GRINDING AND OTHER ABRASIVE PROCESSES

1. Grinding
2. Related Abrasive Processes (Honing, Lapping, Super-finishing and Polishing & Buffing)

Abrasive Machining
- Material removal by the action of hard, abrasive particles usually in a form of a bonded wheel.
- 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,
  - Higher negative rake angle,
  - Self-sharpening as each abrasive falls off
- Other abrasive processes: honing, lapping, superfinishing, polishing, and buffing.
- Can be used on all types of materials.
- Generally a finishing operation achieving the surface finish of up to 0.025µm and extremely close tolerance.

Grinding wheel
- Consists of abrasive material and bonding material,
  - Abrasive particles accomplish cutting
  - Bonding material holds particles in place and establishes shape and structure of wheel.
- Parameters
  - Abrasive materials
  - Grain size
  - Bonding material
  - Wheel grade
  - Wheel structure

Abrasive Materials
- Properties
  - High hardness, Wear resistance, Toughness
  - Friability - Capacity to fracture when cutting edge dulls, so a new sharp edge is exposed.
- Materials
  - Al₂O₃ – most common, for ferrous and high-strength alloys (Hknoop=2100)
  - SiC – harder but not as tough, for aluminum, brass, stainless steel, cast irons and certain ceramics (Hknoop=2500).
  - cBN – very hard, very expensive, ex.: Borazon by GE, for harden tool steels and aerospace alloys (Hknoop=5000)
  - Diamond – Harder and more expensive, natural and synthetic, for hard, abrasive materials such as ceramics, cemented carbides and glass (Hknoop=7000)

Grinding wheel
- Grain size: Grit size between 8 (coarse for harder materials) and 250 (fine for softer materials) based on a screen mesh procedure.
  - 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

Bonding materials
- Requirements
  - Must withstand centrifugal forces and high temperatures
  - Must resist shattering during shock loading of wheel
  - Must hold abrasive grains rigidly
- Type of Bonding Materials
  - Vitrified bond – baked clay and ceramic materials
  - Silicate bond – sodium silicate (low temp.)
  - Rubber bond
  - Resinoid bond – thermosetting resin materials
  - Shellac bond – strong but not rigid
  - Metallic bond – usually bronze
Wheel Structure & Grade

- Proportion of abrasive grain, bond material and pores: \( P_g + P_b + P_p = 1 \)
- Wheel Structure: measures on a scale that ranges between "open" and "dense":
  - the relative spacing of the abrasive grains
  - Open structure: \( P_p \gg P_g \), for chips clearance.
  - Dense structure: \( P_p \ll P_g \) for better surface finish and dimensional control
- Wheel Grade - Bond strength (amount of bonding material in wheel structure (\( P_b \))
  - A scale ranging between soft and hard
  - Soft wheels lose grains readily - for low material removal rates and hard work materials
  - Hard wheels retain grains - for high material 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
    - 30: Grit Size
    - A: Abrasive Type: Al₂O₃, C: SiC
    - 46: Grade: Scale from A (soft) to Z (hard)
    - H: Bond Type: B, BF, E, R, RF, S and V
    - 6: Manufacturer’s symbol for abrasive material
    - V: Manufacturer’s Private marking

Grinding wheel shapes

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

Analysis of Grinding Process

- The peripheral speed: \( v = \pi DN \)
- Infeed: Depth of cut, \( d \)
- Crossfeed: \( w \)

\[ MRR = v_c \cdot w_d \]

- Surface Finish
  - Better finish than machining

\[ l = \sqrt{D \cdot d} \]

The grain aspect ratio (10~20)

\[ r_p = \frac{w touched}{l} \]

Number of chips formed per time

\[ n_i = \pi \cdot C \]

Where \( C = \) grits per area

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
- 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 with extremely negative rake angles result in low shear plane angles & high shear strains
  - Not all grits are engaged in actual cutting

Analysis of Grinding Process

- Force
  - Cutting force on a single grain:
    \[ F_c = k \left( \frac{D}{D_g} \right)^{3/2} \left( \frac{d}{D_g} \right)^{1/2} \]

- Specific Energy:
  - \( U = \frac{F_c}{v_c \cdot w_d} \)
    - \( U > \) machining
      - The size effect
      - Extremely negative rake angles
      - Part of grits is engaged in cutting
      - Cutting, plowing and rubbing
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

Work Surface Temperatures

- Grinding causes high temperatures and friction, and most energy remains in the ground surface (high work surface temperatures)
  - Surface burns and cracks
  - Metallurgical damage immediately beneath the surface
  - Softening of the work surface if heat treated
  - Residual stresses in the work surface
- To Reduce the work surface temperature
  - Decrease infed (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

Analysis of Grinding Process

- Wheel wear
  - Grain fracture - a portion of the grain breaks off and the rest remains bonded in the wheel
  - Tendency to fracture - friability
  - Attrition wear – dulling individual grains
  - Analogous to tool wear and similar mechanisms
  - Bond fracture - the individual grains are pulled

Grinding Applications

- To optimize surface finish, smaller grit size and dense wheel, higher wheel speed and lower work speed, smaller depth of cut and large wheel diameter.
- To max. MRR, select large grit size, more open wheel structure and vitrified bond
- For steels and cast iron, alumina wheel
- For non-ferrous metals, SiC wheel
- For harden materials and aerospace alloys, CBN wheel
- For soft metal, large grit size and harder grade
- For harder metal, small grit size and softer grade
- To min. heat damage, smaller \( d \), lower \( v \) and faster \( v_w \)
- To avoid burn, softer grade and more open structure
- To avoid break down, harder grade & more dense structure
Grinding operations
Cylindrical – (a) External and (b) Internal
(c) Centerless – External and Internal

Creep Feed Grinding
- Depths of cut 1000 to 10,000 times greater
- 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

Related Abrasive Processes
- Honing
- Lapping
- Superfinish
- Polishing
  - 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>0.1-0.6</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>
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</tbody>
</table>

Honing
Abrasive process by a set of bonded abrasive sticks using a combination of rotational & oscillatory motions
- Commonly used to finish the bores of internal combustion engines
- Speed between 50 to 500 ft/min, Pressure of 150 to 450 lb/in² and Grit sizes between 30 and 600
- Surface finishes of 0.12 µm (5 µ-in) or better
- Creates a characteristic cross-hatched surface that retains lubrication

Lapping
Surface finish of extreme accuracy and smoothness
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

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
  - Lower work speed
  - Smaller grit sizes