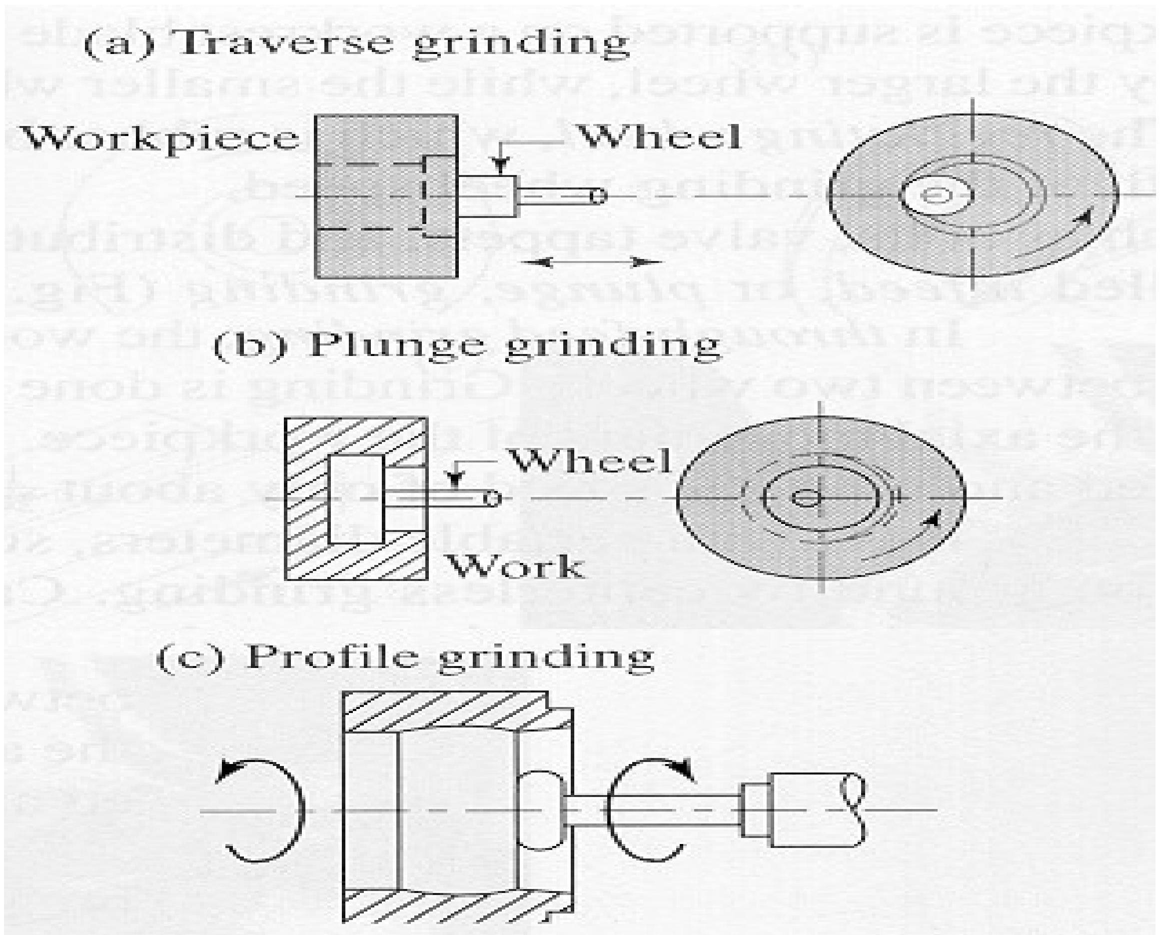
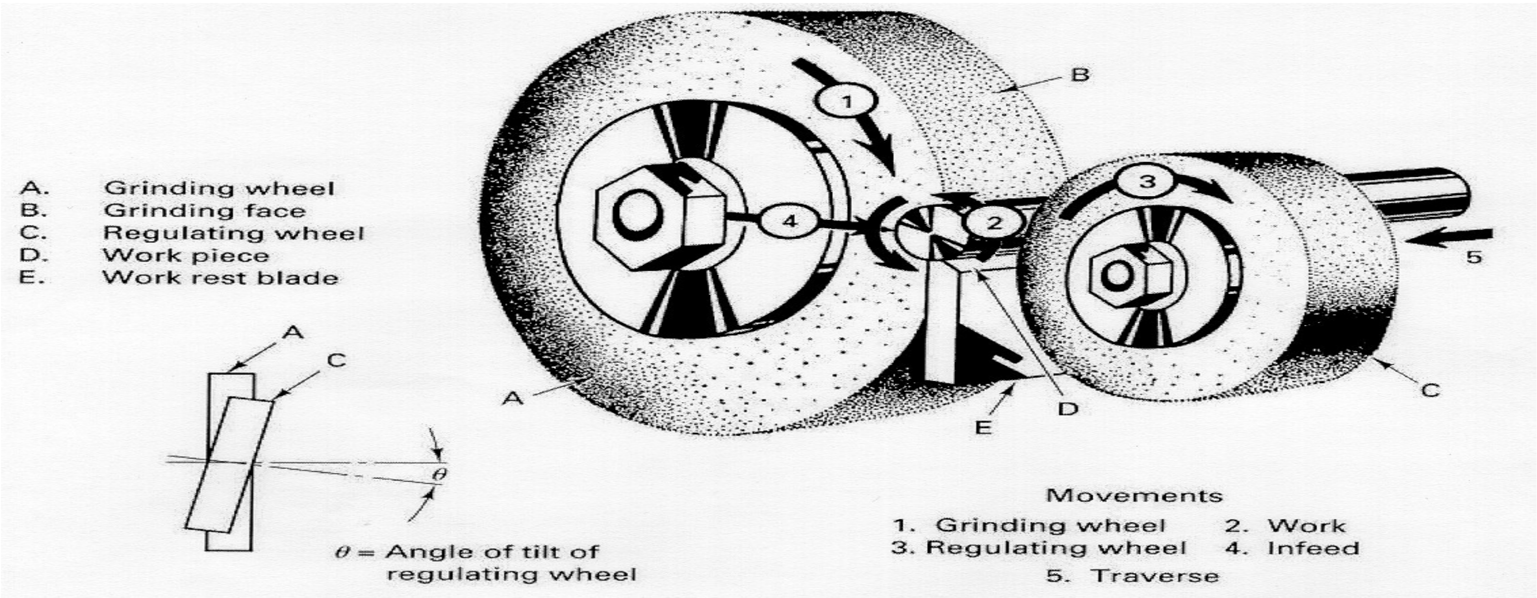


FIGURE 25.17 Plunge grinding of a workpiece on a cylindrical grinder with the wheel dressed to a stepped shape. See also Fig. 25.12.

Internal Grinding

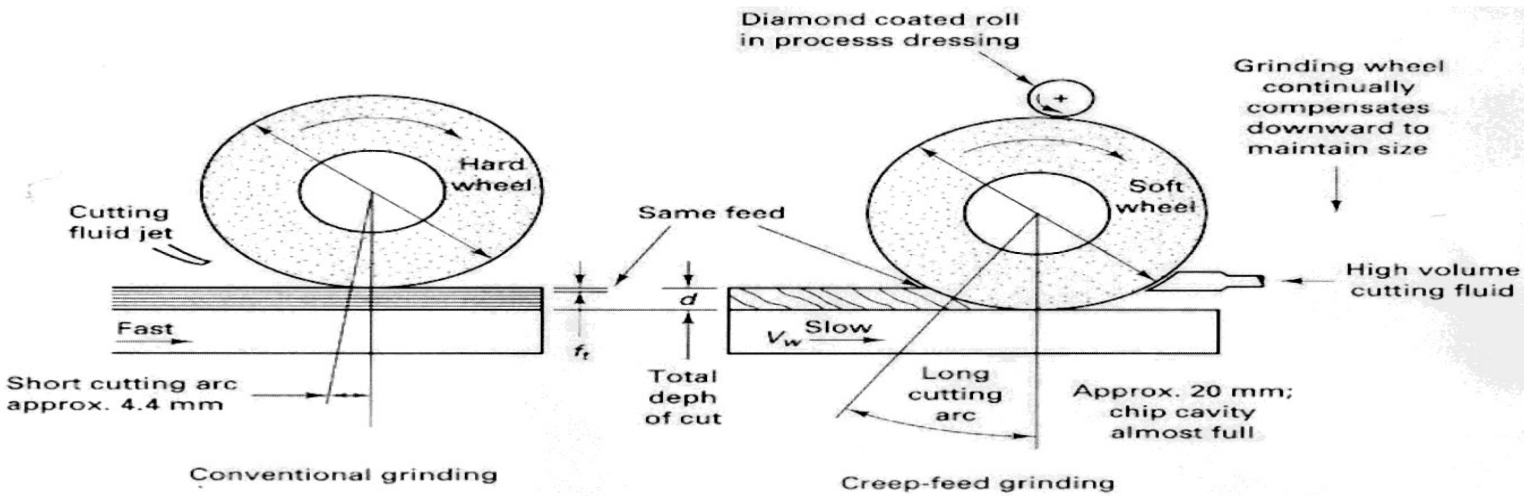


Centerless Grinding



Centerless Grinding

Creep-Feed Grinding



Bonded Abrasives/ Grinding Wheels

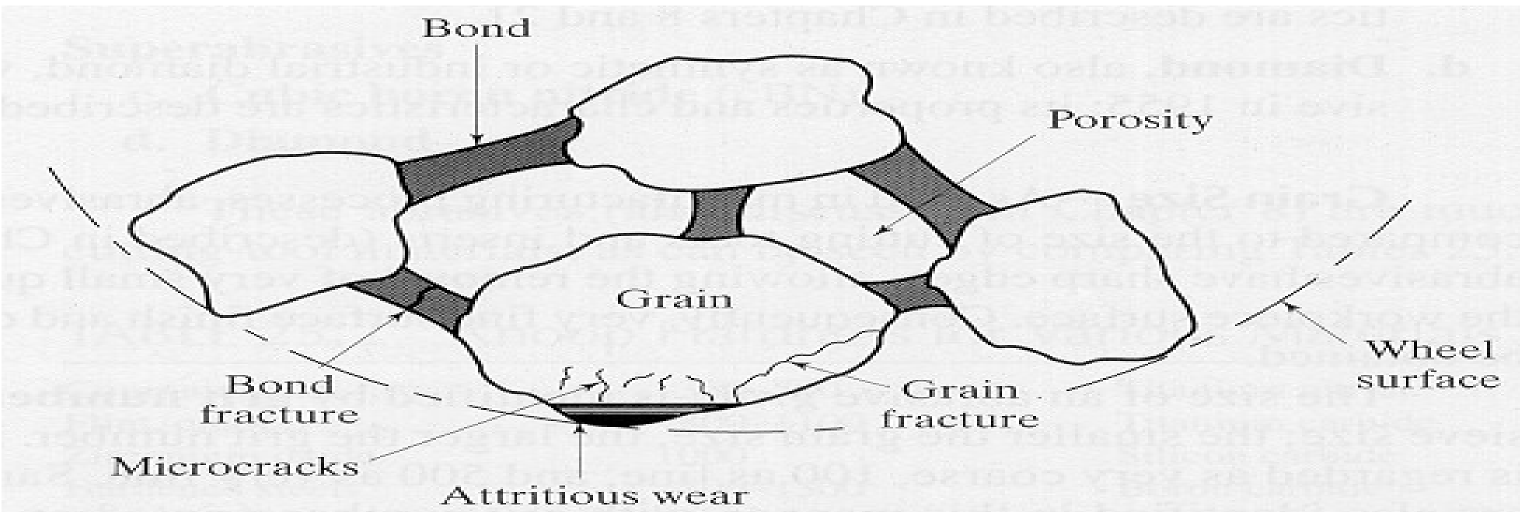
Bonded Abrasives

- Most grinding wheels are made of abrasive grains held together by a bonding material

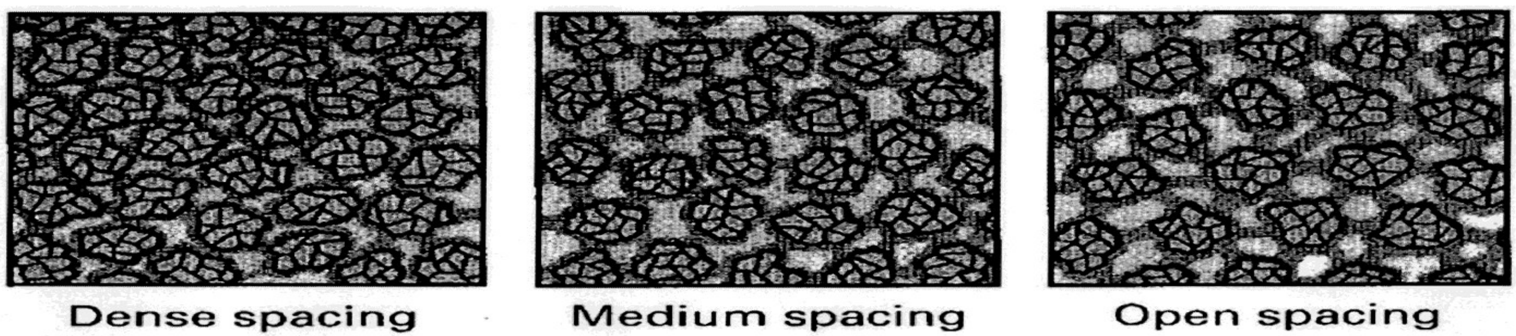
Types of bonding material:

- Vitrified (glass)
- Resinoid (thermosetting resin)
- Rubber
- Metal (the wheel itself is metal;   the grains are bonded to its   surface

Grinding Wheel Components



Grinding Wheel Structure

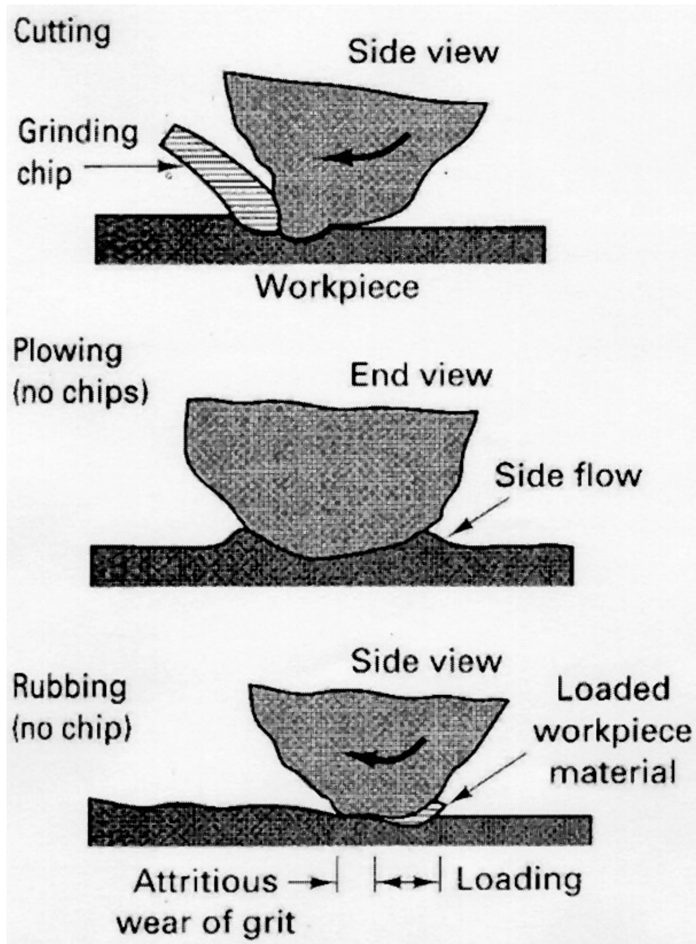


Grinding Process

Grinding

- Grains have irregular shapes and random spacing
- Average rake angle is very negative (about -60° or lower)
- Radial positions of grains vary
- Cutting speed is very high (ca. 600 ft/min)

Grinding Process



Grinding Process

Grain force

✪ $((v/V)\sqrt{(d/D)})$(material strength)

Temperature rise

✪ $D^{1/4}d^{3/4}(V/v)^{1/2}$

Effects caused by grinding temperature increase:

- Sparks
- Tempering
- Burning
- Heat Checking

Grinding Wheel Wear

Types:

Attritious Grain Wear

Grains develop a wear flat

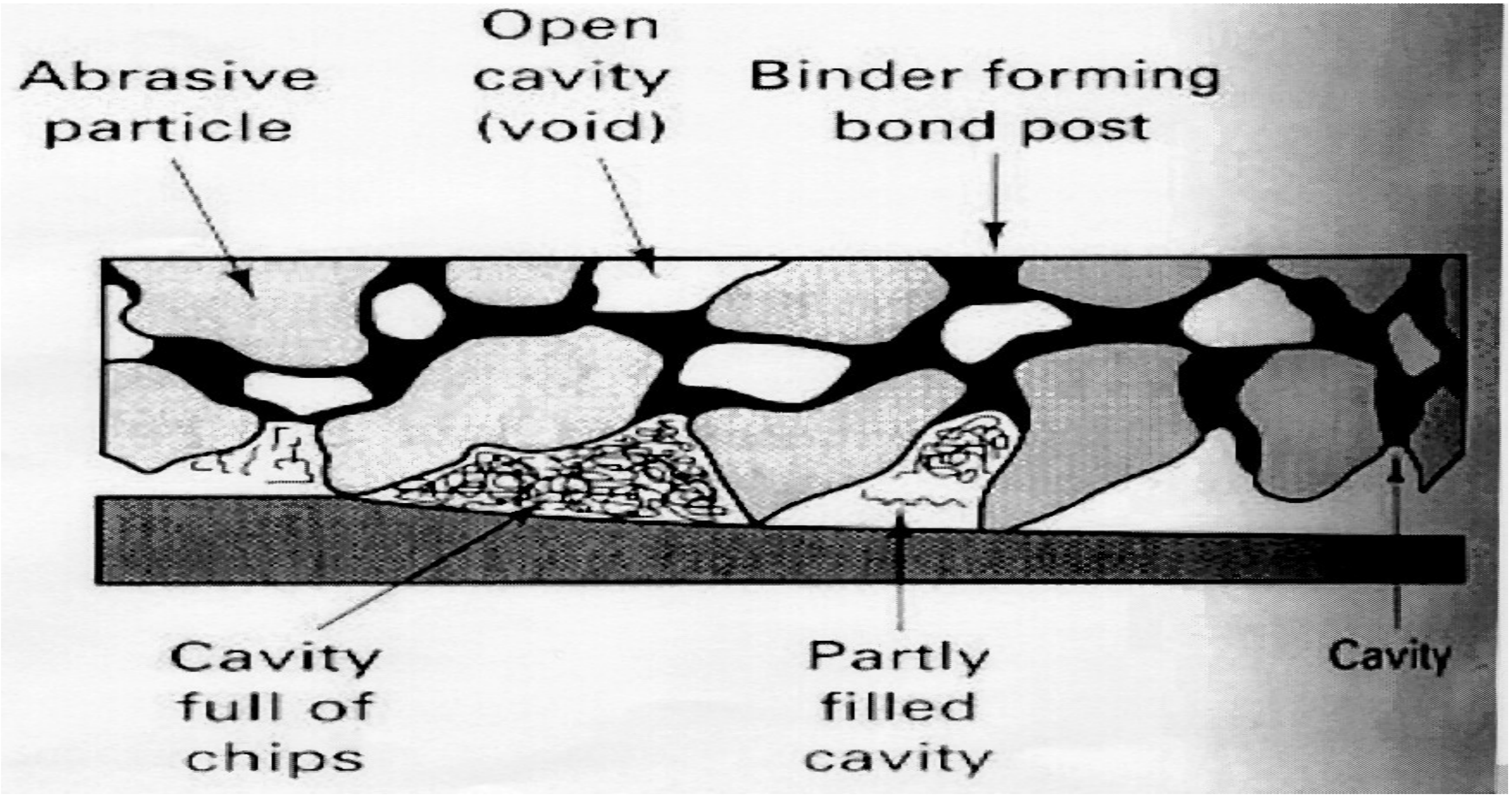
Grain Fracture

Necessary to produce sharp grain edges

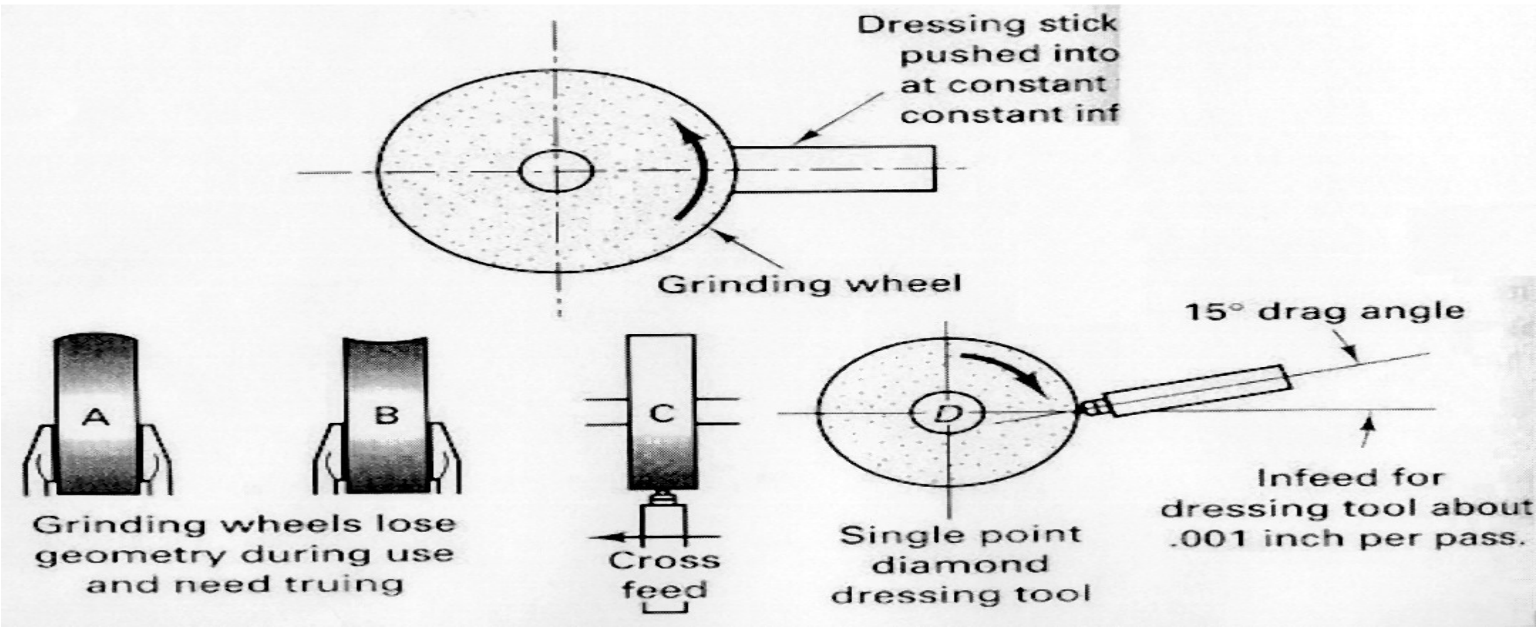
Bond Fracture

Allows dull grains to be dislodged from the wheel

Grinding Wheel Loading



Truing and Dressing



Cutting Fluids

- Remove heat
- Remove chips, grain fragments and dislodged grains
- Are usually water-based emulsions
- Are added by flood application

Grinding Ratio

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

Vary greatly (2-200 or higher) depending on the type of wheel, grinding fluid, and process parameters

Higher forces decrease the grinding ratio

Grinding

Design Considerations:

- Design parts so that they can be held securely
- Avoid interrupted surfaces if high dimensional accuracy is required because they can cause vibrations
- Ensure cylindrical parts are balanced and thick enough to minimize deflections
- Short pieces may be difficult to grind accurately in centerless grinding because of limited support by the blade
- Parts requiring high accuracy form grinding should be kept simple to prevent frequent wheel dressing
- Avoid small deep or blind holes or include a relief

Ultrasonic Machining

Uses fine abrasive grains in a slurry to remove material from brittle workpieces by microchipping and erosion

The tool vibrates at 20 kHz and a low amplitude (.0125-.075 mm) which accelerates the grains to a high velocity

Can create very small holes and slots

Ultrasonic Machining

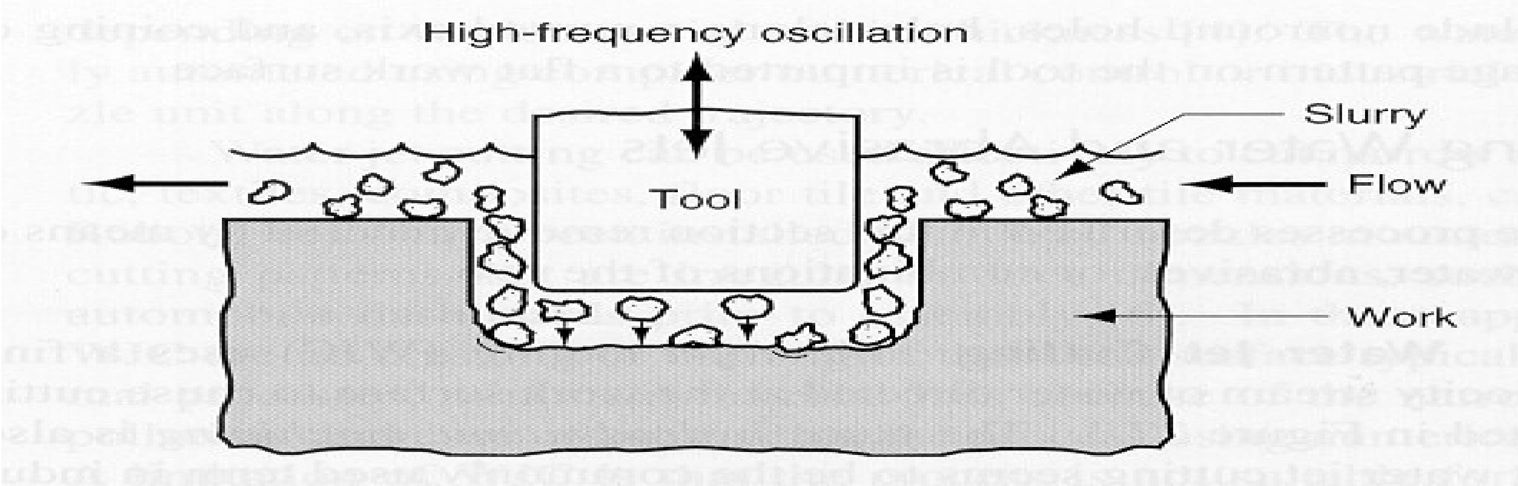
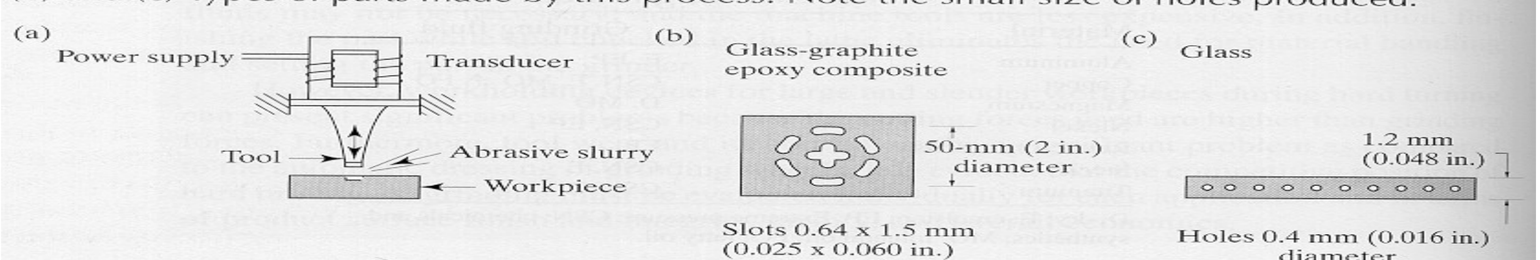


FIGURE 27.1 Ultrasonic machining.

FIGURE 25.24 (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.



Rotary Ultrasonic Machining

Uses a rotating and vibrating tool to remove material, as in face milling

Diamond abrasives are embedded in the tool surface

Effective at producing deep holes in ceramic parts at high MRR

Ultrasonic Machining

Design Considerations:

- Avoid sharp profiles, corners and radii; the slurry erodes corners off
- Allow for slight taper for holes made this way
- Support the exit end of holes being formed with a backup plate to prevent chipping of the holder

Coated Abrasives

Coated Abrasives

- Abrasive grains are deposited on flexible backing; they are more pointed than those in grinding wheels

- Common examples: sandpaper, emery

Coated Abrasives

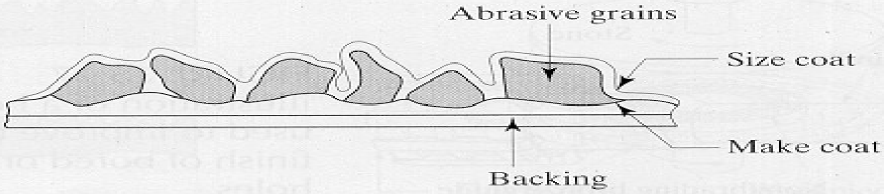


FIGURE 25.25 Schematic illustration of the structure of a coated abrasive. Sandpaper, developed in the 16th century, and emery cloth are common examples of coated abrasives.

Coated Abrasives

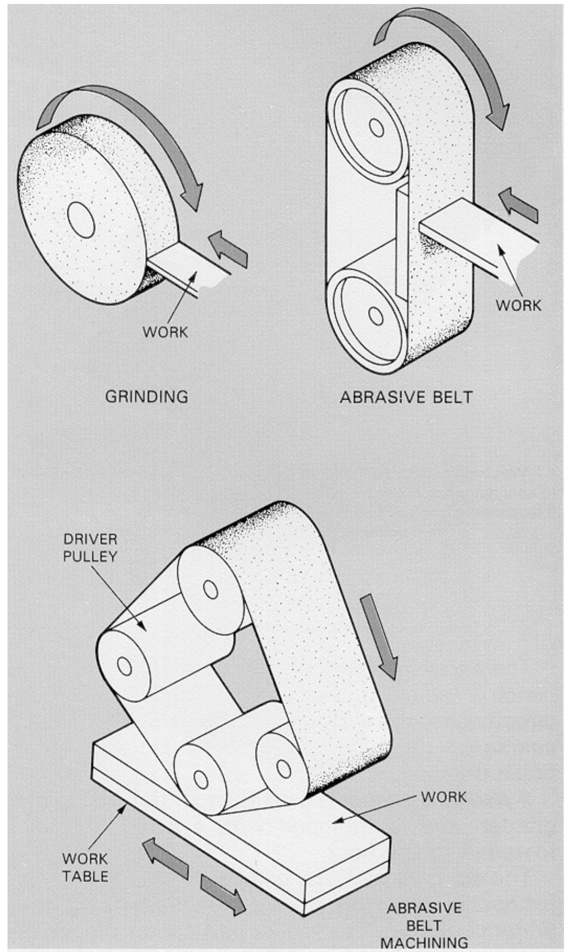
Belt Grinding

Uses coated abrasives in the form of a belt; cutting speeds are about 2500-6000 ft/min

Microreplication

Abrasives with a pyramid shape are placed in a predetermined regular pattern on the belt

Belt Grinding



Honing

Used mainly to improve the surface finish of holes

Bonded abrasives called stones are mounted on a rotating mandrel; also used on cylindrical or flat surfaces and to remove sharp edges on tools

Honing

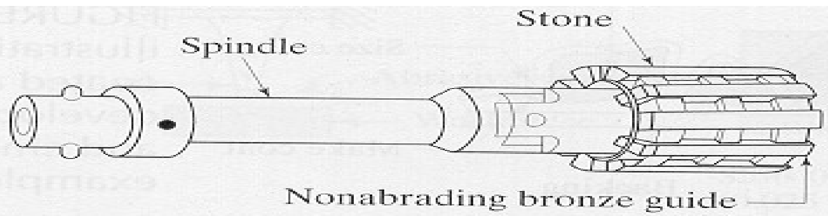
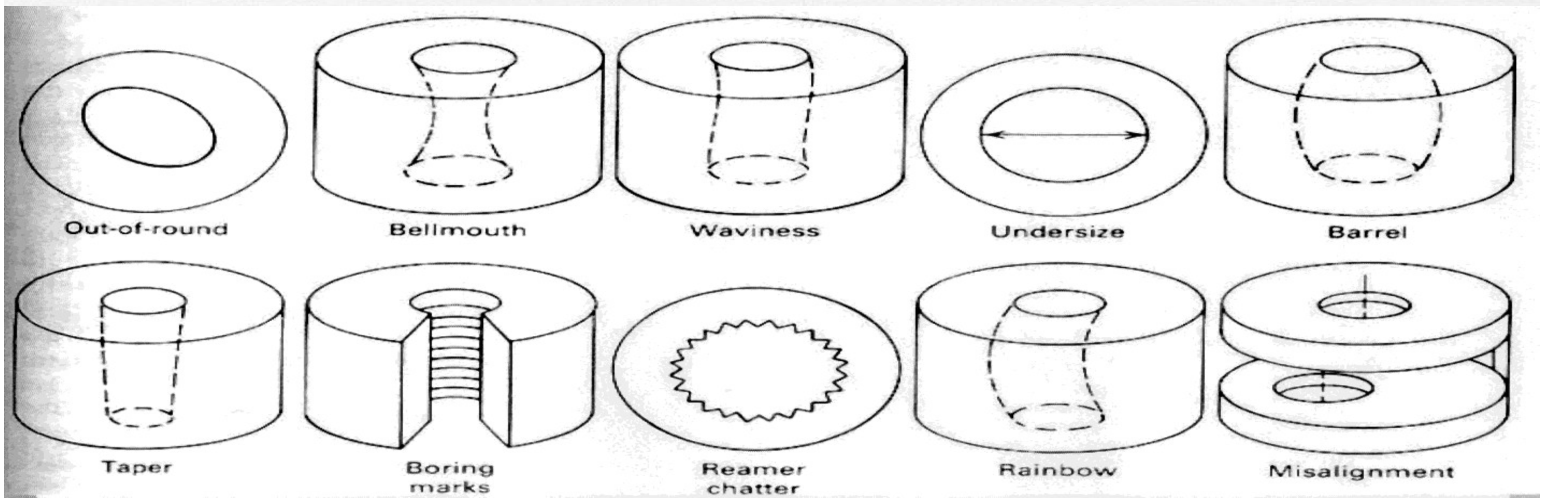


FIGURE 25.27 Schematic illustration of a honing tool used to improve the surface finish of bored or ground holes.



Hole defects correctible by honing

Superfinishing/ Microhoning

Uses very low pressure and short strokes

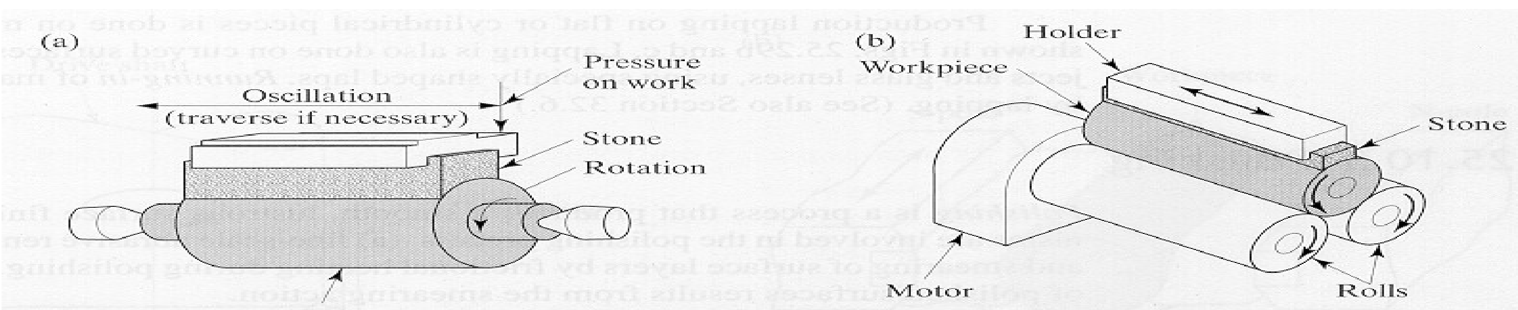


FIGURE 25.28 Schematic illustrations of the superfinishing process for a cylindrical part. (a) Cylindrical microhoning, (b) Centerless microhoning.

Lapping

Used to enhance surface finish and dimensional accuracy of flat or cylindrical surfaces; tolerances are on the order of .0004 mm; surface finish can be as smooth as .025-.1 μm; this improves the fit between surfaces

Abrasive particles are embedded in the lap or carried in a slurry

Pressures range from 7-140 kPa depending on workpiece hardness

Lapping

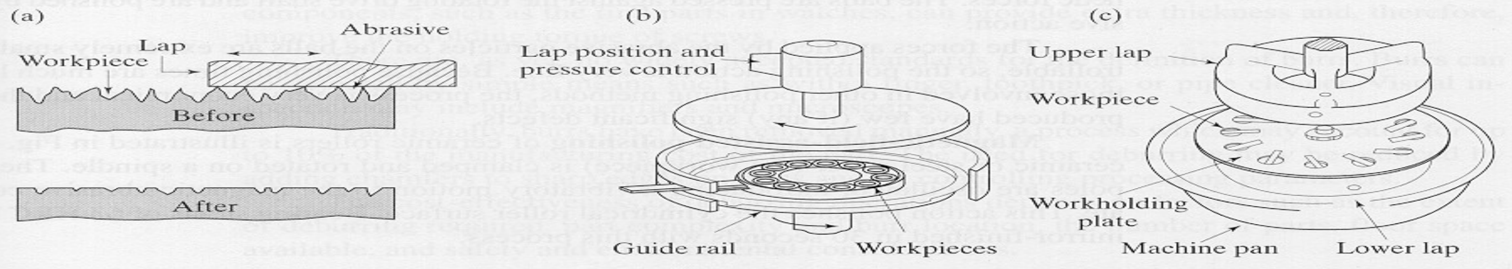
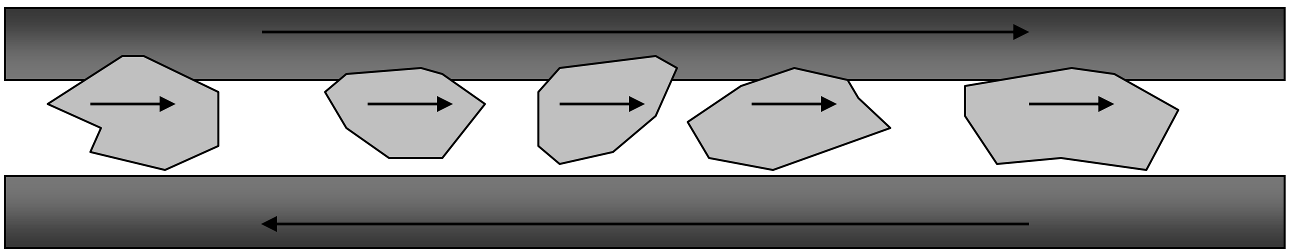


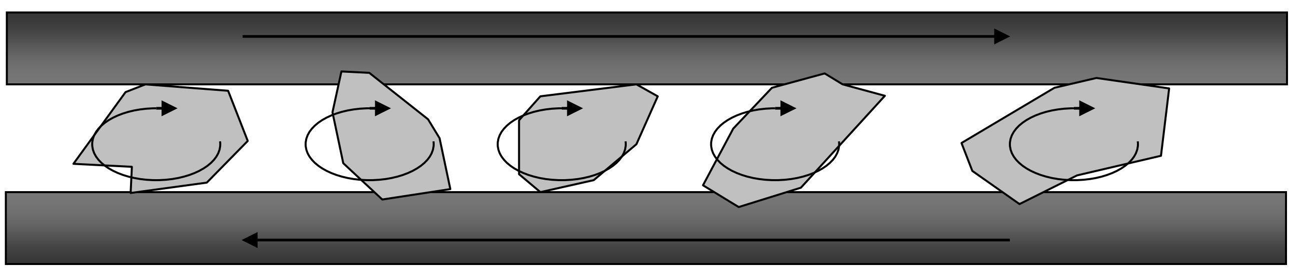
FIGURE 25.29 (a) Schematic illustration of the lapping process. (b) Production lapping on flat surfaces. (c) Production lapping on cylindrical surfaces.

Example of a Lapping Machine

2- and 3-Body Abrasion

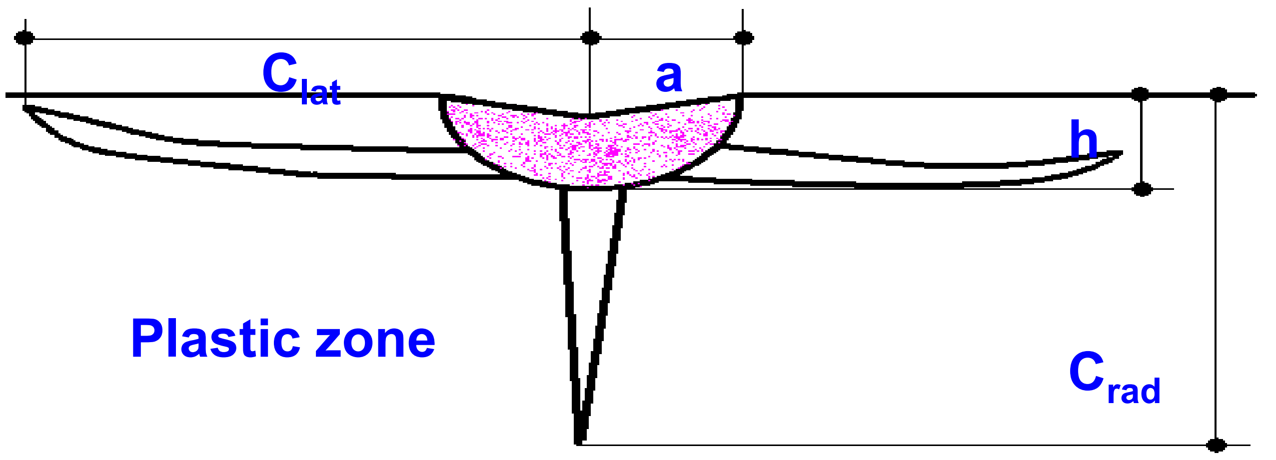


2-body abrasion: grains are embedded in a surface



3-body abrasion: grains move freely between surfaces

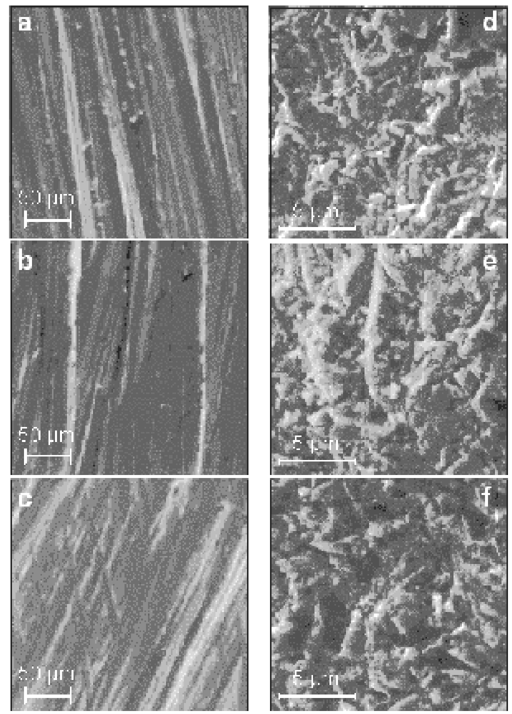
Lapping – Microchipping



Lateral cracks – remove material

Radial cracks – surface damage

Lapping Finish

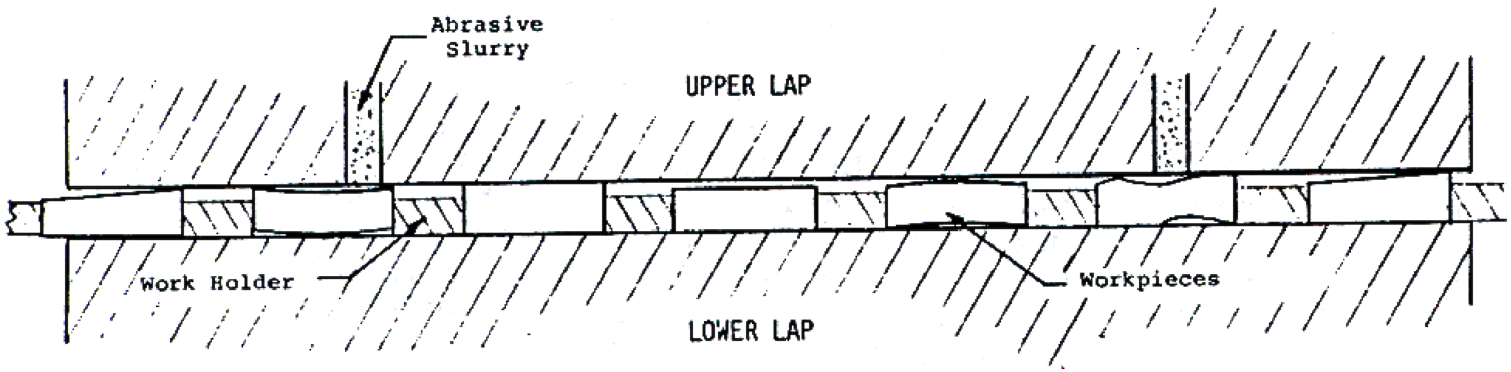


Grinding Lapping

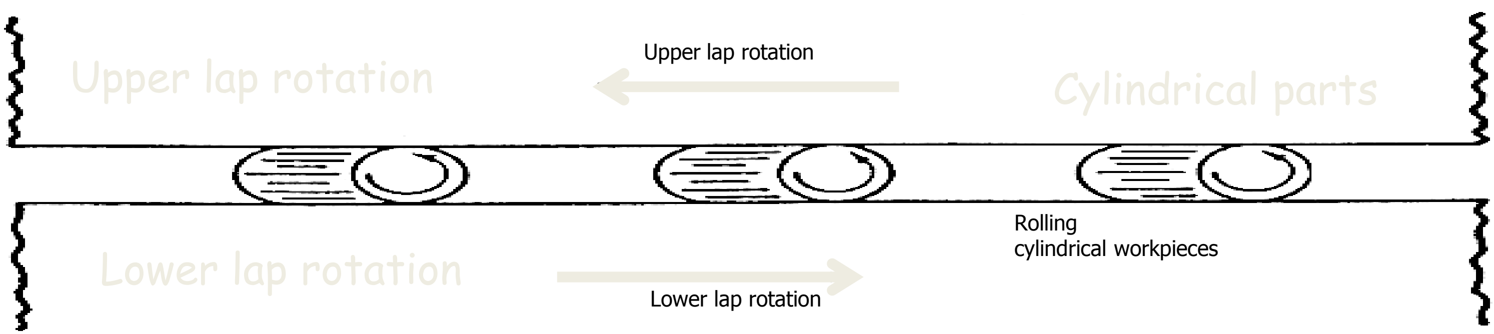
Types of Lapping

Single-sided lapping machine

Types of Lapping

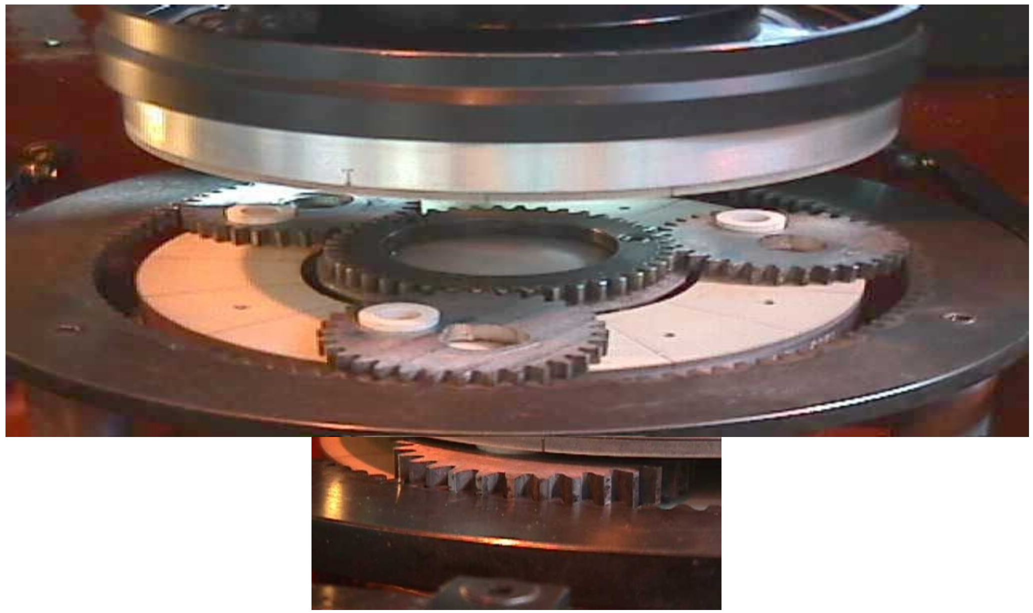


Double-sided lapping

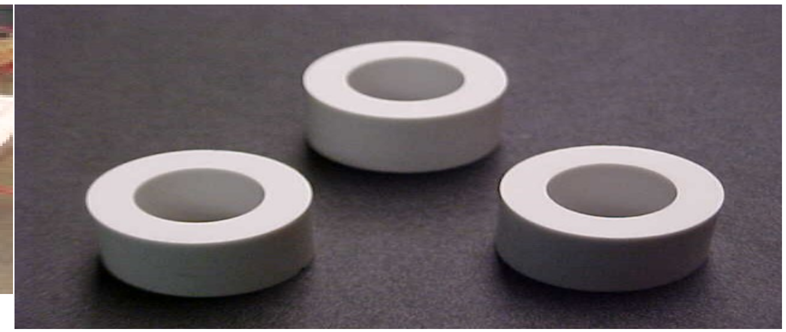


Cylindrical Lapping

Lapping Process



Examples of Lapped Parts



The workpieces made of aluminum oxide were rings having 0.5” ID, 0.8” OD and 0.2” thickness. Its high hardness promotes a series of applications in mechanical engineering, such as bearings and seals.

Initial Ra = 0.65 μm
Final Ra (after lapping) = 0.2 μm

Examples of Lapped Parts

Hexoloy SiC is a new sintered alpha silicon carbide material designed specifically for optimum performance in sliding contact applications. It is produced by pressureless sintering ultra-pure sub-micron powder. This powder is mixed with non-oxide sintering aids, then formed into the desired shapes by a variety of methods and consolidated by sintering at temperatures above 2000° C (3632° F). The sintering process results in single-phase, fine-grain SiC product that is very pure and uniform, with virtually no porosity. Whether used in corrosive environments, subjected to extreme wear and abrasive conditions, or exposed to high temperatures, Hexoloy sintered alpha silicon carbide outperforms other advanced ceramics. This kind of ceramic material is ideal for applications such as chemical and slurry pump seals and bearings, nozzles, pump and valve trim and more.

Initial Ra = 0.053 μm
Final Ra (after lapping) = 0.02 μm.

Examples of Lapped Parts

Hardened steel W-1. The high content of Carbon allows high hardness to be achieved by hardening and also formation of carbide, which gives the high wear resistance. The dimensions for the parts made of W-1 were 0.8”OD and 0.4” thickness (as seen in figure 3.3). The initial hardness of the steel was about 10-14 HRC.

The parts were heat-treated and, after quenching in oil, the resulting hardness was 44 – 48 HRC. The steps followed for the heat treatment were: 1) preheat oven to 1425-1500°F; 2) place part in the oven for ½ hour per inch of thickness; 3) quench the part in oil; 4) test the hardness.

Initial Ra = 0.5 μm

Final Ra (after lapping) = 0.1 μm.

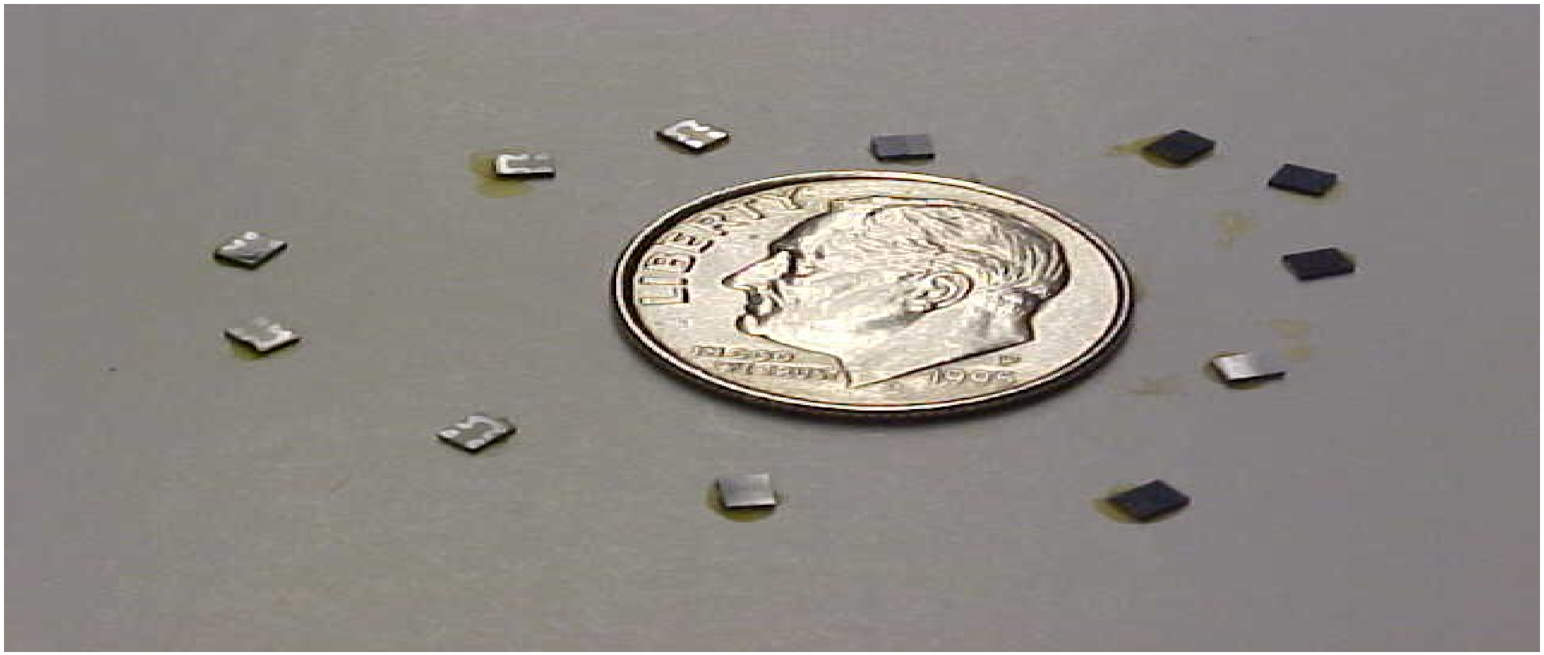
Other Finishing Operations

- Polishing
  - Produces a smooth, reflective surface finish; done with disks or belts with fine abrasive grains

- Electropolishing
  - Produces mirror-like surfaces on metals; the electrolyte removes peaks and raised areas faster than lower areas; also used for deburring

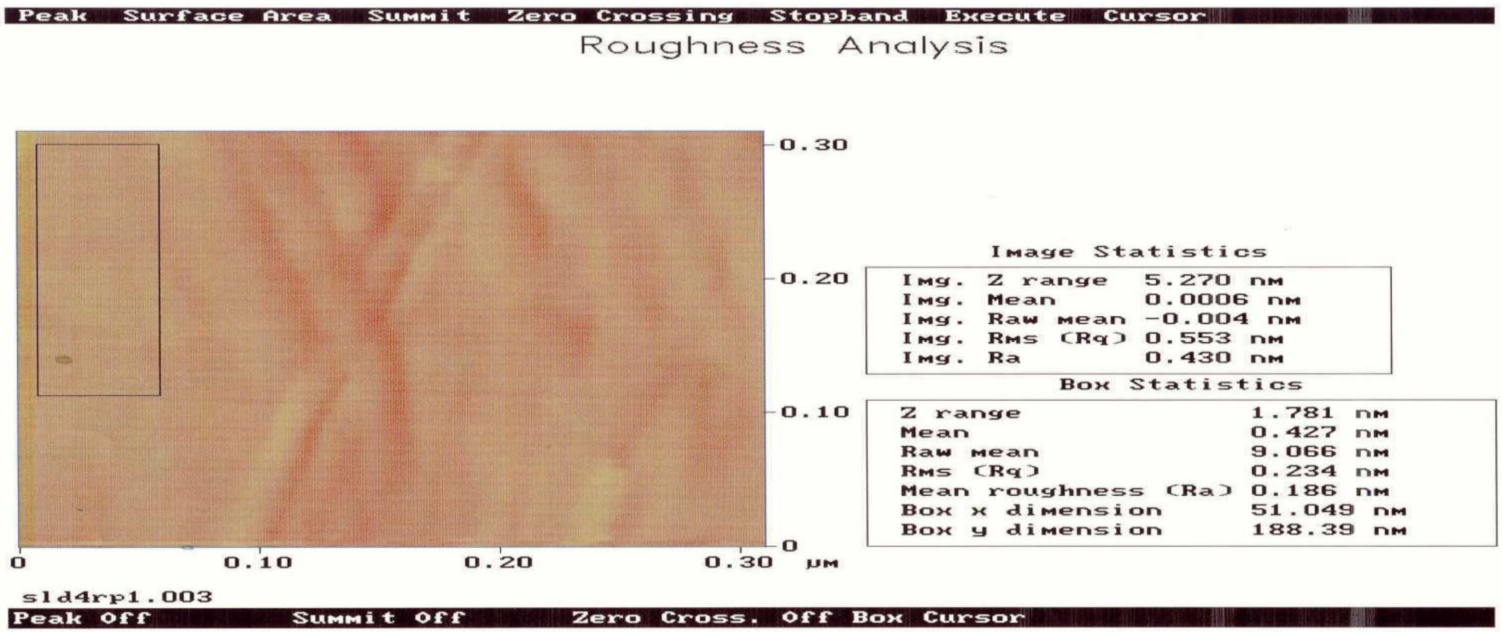
Example of a Polishing Machine

Examples of Polished Parts

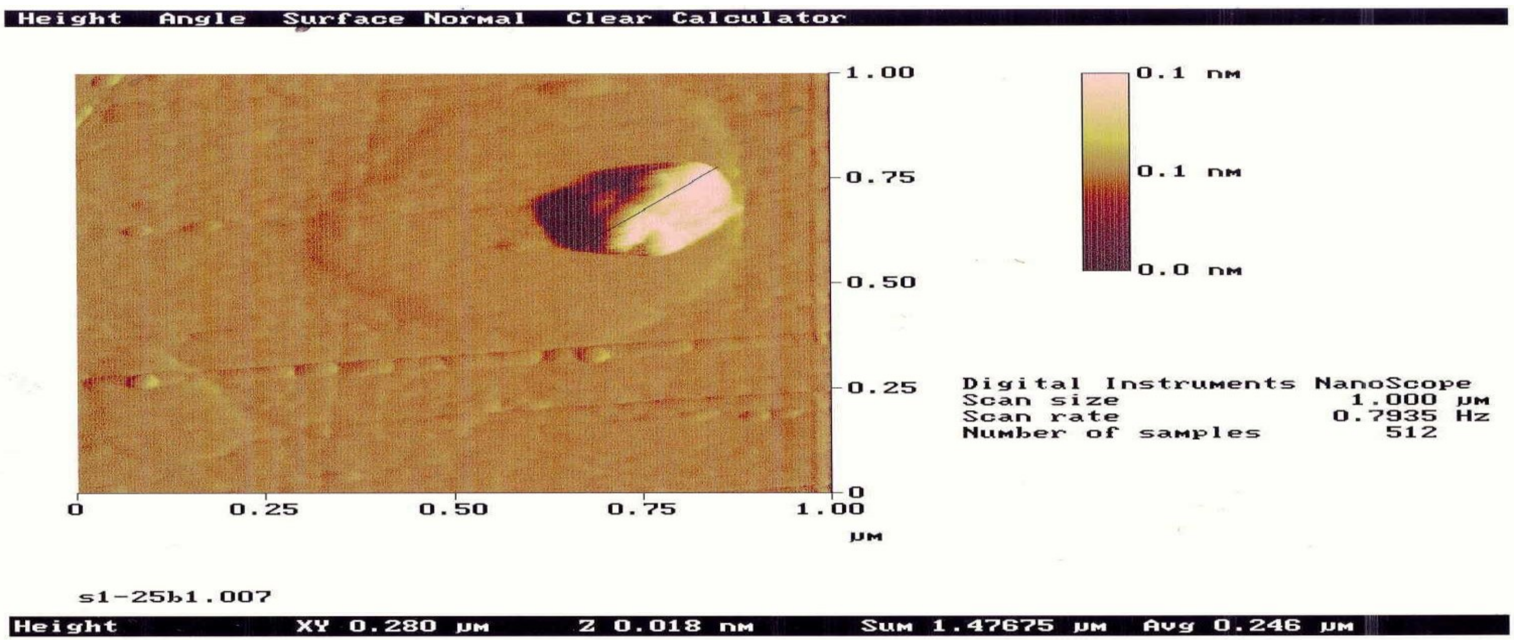


Polished disk drive heads compared to the size of a dime

Polishing Results



Polishing Results



Magnetic Finishing

Magnetic Float Polishing

A magnetic field pulls on the magnetic abrasive fluid, floating the workpieces and pressing them against a drive shaft; forces are very small and controllable so the polish is very fine

Magnetic Field Assisted Polishing

The workpiece is rotated on a spindle and the magnetic field oscillates, producing vibrations in the magnetic abrasive fluid

Magnetic Finishing

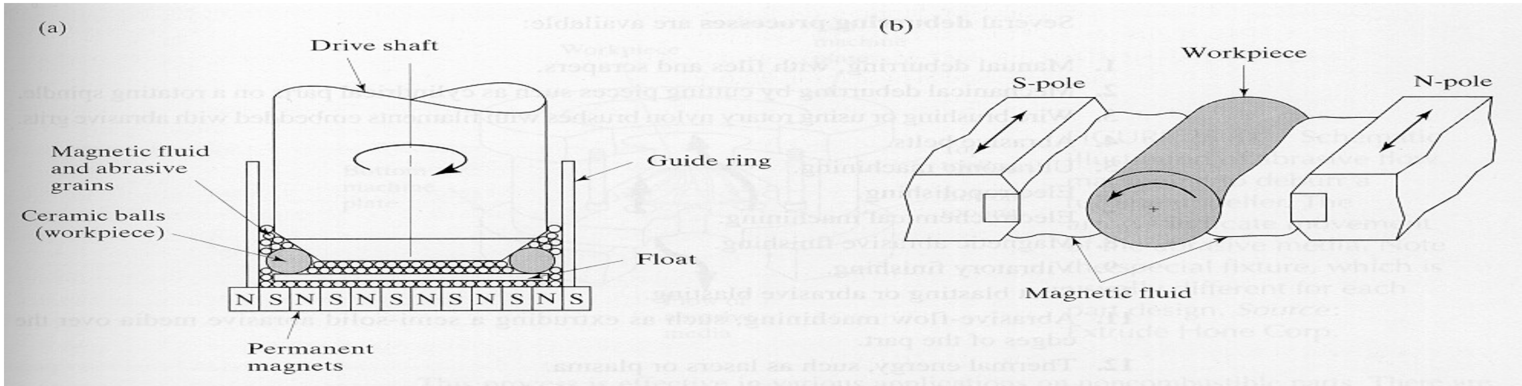
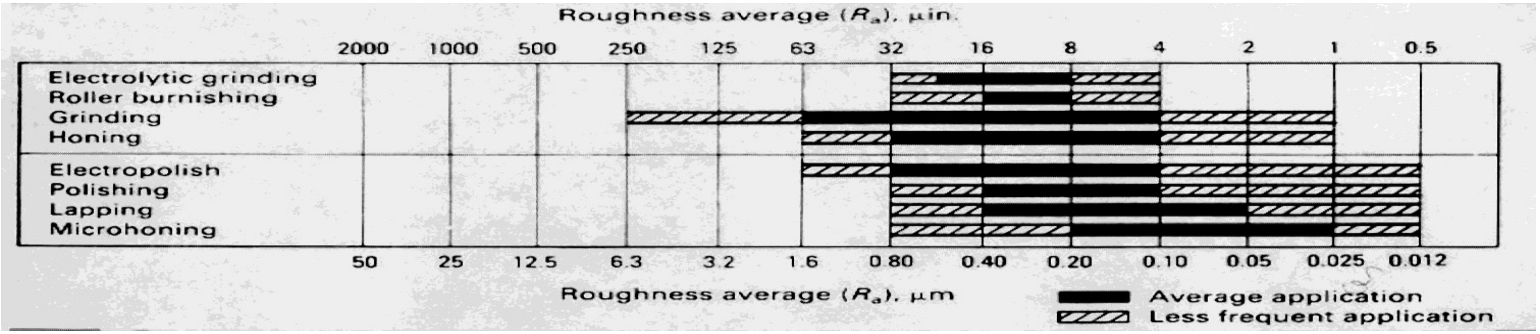


FIGURE 25.30 Schematic illustration of polishing of balls and rollers using magnetic fields. (a) Magnetic float polishing of ceramic balls. (b) Magnetic-field-assisted polishing of rollers. *Source*: R. Komanduri, M. Doc, and M. Fox.

Abrasive Process Capabilities



Deburring

Burrs

- Thin ridges (usually triangular) that form on the workpiece edges during production; can be detrimental to the part or its function
- Traditionally removed manually; can account for up to 10% of the part manufacturing cost

Deburring Processes

- Manual (files and scrapers)
- Mechanical by cutting
- Wire brushing
- Abrasive belts
- Ultrasonic machining
- Electropolishing
- Electrochemical Machining
- Magnetic abrasive finishing
- Vibratory Finishing
- Shot blasting, abrasive blasting
- Abrasive flow machining
- Thermal energy (laser, plasma)

Deburring Processes

Vibratory and Barrel Finishing

Abrasive pellets are placed in a container with the workpiece; the container is vibrated or tumbled

Shot Blasting

Abrasive particles are propelled at the workpiece at high velocity by an air jet or a wheel

Deburring Processes

Abrasive Flow Machining

An putty-like substance with abrasive grains is forced around and through the workpiece; especially useful for pieces with internal spaces that cannot be reached by other means

Thermal Energy

The workpiece is exposed to an instantaneous combustion reaction; the burrs heat up much more rapidly than the solid part and melt away

Summary

Abrasive processes offer a way to increase surface finish and dimensional accuracy

Deburring may be necessary for proper part fit and function