Abrasive Machining and Finishing Operations
• There are many situations where Mill & Lathe processes about cannot produce the required dimensional accuracy and/or surface finish.

  – **Fine finishes** on ball/roller bearings, pistons, valves, gears, cams, etc.

  – The best methods for producing such accuracy and finishes involve **abrasive machining**.
Abrasives and Bonded Abrasives

- An abrasive is a small, hard particle having sharp edges and an irregular shape. (grit)
- Abrasives are capable of removing small amounts of material through a cutting process that produces tiny chips.
1. Grinding
2. Related Abrasive Processes
   - (Honing, Lapping, Super-finishing and Polishing & Buffing, Sanding/emory cloth)
Grinding is the most important abrasive machining

- Similar to slab milling: Cutting occurs at either the periphery or the face of the grinding wheel.
- Different than milling: Cutting occurs by the abrasive grains that are much smaller, numerous and random.
- Cutting speeds are higher, generating more heat
- Higher negative rake angles on grit cutting edges
- Self-sharpening as abrasive falls off
Abrasive Grinding

- Can be viewed as multiple very small cutting edges
- Can result in a very fine finish
- Can leave residual stresses on part
- Slow, small material removal rates
- Sparking out to finish
Grinding Operations and Machines

- Surface Grinding
- Cylindrical Grinding
- Internal Grinding
- Centerless Grinding
- Creep-feed Grinding
  - Heavy Stock Removal by Grinding
- Others
  - Tool and cutter grinders, Tool-post grinding
  - Swing-frame grinders, Bench grinders, …
Surface Grinding Machine
• **Surface Grinding** - grinding of flat surfaces
Surface Grinding

- Wheel guard
- Worktable
- Workpiece
- Saddle
- Feed
- Wheel head
- Column
- Bed
Grinding Operations and Machines

- Cylindrical Grinding
  - axially ground
Cylindrical Grinding

 Movements

1. Wheel
2. Work (rotates)
3. Traverse
4. Infeed

A. Grinding wheel
B. Grinding face
C. Wheel spindle
D. Work piece
E. Work centers
F. Face plate
G. Dog
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** - grinding the inside diameter of a part
Internal Grinding

(a) Traverse grinding

Workpiece → Wheel

(b) Plunge grinding

Wheel → Work

(c) Profile grinding
Centerless Grinding
3-Types

Through-feed
In through-feed centerless grinding, the workpiece is fed through the grinding wheels completely, entering on one side and exiting on the opposite.

Through-feed grinding can be very efficient because it does not require a separate feed mechanism; however, it can only be used for parts with a simple cylindrical shape.
Centerless grinding differs from centered grinding operations in that no spindle or fixture is used to locate and secure the workpiece.
• **Centerless Grinding** – continuously ground cylindrical surfaces
• Creep-feed Grinding
  – large rates of grinding for a close to finished piece
Creep Feed Grinding

- High Depths of cut 1000 to 10,000 times greater than normal
- 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

Comparison of (a) conventional surface grinding and (b) creep feed grinding.
Creep-Feed Grinding

Comparison between Conventional and Creep-feed grinding:

- **Conventional grinding**:
  - Short cutting arc: approx. 4.4 mm
  - Fast
  - Cutting fluid jet

- **Creep-feed grinding**:
  - Long cutting arc: approx. 20 mm; chip cavity almost full
  - Slow
  - High volume cutting fluid
  - Diamond coated roll in processs dressing
  - Grinding wheel continually compensates downward to maintain size
• **Heavy Stock Removal** - economical process to remove large amount of material (Creep)

• **Grinding Fluids**
  - Prevent workpiece temperature rise
  - Improves surface finish and dimensional accuracy
  - Reduces wheel wear, loading, and power consumption
Finishing Operations

- Coated abrasives
- Belt Grinding
- Wire Brushing
- Honing
- Superfinishing
- Lapping
- Chemical-Mechanical Polishing
- Electroplating
Finishing Operations

- **Coated Abrasives** – have a more pointed and open structure than grinding wheels

- **Belt Grinding** – high rate of material removal with good surface finish
Finishing Operations

- **Wire Brushing** - produces a fine or controlled texture

- **Honing** – improves surface after boring, drilling, or internal grinding
Finishing Operations

- **Superfinishing** – very light pressure in a different path to the piece

- **Lapping** – abrasive or slurry wears the piece’s ridges down softly
Finishing Operations

- **Chemical-mechanical Polishing** – slurry of abrasive particles and a controlled chemical corrosive
- **Electropolishing** – an unidirectional pattern by removing metal from the surface
Deburring Operations

• Manual Deburring
• Mechanical Deburring
• Vibratory and Barrel Finishing
• Shot Blasting
• Abrasive-Flow Machining
• Thermal Energy Deburring
• Robotic Deburring
Deburring Operations

- **Vibratory and Barrel Finishing** – abrasive pellets are tumbled or vibrated to deburr

- **Abrasive-flow Machining** – a putty of abrasive grains is forced through a piece
Deburring Operations

- **Thermal Energy Deburring** – natural gas and oxygen are ignited to melt the burr.

- **Robotic Deburring** – uses a force-feedback program to control the rate and path of deburring.
The use of abrasives and finishing operations achieve a higher dimensional accuracy than the solitary machining process.

Automation has reduced labor cost and production times.

The greater the surface-finish, the more operations involved, increases the product cost.

Abrasive processes and finishing processes are important to include in the design analysis for pieces requiring a surface finish and dimensional accuracy.

Creep-feed grinding is an economical alternative to other machining operations.
Related Abrasive Processes

- Honing
- Lapping
- Superfinish
  - Grit sizes: 20 to 80, 90-120 and >120)
- Buffing
  - Surface luster

<table>
<thead>
<tr>
<th>Process</th>
<th>Usual Part</th>
<th>Surface Finish (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grinding (Med. Grit)</td>
<td>Flat, ext. Cylinder, holes</td>
<td>0.4-0.6</td>
</tr>
<tr>
<td>Grinding (Fine Grit)</td>
<td>Flat, ext. Cylinder, holes</td>
<td>0.2-0.4</td>
</tr>
<tr>
<td>Honing</td>
<td>Round hole</td>
<td>0.1-0.8</td>
</tr>
<tr>
<td>Lapping</td>
<td>Near flat</td>
<td>0.025-0.4</td>
</tr>
<tr>
<td>Superfinishing</td>
<td>Flat, ext. cylinder</td>
<td>0.013-0.2</td>
</tr>
<tr>
<td>Polishing</td>
<td>Misc. Shape</td>
<td>0.025-0.8</td>
</tr>
<tr>
<td>Buffing</td>
<td>Misc. Shape</td>
<td>0.013-0.4</td>
</tr>
</tbody>
</table>
Commonly used abrasives in abrasive machining are:

- **Conventional Abrasives**
  - Aluminum Oxide
  - Silicon Carbide

- **Super Abrasives**
  - Cubic boron nitride
  - Diamond
Friability

- Characteristic of abrasives.
- Defined as the ability of abrasive grains to fracture into smaller pieces, essential to maintaining sharpness of abrasive during use.
- High friable abrasive grains fragment more under grinding forces, low friable abrasive grains fragment less.
Abrasives commonly found in nature include:

- Emery
- Corundum
- Quartz
- Garnet
- Diamond

Knoop hardness test is a microhardness test – a test for mechanical hardness used particularly for very brittle materials.
• Synthetically created abrasives include:
  – Aluminum oxide (1893)
  – Seeded gel (1987)
  – Silicon carbide (1891)
  – Cubic-boron nitride (1970’s)
  – Synthetic diamond (1955)
When to use the different abrasive types

- **Al₂O₃** – most common, for ferrous and high-strength alloys \( (H_{\text{knoop}} = 2100) \)
- **SiC** – harder but not as tough, for aluminum, brass, stainless steel, cast irons and certain ceramics \( (H_{\text{knoop}} = 2500) \).
- **CBN** – very hard, very expensive, … for harden tool steels and aerospace alloys \( (H_{\text{knoop}} = 5000) \)
- **Diamond** – Harder and even more expensive, natural and synthetic, for hard, abrasive materials such as ceramics, cemented carbides and glass \( (H_{\text{knoop}} = 7000) \)
• Abrasive grits are usually much smaller than the cutting tools in manufacturing processes.

• Size of abrasive grain measured by grit number.
  – Smaller grain size, the larger the grit number.
  – Ex: with sandpaper 10 is very coarse, 100 is fine, and 500 is very fine grain.
De-Coding Abrasive

Standard Grinding Wheel Designation

Manufacturer's symbol indicating exact kind of abrasive (Use optional)
A Aluminium oxide
C Silicon carbide

Prefix  Abrasive type  Abrasive grain size  Structure  Grade  Bond type
51 - A - 36 - L - 5 - V - 23

Manufacturer's record
Manufacturer's private marking to identify wheel (Use optional)
B Resinoid
BF Resinoid reinforced
E Shellac
O Oxychloride
R Rubber
RF Rubber reinforced
S Silicate
V Vitrified

Abrasive grain size
Coarse 8 10 12
Medium 30 36 46
Fine 70 80 90

Grade scale
Soft A B C D E F G H I J K
Medium M N O P Q R S T U V
Hard W X Y Z

Open 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
etc. 16
While this is specific to grinding, realize that there are similar standard designations in most industries.

Take the time to learn the standard designations early so that you can speak intelligibly with those within the industry.
Table 2. Grit size of diamond particles.

<table>
<thead>
<tr>
<th>Grit Size</th>
<th>Microns</th>
<th>Inches</th>
<th>Expected Surface Finish (RA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>267</td>
<td>0.0105</td>
<td>24-36</td>
</tr>
<tr>
<td>150</td>
<td>122</td>
<td>0.0048</td>
<td>14-16</td>
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<tr>
<td>180</td>
<td>86</td>
<td>0.0034</td>
<td>12-14</td>
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<tr>
<td>220</td>
<td>66</td>
<td>0.0026</td>
<td>10-12</td>
</tr>
<tr>
<td>320</td>
<td>32</td>
<td>0.0012</td>
<td>8</td>
</tr>
<tr>
<td>400</td>
<td>23</td>
<td>0.0009</td>
<td>7-8</td>
</tr>
<tr>
<td>600</td>
<td>14</td>
<td>0.0006</td>
<td>2-4</td>
</tr>
<tr>
<td>1,200</td>
<td>3</td>
<td>0.0001</td>
<td>1-2</td>
</tr>
</tbody>
</table>
Good Surface Finish

• Most grinding 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
Grinding Wheels

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

• Large amounts can be removed when many grains act together. This is done by using bonded abrasives.
  – This is typically in the form of a grinding wheel.
  – The abrasive grains in a grinding wheel are held together by a bonding material.
• Bonding materials act as supporting posts or braces between grains.
• Bonding abrasives are marked with letters and numbers indicating:
  – Type of abrasive
  – Grain size
  – Grade
  – Structure
  – Bond type
• Vitrified: a glass bond, most commonly used bonding material.
  – However, it is a brittle bond.
• Resinoid: bond consisting of thermosetting resins, bond is an organic compound.
  – More flexible bond than vitrified, also more resistant to higher temps.
• Reinforced Wheels: bond consisting of one or more layers of fiberglass.
  – Prevents breakage rather than improving strength.
• Rubber: flexible bond type, inexpensive.
• Metal: different metals can be used for strength, ductility, etc.
  – Most expensive bond type.
Grinding is a chip removal process that uses an individual abrasive grain as the cutting tool.

The differences between grinding and a single point cutting tool are:

- The abrasive grains have irregular shapes and are spaced randomly along the periphery of the wheel.
- The average rake angle of the grain is typically -60 degrees. Consequently, grinding chips undergo much larger plastic deformation than they do in other machining processes.
- Not all grains are active on the wheel.
- Surface speeds involving grinding are very fast.
3 types of action

- Cutting, rubbing and plowing actions occur
Grinding Process
Grinding Forces

A knowledge of grinding forces is essential for:

- Estimating power requirements.
- Designing grinding machines and work-holding fixtures and devices.
- Determining the deflections that the work-piece as well as the grinding machine may undergo. Deflections adversely affect dimensioning.
Grinding Forces

• Forces in grinding are usually smaller than those in machining operations because of the smaller cutting dimensions involved.
• Low grinding forces are recommended for dimensional accuracy.
Problems with Grinding

- Wear Flat
  - After some use, grains along the periphery of the wheel develop a wear flat.
- Wear flats rub along the ground surface, creating friction, and making grinding very inefficient.
Problems with Grinding

• **Sparks**
  - Sparks produced from grinding are actually glowing hot chips.

• **Tempering**
  - Excessive heat, often times from friction, can soften the work-piece.

• **Burning**
  - Excessive heat may burn the surface being ground. Characterized as a bluish color on ground steel surfaces. Coolant needed.
Problems with Grinding

• Heat Checking
  – High temps in grinding may cause cracks in the work-piece, usually perpendicular to the grinding surface.

• Loading
  – Work-piece material either adhere to the grits or become embedded in the spaces between abrasive grains on grinding wheels

• Glazing
  – Worn cutting edges of grits, wheel becomes smoother
Grinding wheel operating conditions

- Normal
- Shedding
- Loading
- Glazing

[Diagrams showing different conditions of the grinding wheel]
Grain Fracture

- Abrasive grains are brittle, and their fracture characteristics are important.
- Wear flat creates unwanted high temps.
- Ideally, the grain should fracture at a moderate rate so as to create new sharp cutting edges continuously.
• The strength of the abrasive (grit) bond is very important!
• If the bond is too strong, dull grains cannot dislodge to make way for new sharp grains.
  – Hard grade bonds are meant for soft materials.
• If too weak, grains dislodge too easily and the wear of the wheel increases greatly.
  – Soft grade bonds are meant for hard materials.
Grinding Ratio

- \( G = \frac{\text{Volume of material removed}}{\text{Volume of wheel wear}} \)
- The higher the ratio, the longer the wheel will last.
- During grinding, the wheel may act “soft” or hard” regardless of wheel grade.
  - Ex: pencil acting hard on soft paper and soft on rough paper.
Cutting Fluids

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

- Abrasive particle
- Open cavity (void)
- Binder forming bond post
- Cavity full of chips
- Partly filled cavity
Truing and Dressing

Grinding wheels lose geometry during use and need truing.

Single point diamond dressing tool

Infeed for dressing tool about .001 inch per pass.

Grinding wheel

Dressing stick pushed into at constant constant inf

15° drag angle
“Dressing” a wheel is the process of:
- Conditioning worn grains by producing sharp new edges.
- Truing, which is producing a true circle on the wheel that has become out of round.

Grinding wheels can also be shaped to the form of the piece you are grinding.

These are important because they affect the grinding forces and surface finish.
• Chips ground by grinding are fine, but similar to chips ground by turning tool and milling cutter.

• The chip is divided into five types.
Chips are divided into 5 types

1. Flowing chip
   - Ribbon shape chip occurs when grinding wheel sharpness is good.

2. Sheared chip
   - This chip occurs when grinding wheel sharpness is good on brittle materials.
Chips are divided into 5 types

3. Peeling chip
   – Powder chip occurs when grinding wheel sharpness becomes dull.

4. Built-up edge chip
   – Chips adhered on grinding wheel face,
   – Chips of texture same as built-up edge.

5. Melted chips
   – These chips are spherical or semi-spherical
   – Melting when powder chips are scattered by over-heat.
   This is mostly found when ground by loaded or glazed grinding wheel.
Design Consideration for Grinding

- Part design should include secure mounting into workholding devices.
- Holes and keyways may cause vibration and chatter, reducing dimensional accuracy.
- Cylindrically ground pieces should be balanced. Fillets and radii made as large as possible, or relieved by prior machining.
Design Considerations for Grinding

- Long pieces are given better support in centerless grinding, and only the largest diameter may be ground in through-feed grinding.
- Avoid frequent wheel dressing by keeping the piece simple.
- A relief should be included in small and blind holes needing internal grinding.