GRINDING AND OTHER ABRASIVE PROCESSES

- Grinding
- Related Abrasive Process

Abrasive Machining

Material removal by action of hard, abrasive particles usually in the form of a bonded wheel

- Generally used as finishing operations after part geometry has been established y conventional machining
- Grinding is most important abrasive processes
- Other abrasive processes: honing, lapping, superfinishing, polishing, and buffing

Why Abrasive Processes are Important

- Can be used on all types of materials
- Some can produce extremely fine surface finishes, to 0.025 μm (1 μ-in)
- Some can hold dimensions to extremely close tolerances

Grinding

Material removal process in which abrasive particles are contained in a bonded grinding wheel that operates at very high surface speeds

- Grinding wheel usually disk-shaped and precisely balanced for high rotational speeds

The Grinding Wheel

- Consists of abrasive particles and bonding material
  - Abrasive particles accomplish cutting
  - Bonding material holds particles in place and establishes shape and structure of wheel

Grinding Wheel Parameters

- Abrasive material
- Grain size
- Bonding material
- Wheel grade
- Wheel structure

Abrasive Material Properties

- High hardness
- Wear resistance
- Toughness
- Friability - capacity to fracture when cutting edge dulls, so a new sharp edge is exposed

Traditional Abrasive Materials

- *Aluminum oxide* (Al_2O_3) - most common abrasive
  - Used to grind steel and other ferrous high-strength alloys
- *Silicon carbide* (SiC) - harder than Al_2O_3 but not as tough
  - Used on aluminum, brass, stainless steel, some cast irons and certain ceramics

Newer Abrasive Materials

- *Cubic boron nitride* (cBN) – very hard, very expensive
  - Suitable for steels
  - Used for hard materials such as hardened tool steels and aerospace alloys (e.g., Ni-based alloys)
- *Diamond* – Even harder, very expensive
  - Occur naturally and also made synthetically
  - Not suitable for grinding steels
  - Used on hard, abrasive materials such as ceramics, cemented carbides, and glass

Hardness of Abrasive Materials

Abrasive material	Knoop hardness
Aluminum oxide	2100
Silicon carbide	2500
Cubic boron nitride	5000
Diamond (synthetic)	7000

Grain Size

- Small grit sizes produce better finishes
- Larger grit sizes permit larger material removal rates
- Harder work materials require smaller grain sizes to cut effectively
- Softer materials require larger grit sizes

Measurement of Grain Size

- Grit size is measured using a screen mesh procedure
  - Smaller grit sizes indicated by larger numbers in the screen mesh procedure and vice versa
  - Grain sizes in grinding wheels typically range between 8 (very coarse) and 250 (very fine)

Bonding Material Properties

- Must withstand centrifugal forces and high temperatures
- Must resist shattering during shock loading of wheel
- Must hold abrasive grains rigidly in place for cutting yet allow worn grains to be dislodged so new sharp grains are exposed

Wheel Structure

Refers to the relative spacing of abrasive grains in wheel

- In addition to abrasive grains and bond material, grinding wheels contain air gaps or pores
- Volumetric proportions of grains, bond material, and pores can be expressed as:

$$P_g + P_b + P_p = 1.0$$

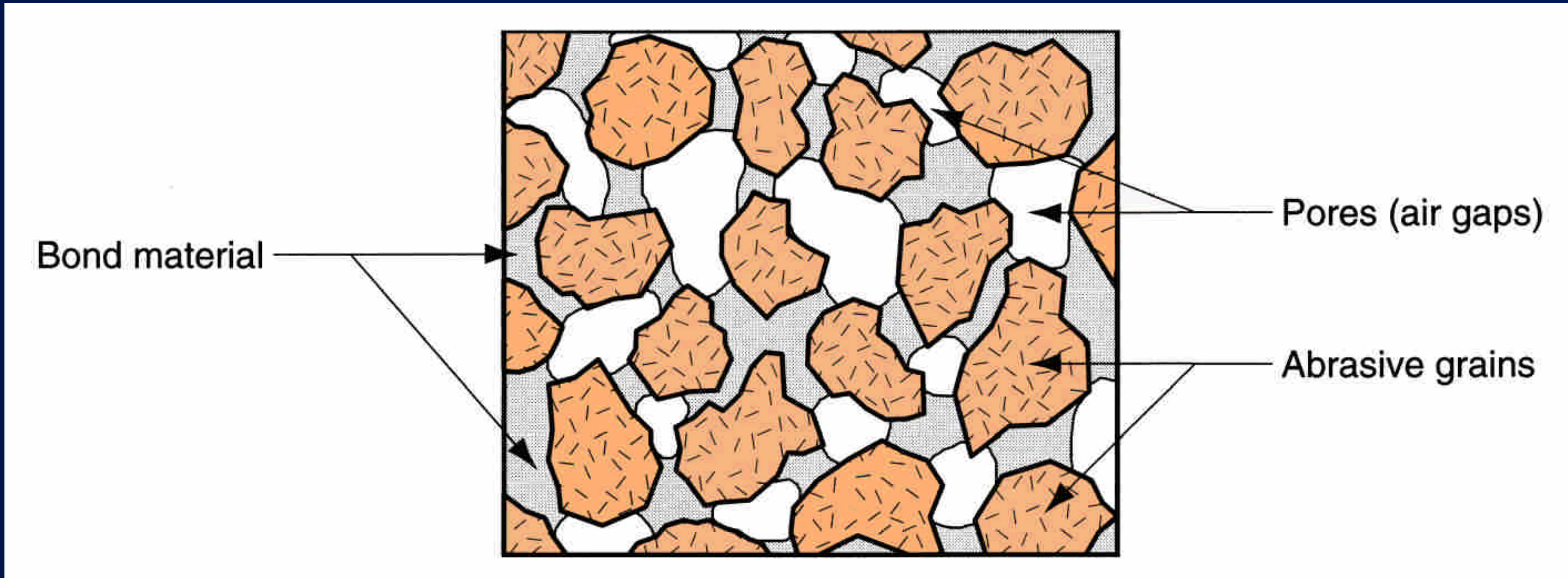

Figure 25.1 - Typical structure of a grinding wheel

Wheel Structure

- Measured on a scale that ranges between "open" and "dense."
  - Open structure means P_p is relatively large and P_g is relatively small - recommended when clearance for chips must be provided
  - Dense structure means P_p is relatively small and P_g is larger - recommended to obtain better surface finish and dimensional control

Wheel Grade

Indicates bond strength in retaining abrasive grits during cutting

- Depends on amount of bonding material in wheel structure (P_b)
- Measured on a scale ranging between soft and hard
  - Soft" wheels lose grains readily - used for low material removal rates and hard work materials
  - Hard wheels retain grains - used for high stock removal rates and soft work materials

Grinding Wheel Specification

- Standard grinding wheel marking system used to designate abrasive type, grit size, grade, structure, and bond material
  - Example: A-46-H-6-V
- Also provides for additional identifications for use by grinding wheel manufacturers

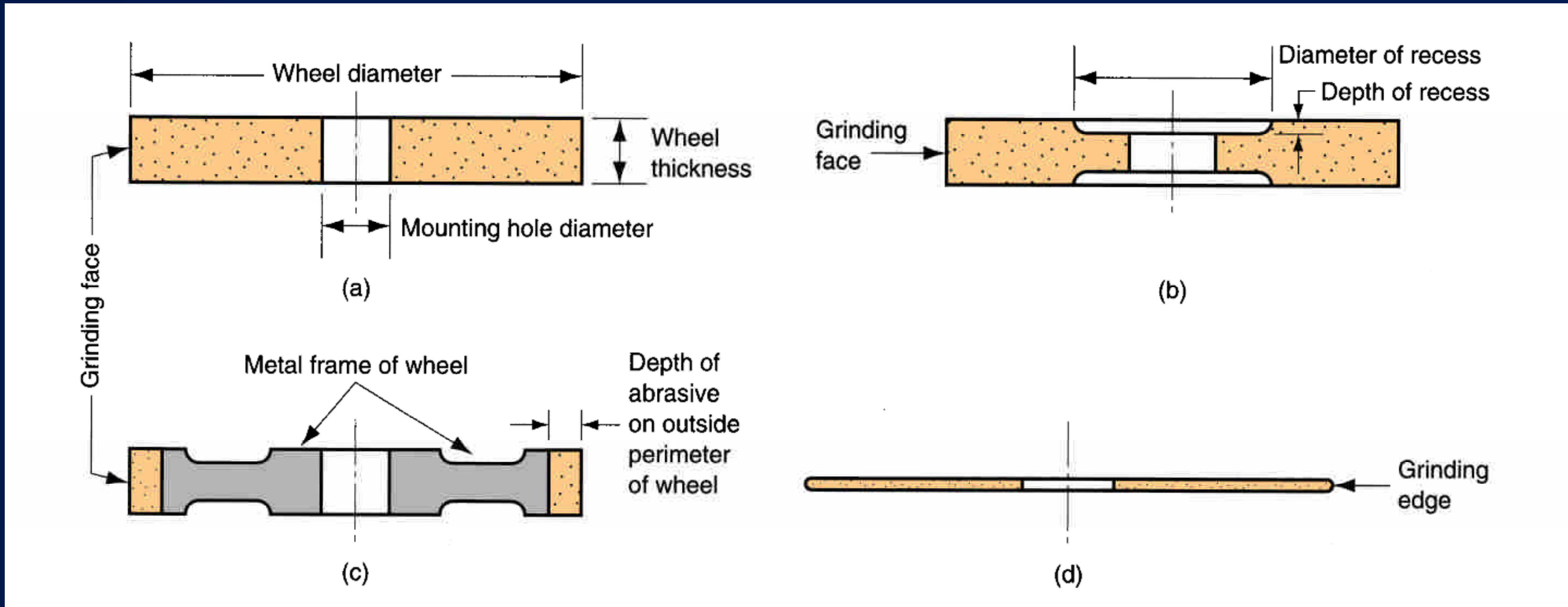

Figure 25.2 - Some of the standard grinding wheel shapes:

(a) straight, (b) recessed two sides, (c) metal wheel frame with abrasive bonded to outside circumference, (d) abrasive cut- off wheel

Surface Finish

- Most grinding is performed to achieve good surface finish
- Best surface finish is achieved by:
  - Small grain sizes
  - Higher wheel speeds
  - Denser wheel structure = more grits per wheel area

Why Specific Energy in Grinding is High

- *Size effect* - small chip size causes energy to remove each unit volume of material to be significantly higher - roughly 10 times higher
- Individual grains have extremely negative rake angles, resulting in low shear plane angles and high shear strains
- Not all grits are engaged in actual cutting

Three Types of Grain Action

- *Cutting* - grit projects far enough into surface to form a chip - material is removed
- *Plowing* - grit projects into work, but not far enough to cut - instead, surface is deformed and energy is consumed, but no material is removed
- *Rubbing* - grit contacts surface but only rubbing friction occurs, thus consuming energy, but no material is removed

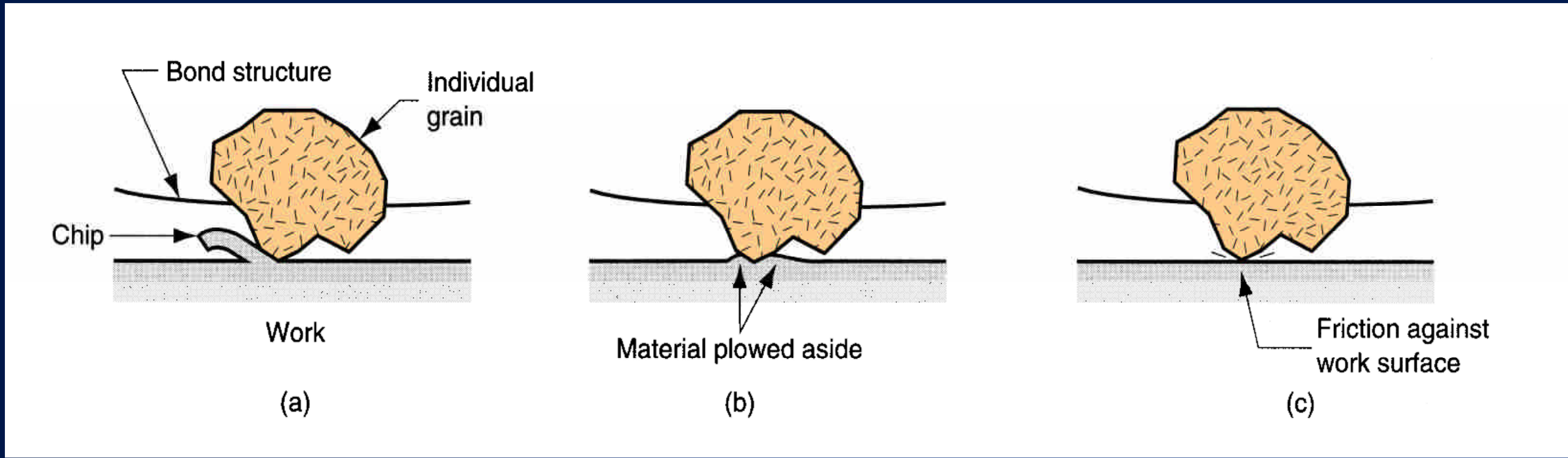

Figure 25.4 - Three types of grain action in grinding: (a) cutting, (b) plowing, and (c) rubbing

Temperatures at the Work Surface

- Grinding is characterized by high temperatures and high friction, and most of the energy remains in the ground surface, resulting in high work surface temperatures
- Damaging effects include:
  - Surface burns and cracks
  - Metallurgical damage immediately beneath the surface
  - Softening of the work surface if heat treated
  - Residual stresses in the work surface

How to Reduce Work Surface Temperatures

- Decrease infeed (depth of cut) d
- Reduce wheel speed v
- Reduce number of active grits per square inch on the grinding wheel C
- Increasing work speed v_w
- Use a cutting fluid

Causes of Wheel Wear - 1

Grain fracture - when a portion of the grain breaks off, but the rest remains bonded in the wheel

- Edges of the fractured area become new cutting edges
- Tendency to fracture is called *friability*

Causes of Wheel Wear - 2

Attritious wear - dulling of individual grains, resulting in flat spots and rounded edges

- Analogous to tool wear in conventional cutting tool
- Caused by similar mechanisms including friction, diffusion, and chemical reactions

Causes of Wheel Wear - 3

Bond fracture - the individual grains are pulled out of the bonding material

- Depends on wheel grade, among other factors
- Usually occurs because grain has become dull due to attritious wear, and resulting cutting force becomes excessive

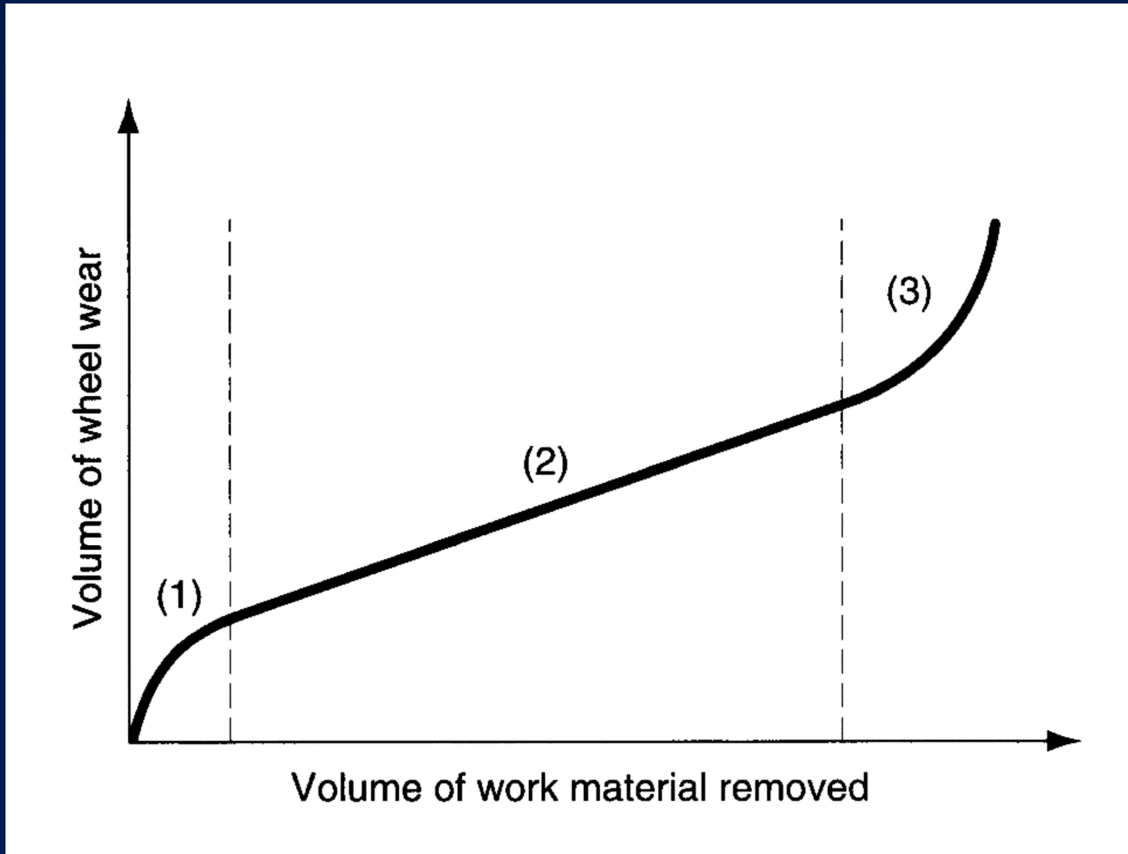

Figure 25.5 - Typical wear curve of a grinding wheel. Wear is conveniently plotted as a function of volume of material removed, rather than as a function of time (based on [13])

Grinding Ratio

Indicates slope of the wheel wear curve

$$GR = \frac{V_w}{V_g}$$

where GR = grinding ratio; V_w = volume of work material removed; and V_g = corresponding volume of grinding wheel worn

Dressing the Wheel

Dressing - accomplished by rotating disk, abrasive stick, or another grinding wheel held against the wheel being dressed as it rotates

- Functions:
  - Breaks off dulled grits to expose new sharp grains
  - Removes chips clogged in the wheel
- Accomplished by a rotating disk, an abrasive stick, or another grinding wheel operating at high speed, held against the wheel being dressed as it rotates
- Required when wheel is in third region of wear curve

Truing the Wheel

Truing - use of a diamond-pointed tool fed slowly and precisely across wheel as it rotates

- Very light depth is taken (0.025 mm or less) against the wheel
- Not only sharpens wheel, but restores cylindrical shape and insures straightness across outside perimeter
  - Although dressing sharpens, it does not guarantee the shape of the wheel

Application Guidelines - I

- To optimize surface finish, select
  - Small grit size and dense wheel structure
  - Use higher wheel speeds (v) and lower work speeds (v_w)
  - Smaller depths of cut (d) and larger wheel diameters (D) will also help
- To maximize material removal rate, select
  - Large grit size
  - More open wheel structure
  - Vitrified bond

Application Guidelines - II

- For grinding steel and most cast irons, select
  – Aluminum oxide as the abrasive
- For grinding most nonferrous metals, select
  – Silicon carbide as the abrasive
- For grinding hardened tool steels and certain aerospace alloys, choose
  – Cubic boron nitride as the abrasive
- For grinding hard abrasive materials such as ceramics, cemented carbides, and glass, choose
  – Diamond as the abrasive

Application Guidelines - III

- For soft metals, choose
  - Large grit size and harder grade wheel
- For hard metals, choose
  - Small grit size and softer grade wheel

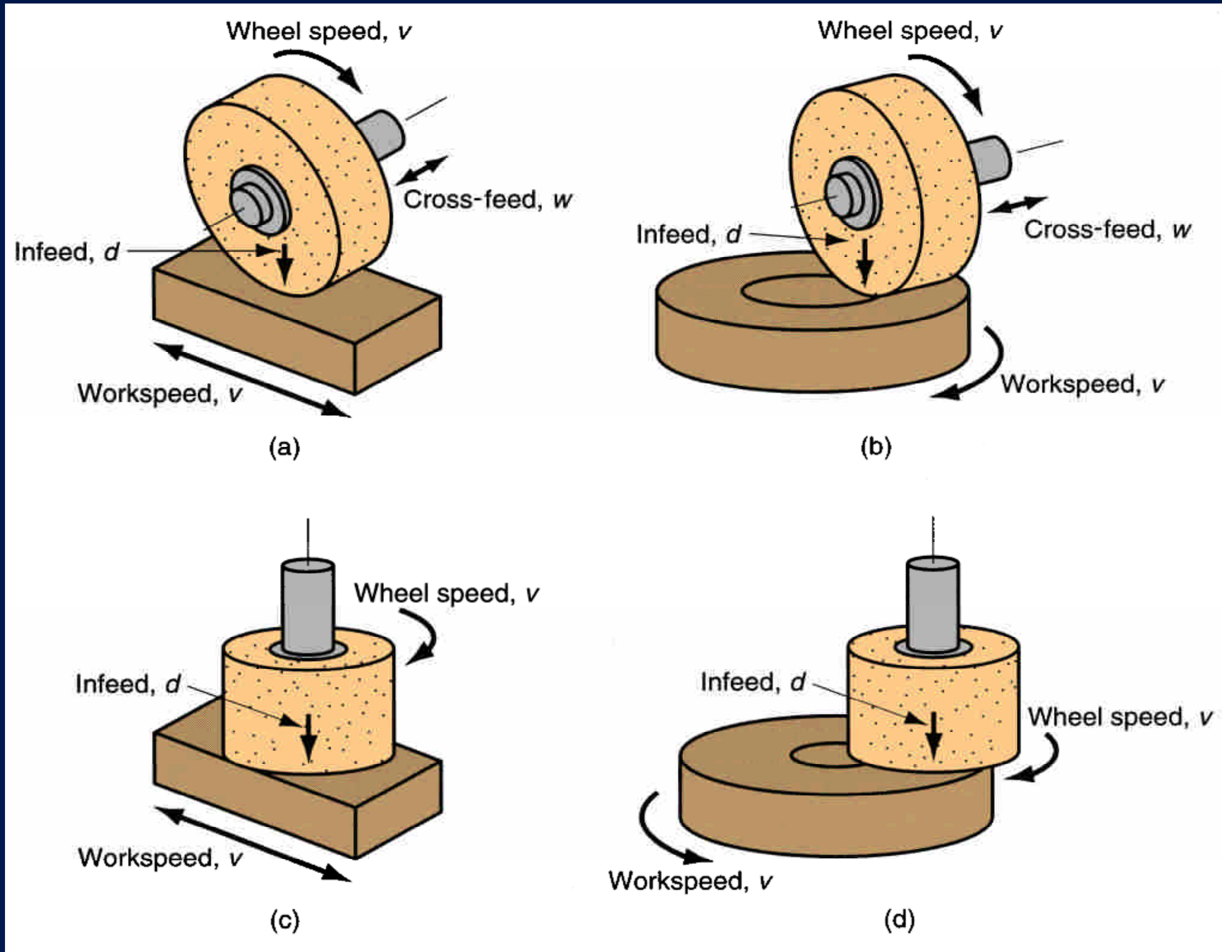

Figure 25.7 - Four types of surface grinding: (a) horizontal spindle with reciprocating worktable, (b) horizontal spindle with rotating worktable, (c) vertical spindle with reciprocating worktable, and (d) vertical spindle with rotating worktable

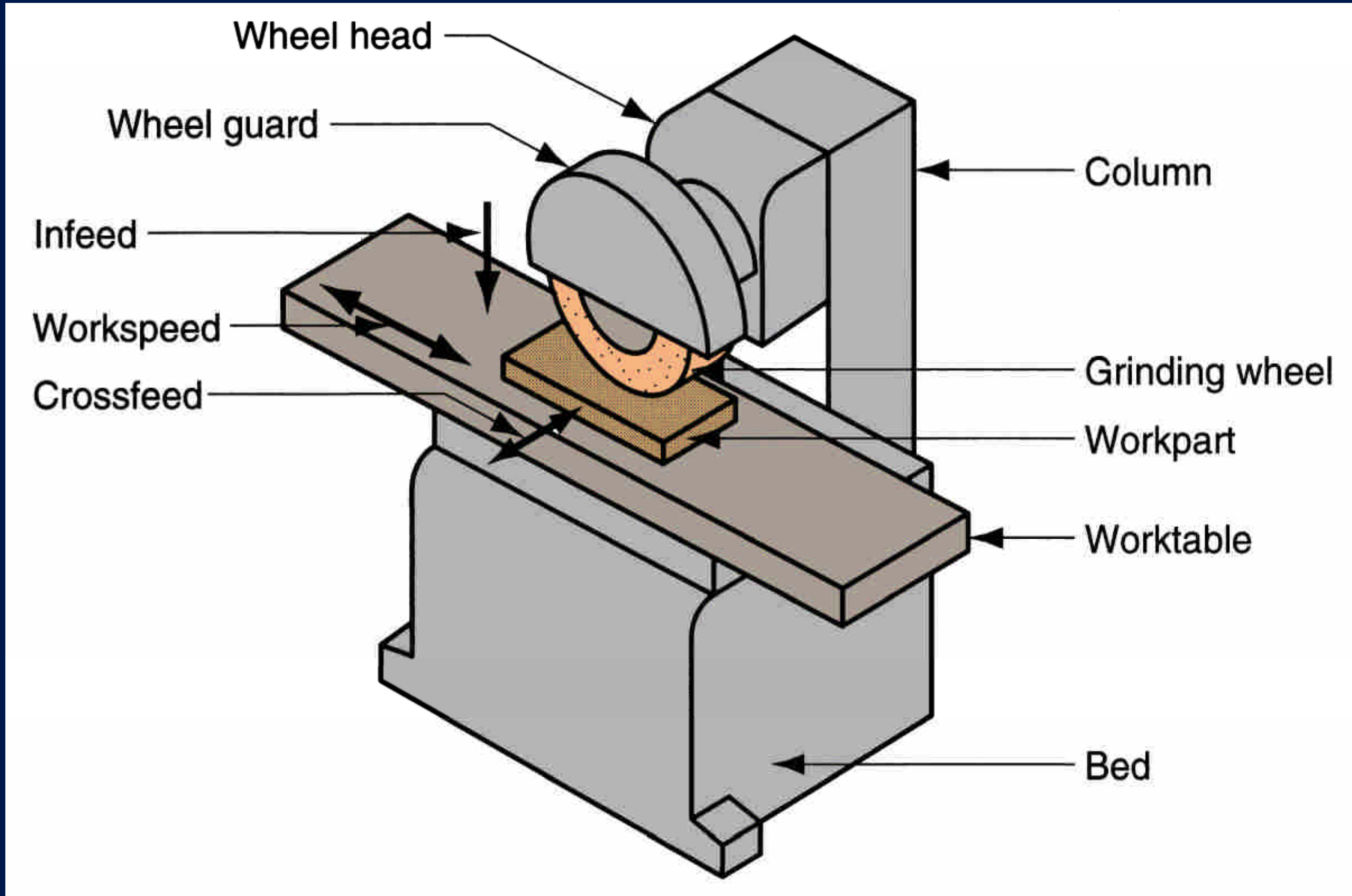

Figure 25.8 - Surface grinder with horizontal spindle and reciprocating worktable (most common grinder type)

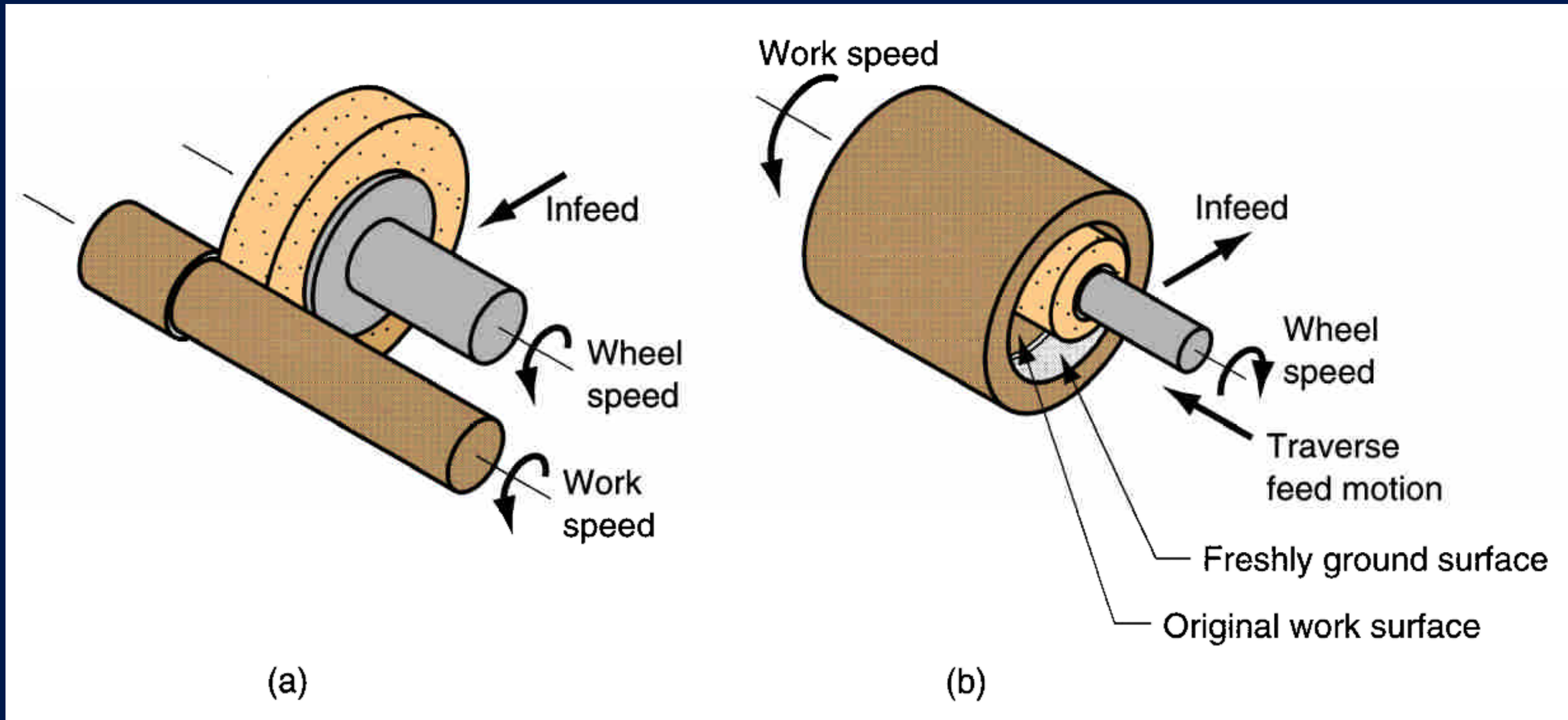

Figure 25.9 ‑ Two types of cylindrical grinding: (a) external, and (b) internal

Centerless Grinding

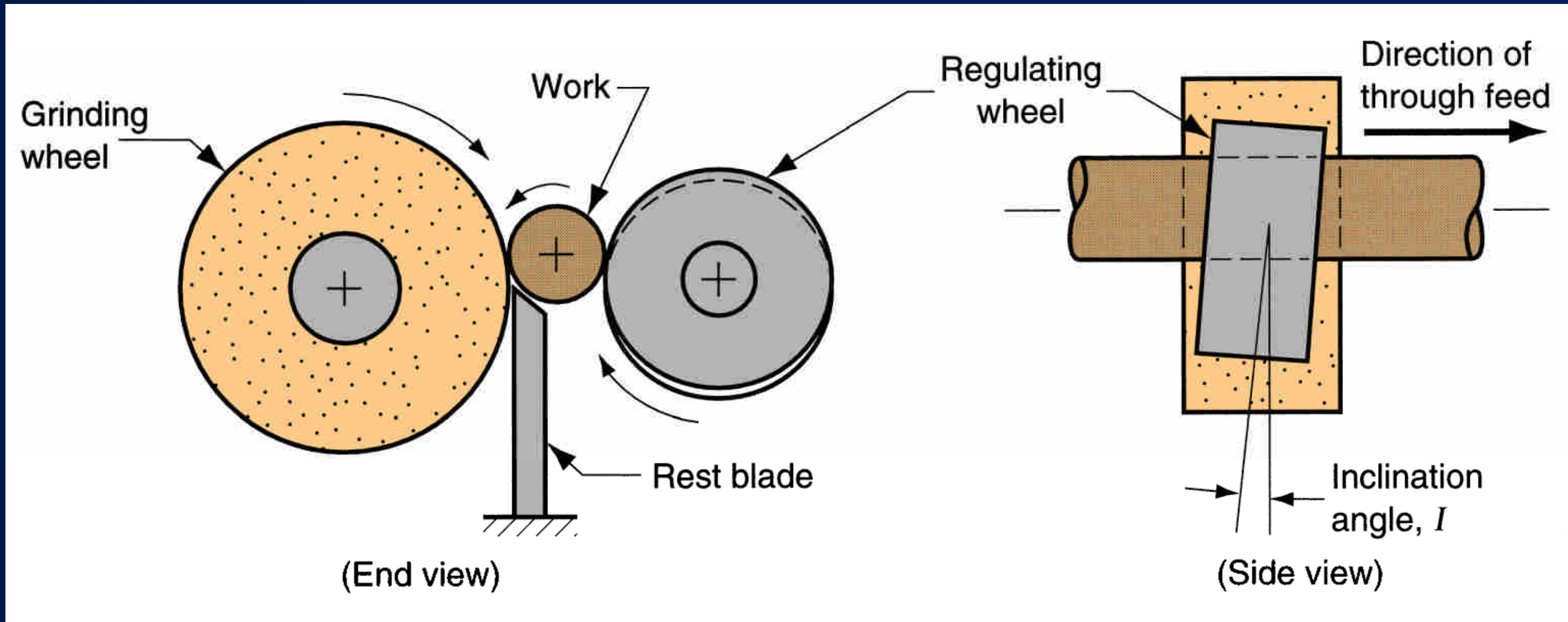

Figure 25.11 - External centerless grinding

Creep Feed Grinding

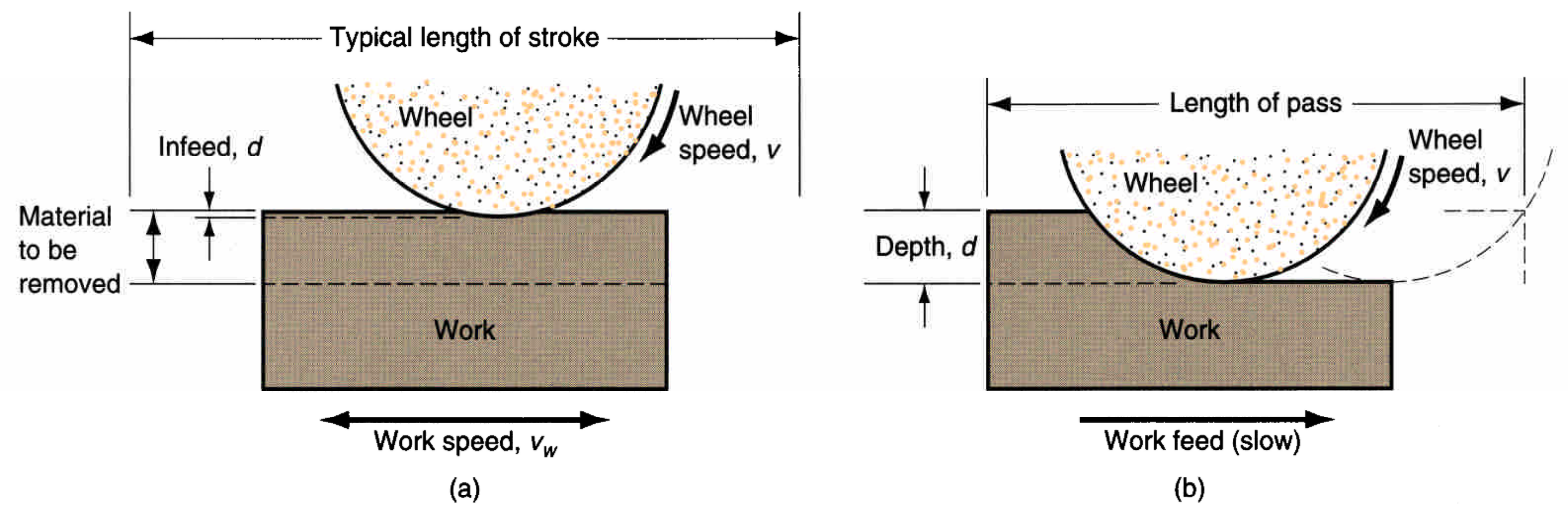

Figure 25.13 - Comparison of (a) conventional surface grinding and (b) creep feed grinding

Creep Feed Grinding

- Depths of cut 1000 to 10,000 times greater than in conventional surface grinding
- Feed rates reduced by about the same proportion
- Material removal rate and productivity are increased in creep feed grinding because the wheel is continuously cutting
- In conventional surface grinding, wheel is engaged in cutting for only a portion of the stroke length

Honing

Abrasive process performed by a set of bonded abrasive sticks using a combination of rotational and oscillatory motions

- Common application is to finish the bores of internal combustion engines
- Grit sizes range between 30 and 600
- Surface finishes of 0.12 μm (5 μ-in) or better
- Creates a characteristic cross-hatched surface that retains lubrication

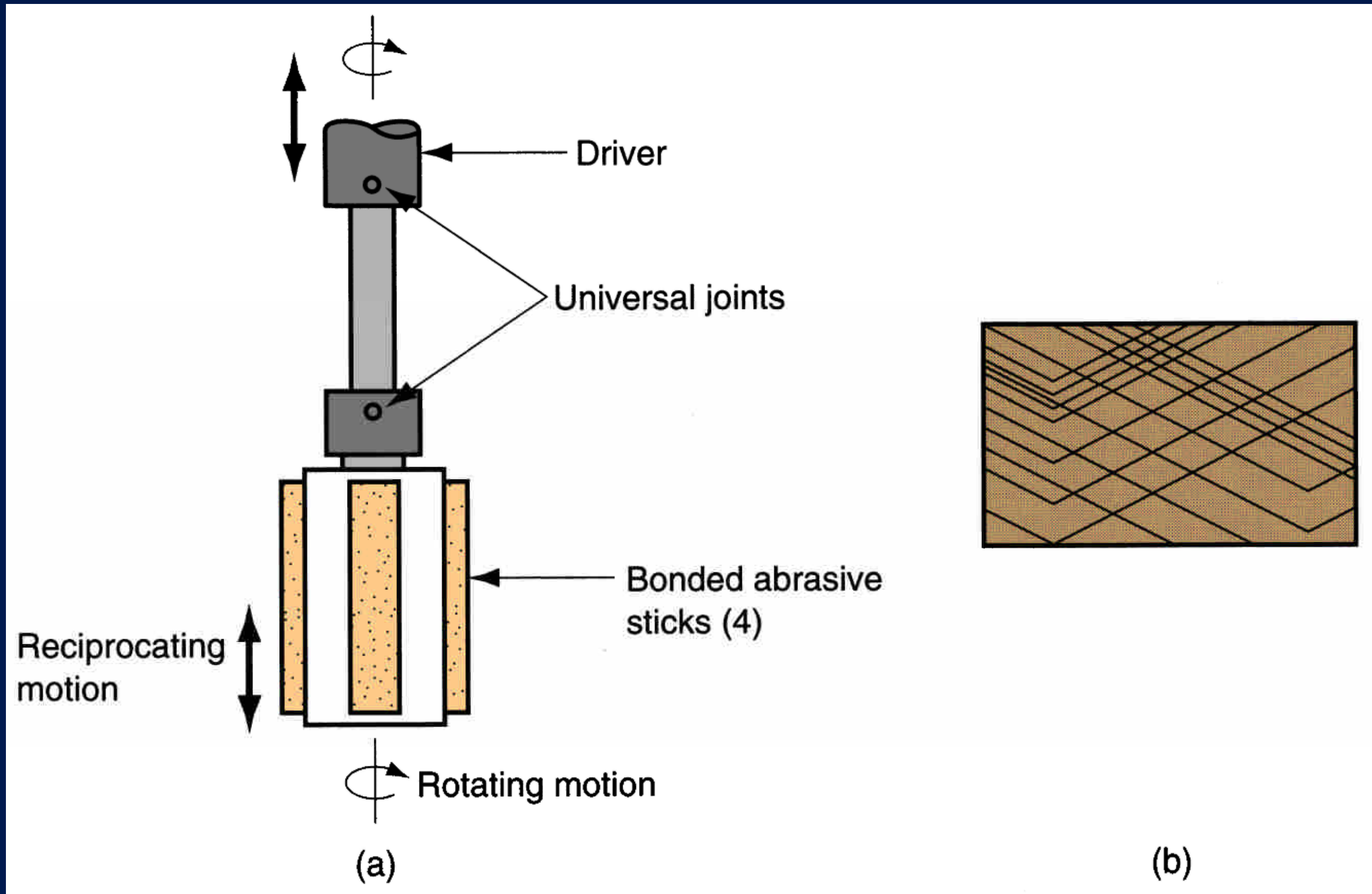

Figure 25.16 - The honing process: (a) the honing tool used for internal bore surface, and (b) cross-hatched surface pattern created by the action of the honing tool

Lapping

Uses a fluid suspension of very small abrasive particles between workpiece and lap (tool)

- *Lapping compound* - fluid with abrasives, general appearance of a chalky paste
- Typical grit sizes between 300 to 600
- Applications: optical lenses, metallic bearing surfaces, gages

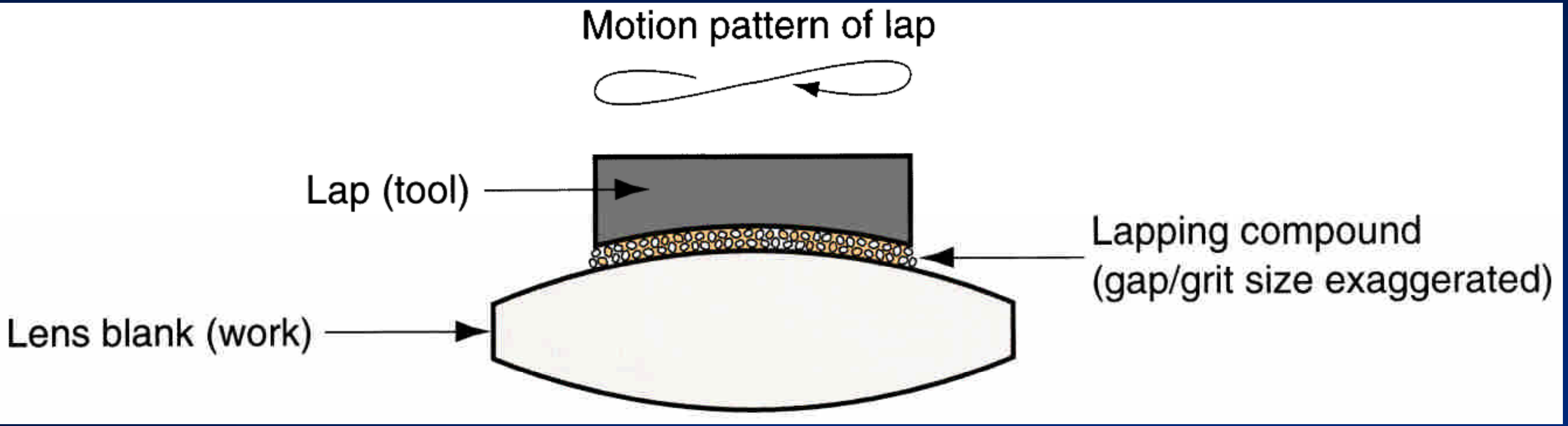

Figure 25.17 - The lapping process in lens-making

Superfinishing

Similar to honing - uses bonded abrasive stick pressed against surface and reciprocating motion

- Differences with honing:
  - Shorter strokes
  - Higher frequencies
  - Lower pressures between tool and surface
  - Smaller grit sizes

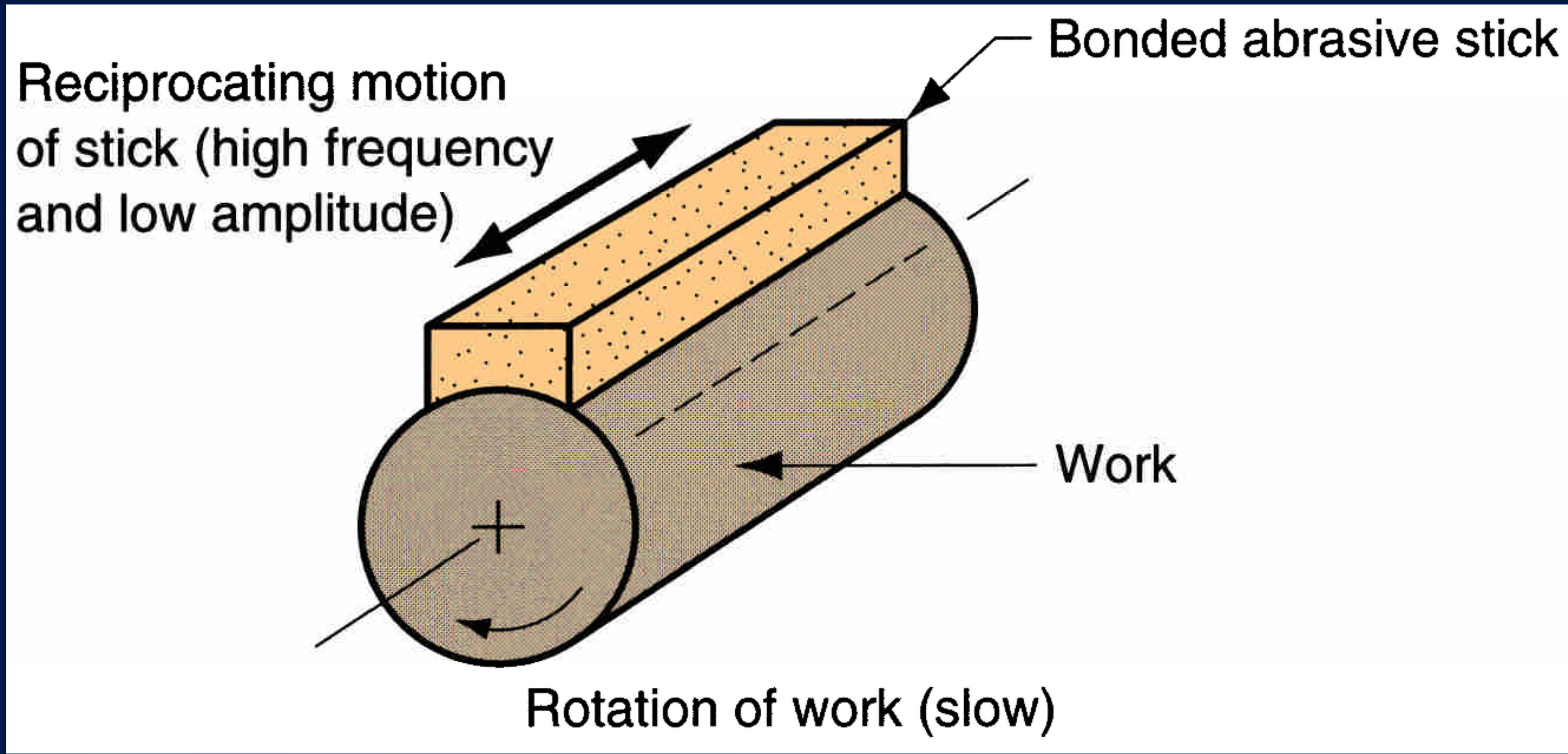

Figure 25.18 - Superfinishing on an external cylindrical surface