Abraasive 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 by conventional machining
- Grinding is most important abrasive process
- 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
- 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$_2$O$_3$) - most common abrasive
  - Used to grind steel and other ferrous high-strength alloys
- Silicon carbide (SiC) - harder than Al$_2$O$_3$ 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
- 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

<table>
<thead>
<tr>
<th>Abrasive material</th>
<th>Knoop hardness</th>
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<tbody>
<tr>
<td>Aluminum oxide</td>
<td>2100</td>
</tr>
<tr>
<td>Silicon carbide</td>
<td>2500</td>
</tr>
<tr>
<td>Cubic boron nitride</td>
<td>5000</td>
</tr>
<tr>
<td>Diamond (synthetic)</td>
<td>7000</td>
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</tbody>
</table>
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 to expose new sharp grains
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
Surface Finish

Let us examine the dimensions of an individual chip. From the geometry of the grinding process in Figure 25.3, it can be shown that the average length of a chip is given by

\[ l_c = \sqrt{Dd} \]

where \( l_c \) is the length of the chip, mm (in); \( D = \) wheel diameter, mm (in); and \( d = \) depth of cut, or infeed, mm (in). This assumes the chip is formed by a grit that acts throughout the entire sweep arc shown in the diagram. Figure 25.3(c) shows the assumed cross section of a chip in grinding. The cross sectional shape is triangular with width \( w' \) being greater than the thickness \( t \) by a factor called the grain aspect ratio \( r_g \) defined by

\[ r_g = \frac{w'}{t} \]

Typical values of grain aspect ratio are between 10 and 20.
Surface Finish

The number of active grits (cutting teeth) per square inch on the outside periphery of the grinding wheel is denoted by $C$, whose value is normally inversely proportional to grit size. $C$ is also related to the wheel structure. A denser structure means more grits per area. Based on the value of $C$, the number of chips formed per time $n_c$ is given by

$$n_c = vwC$$

where $v =$ wheel speed, mm/min (in/min); $w =$ crossfeed, mm (in); and $C =$ grits per area on the grinding wheel surface, grits/mm$^2$ (grits/in$^2$). It stands to reason that surface finish will be improved by increasing the number of chips formed per unit time on the work surface for a given width $w$. Therefore, increasing $v$ and/or $C$ will improve finish. Recall that smaller grain sizes give larger $C$ values.
Forces and Energy

- If the force required to drive the work past the grinding wheel were known, the specific energy in grinding could be determined as

\[
U = \frac{F_c v}{v_w w d}
\]

where \(U\) = specific energy, J/mm\(^3\) (in-lb/in\(^3\)); \(F_c\) = cutting force, which is the force to drive the work past the wheel, N (lb); \(v\) = wheel speed, m/min (ft/min); \(v_w\) = work speed, mm/min (in/min); \(w\) = width of cut, mm (in); and \(d\) = depth of cut, mm (in).
Forces and Energy

- Using the specific energy relationship and assuming that the cutting force acting on a single grain in the grinding wheel is proportional to $r_g t$ then:

$$ F'_c = K_1 \left( \frac{r_g v_w}{v C} \right)^{0.5} \left( \frac{d}{D} \right)^{0.25} $$

where $F'_c$ is the cutting force acting on an individual grain, $K_1$ is a constant of proportionality that depends on the strength of the material being cut and the sharpness of the individual grain.
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

- 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

- For steel and most cast irons, use
  - Aluminum oxide as the abrasive
- For most nonferrous metals, use
  - Silicon carbide as the abrasive
- For hardened tool steels and certain aerospace alloys, use
  - Cubic boron nitride as the abrasive
- For hard abrasive materials (e.g., ceramics, cemented carbides, and glass) use
  - Diamond as the abrasive
Application Guidelines

- For soft metals, use
  - Large grit size and harder grade wheel
- For hard metals, use
  - Small grit size and softer grade wheel
Four Types of Surface Grinding

Figure 25.7 (a) horizontal spindle with reciprocating worktable, (b) horizontal spindle with rotating worktable, (c) vertical spindle with reciprocating worktable, (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.
Figure 25.11  External centerless grinding.
What is Centerless Grinding

Centerless grinding is an alternative process for grinding external and internal cylindrical surfaces. As its name suggests, the workpiece is not held between centers. This results in a reduction in work handling time; hence, centerless grinding is often used for high-production work. The setup for external centerless grinding consists of two wheels; the grinding wheel and a regulating wheel. The workparts, which may be many individual short pieces or long rods (e.g., 3-4m long), are supported by a rest blade and fed through between the two wheels. The grinding wheel does the cutting, rotating at surface speeds of 1200-1800 m/min (4000-6000 ft/min). The regulating wheel rotates at much lower speeds and is inclined at a slight angle $I$ to control through-feed of the work. The following equation can be used to predict through-feed rate, based on inclination angle and other parameters of the process [16]:

$$f_r = \pi D_r N_r \sin I$$

(25.11)

where $f_r =$ through-feed rate, mm/min (in/min); $D_r =$diameter of the regulating wheel mm (in); $N_r =$ rotational speed of the regulating wheel, rev/min; and $I =$ inclination angle of the regulating wheel.
Figure 25.12 Internal 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
Other Abrasive Processes

- Honing
- Lapping
- Superfinishing
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 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.