GRINDING AND OTHER ABRASIVE PROCESSES

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

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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.

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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

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Abrasive Materials

- Properties
  – High hardness, Wear resistance, Toughness
  – Friability - Capacity to fracture when cutting edge dulls, so a new sharp edge is exposed.
- Materials
  – Al_2O_3 – most common, for ferrous and high-strength alloys (H_{knoop}=2100)
  – SiC – harder but not as tough, for aluminum, brass, stainless steel, cast irons and certain ceramics (H_{knoop}=2500).
  – cBN – very hard, very expensive, ex.: Borazon by GE, for harden tool steels and aerospace alloys (H_{knoop}=5000)
  – Diamond – Harder and more expensive, natural and synthetic, for hard, abrasive materials such as ceramics, cemented carbides and glass (H_{knoop}=7000)

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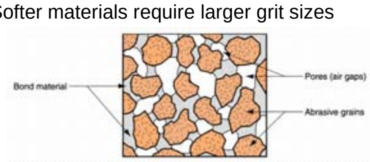
Grinding wheel

- 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



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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

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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: $P_p >> P_g$, for chips clearance.
  - Dense structure: $P_p << P_g$ 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

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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 A 46 H 6 V XX

Manufacturer's Private marking
Bond Type: B, BF, E, R, RF, S and V
Structure: Scale from 1 to 15
Grade: Scale from A (soft) to Z (hard)
Grit Size
Abrasive Type: A=Al_2O_3, C=SiC
Manufacturer's symbol for abrasive

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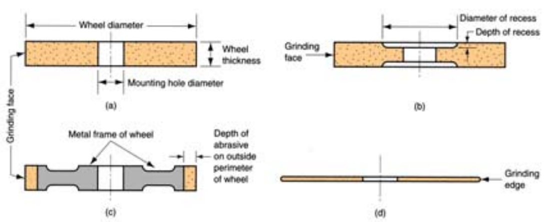
Grinding wheel shapes



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

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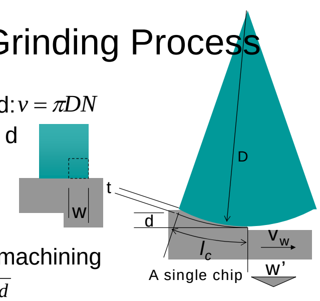
Analysis of Grinding Process

- The peripheral speed: $v = \pi DN$
- Infeed: Depth of cut, d
- Crossfeed: w
  $MRR = v_w wd$
- Surface Finish
  - Better finish than machining



Chip length $l_c = \sqrt{Dd}$

The grain aspect Ratio (10~20) $r_g = \frac{w'}{t}$

Number of chips Formed per time $n_c = vwC$ C = grits per area

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Analysis of Grinding Process

- Force
  - Cutting force on a single grain:

$$F_c' = K_1\left(\frac{r_g v_w}{vC}\right)^{0.5}\left(\frac{d}{D}\right)^{0.25}$$

- Specific Energy: $U = \frac{F_c v}{v_w wd}$
  - U is greater than machining
    - The size effect
    - Extremely negative rake angles
    - Part of grits is engaged in cutting
    - Cutting, plowing and rubbing

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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

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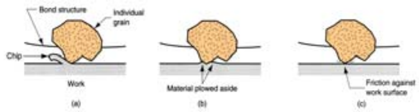
Three Types of Grain Action

- *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



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Analysis of Grinding Process

- Temperature at the work surface
  - High temperature and friction
  - Most of the energy remains on the surface – (1) surface burn and cracks (2) softening of the work surface and (3) residual stress

$$T_s = K_2 d^{0.75} \left(\frac{r_g C v}{v_w} \right)^{0.5} D^{0.25}$$

  - Dull and a hard grade wheel – thermal problems
  - Cutting fluids – lower temperature by reducing friction and dissipating heat
    - Grinding oils and emulsified oils

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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 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

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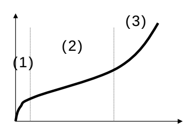
Analysis of Grinding Process

- 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



(1) Grain fracture
(2) Attrition wear
(3) Grain become dull

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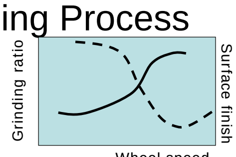
Analysis of Grinding Process

- Grinding ratio

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



where V_w = volume of work material removed; and V_g = corresponding volume of grinding wheel worn
  - 5 order of magnitude smaller than conventional machining
- Dressing – 'resharpening' after the 3rd stage of wear
  - Breaks off dulled grits to expose new sharp grains
  - Removes chips clogged in the wheel
- Truing – Not only sharpens wheel, but restore its cylindrical shape

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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

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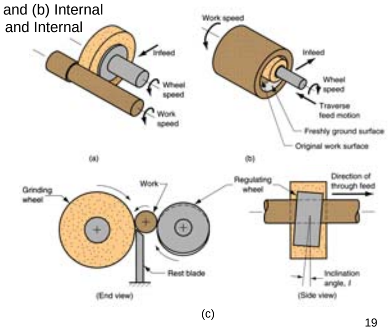
Grinding operations

Cylindrical – (a) External and (b) Internal
(c) Centerless – External and Internal



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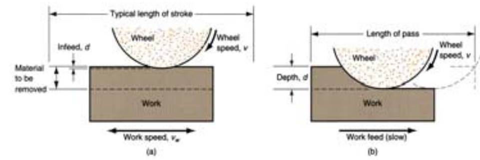
Creep Feed Grinding

- 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



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Related Abrasive Processes

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

Process	Usual Part	Surface Finish (μm)
Grinding (Med. Grit)	Flat, ext. Cylinder, holes	0.4-0.6
Grinding (Fine Grit)	Flat, ext. Cylinder, holes	0.2-0.4
Honing	Round hole	0.1-0.8
Lapping	Near flat	0.025-0.4
Superfinishing	Flat, ext. cylinder	0.013-0.2
Polishing	Misc. Shape	0.025-0.8
Buffing	Misc. Shape	0.013-0.4

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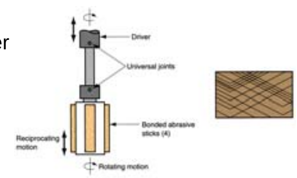
Honing

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/in^2 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



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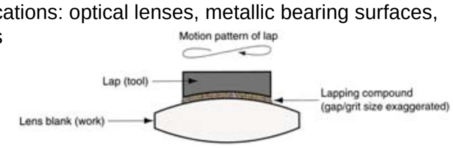
Lapping

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



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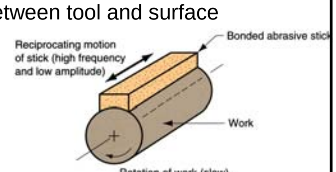
Superfinishing

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



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