Abrasive Machining Processes

N. Sinha, Mechanical Engineering
Department, IIT Kanpur

Introduction

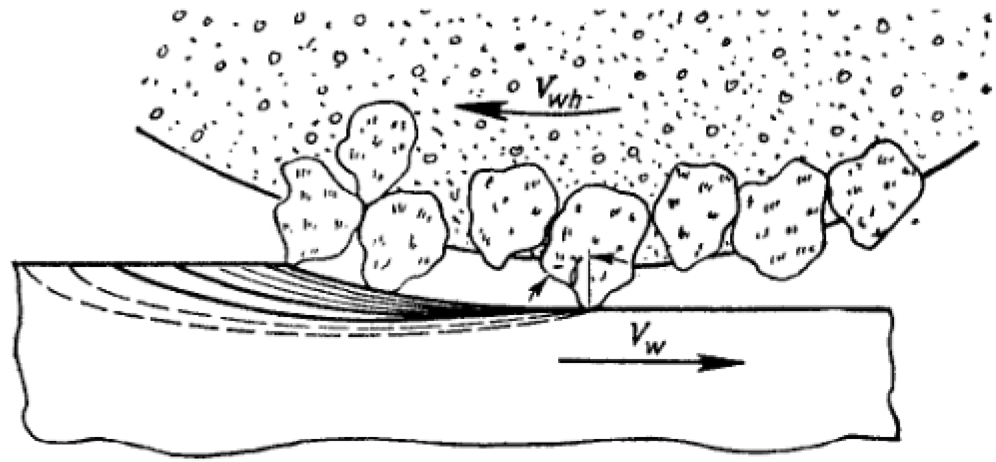
- Abrasive machining involves material removal by the action of hard, abrasive particles.
- The use of abrasives to shape parts is probably the oldest material removal process.

They are important because

- They can be used on all types of materials ranging from soft metals to hardened steels and hard nonmetallic materials such as ceramics and silicon.
- Extremely fine surface finishes (0.025 μm).
- For certain abrasive processes, dimensions can be held to extremely close tolerances.

Types of Abrasive Machining Processes

- ✓ Grinding
- ✓ Honing
- ✓ Lapping
- ✓ Superfinishing
- ✓ Polishing
- ✓ Buffing
- ✓ Abrasive water jet machining
- ✓ Ultrasonic machining



Difference between grinding and milling

- The abrasive grains in the wheel are much smaller and more numerous than the teeth on a milling cutter.

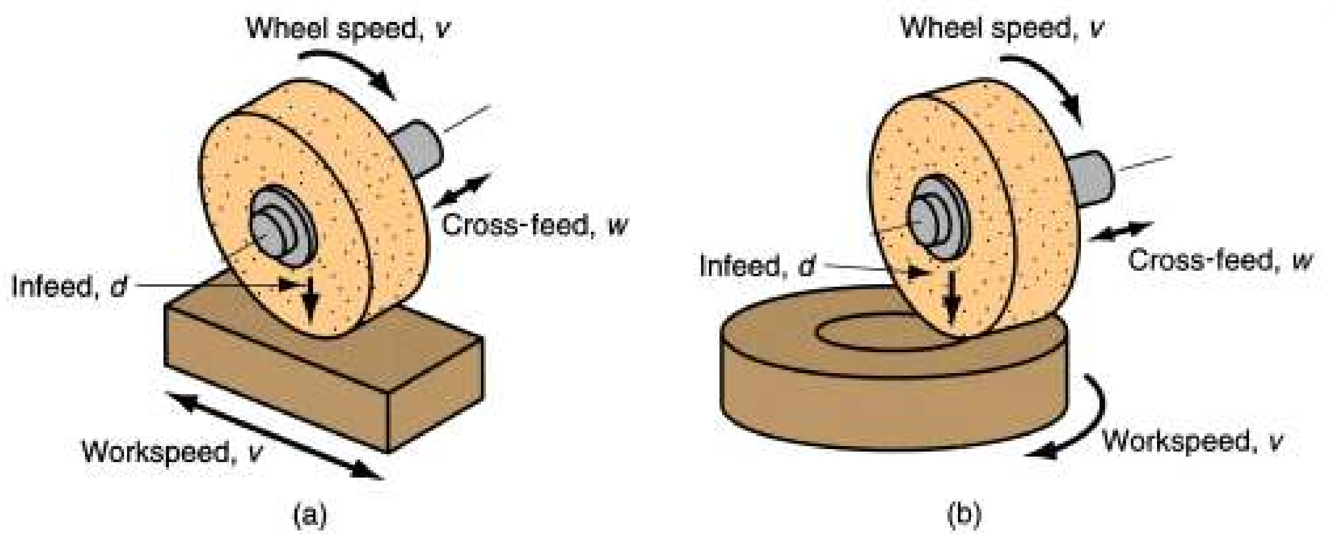
- Cutting speeds in grinding are much higher than in milling.

- The abrasive grits in a grinding wheel are randomly oriented.

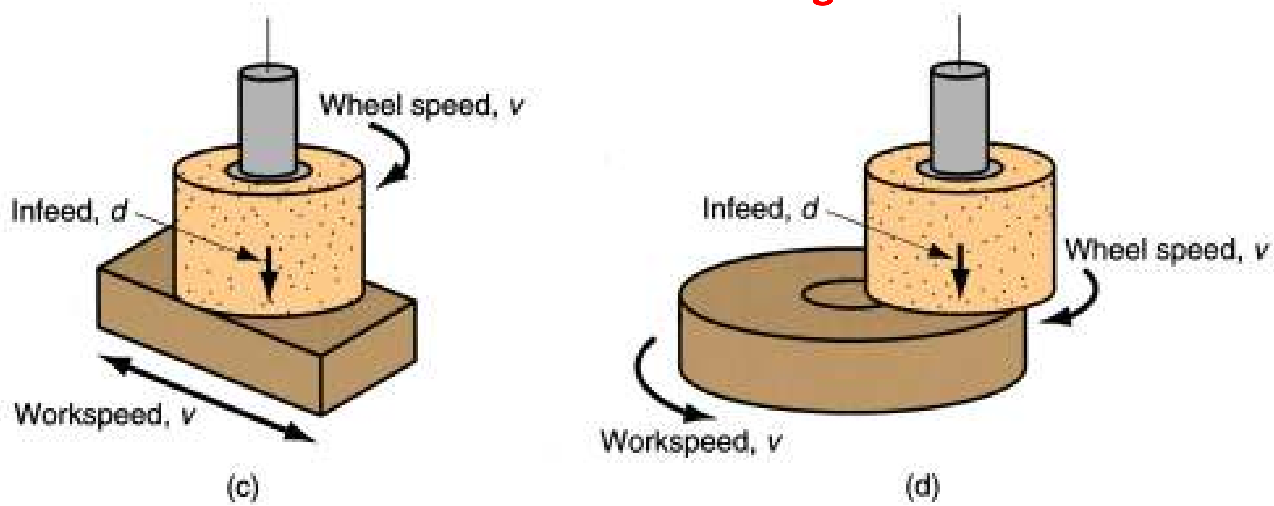
- A grinding wheel is **self-sharpening**.

  Particles on becoming dull either fracture to create new cutting edges or are pulled out of the surface of the wheel to expose new grains.

Surface Grinding

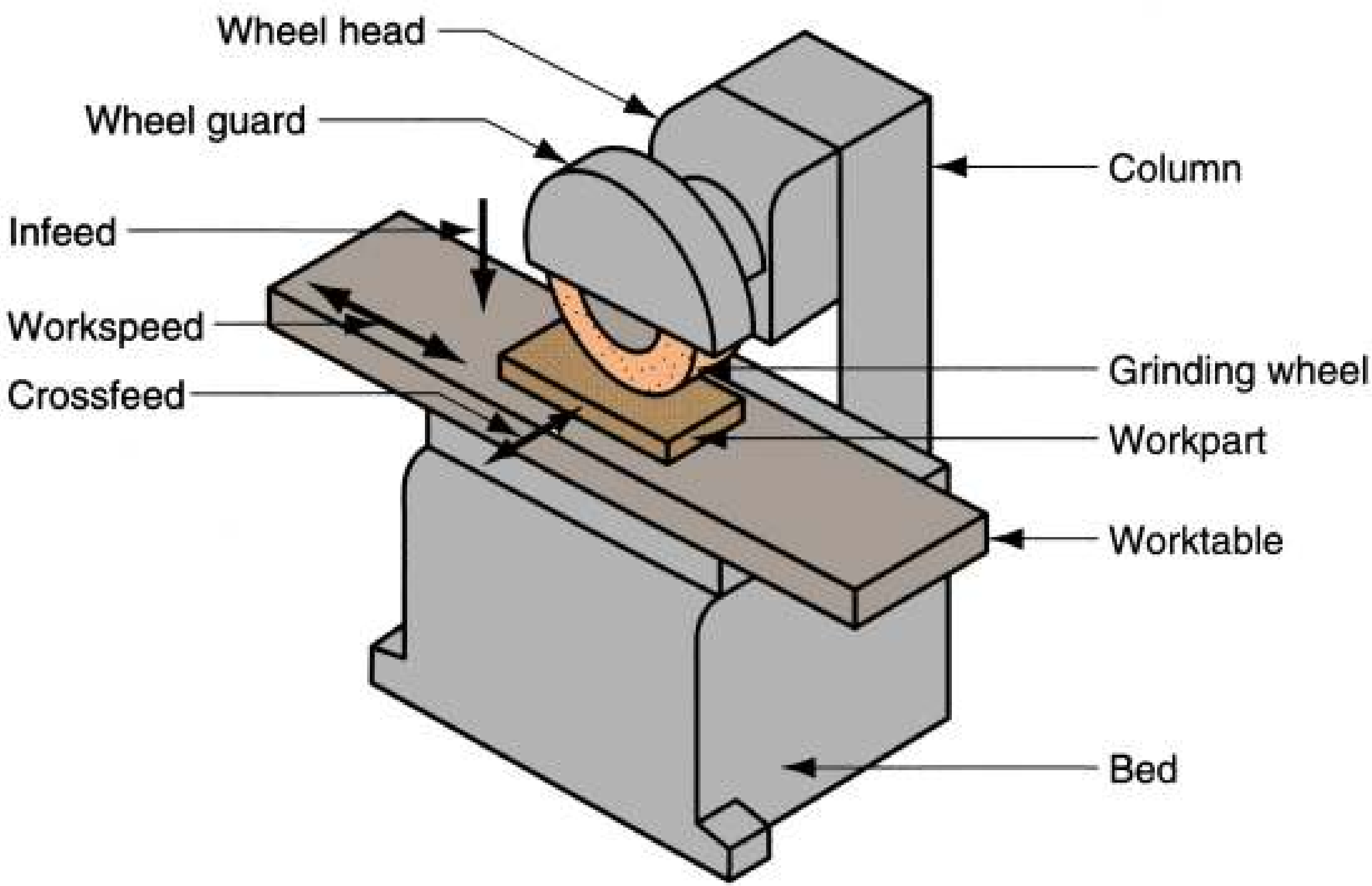


Horizontal Surface Grinding



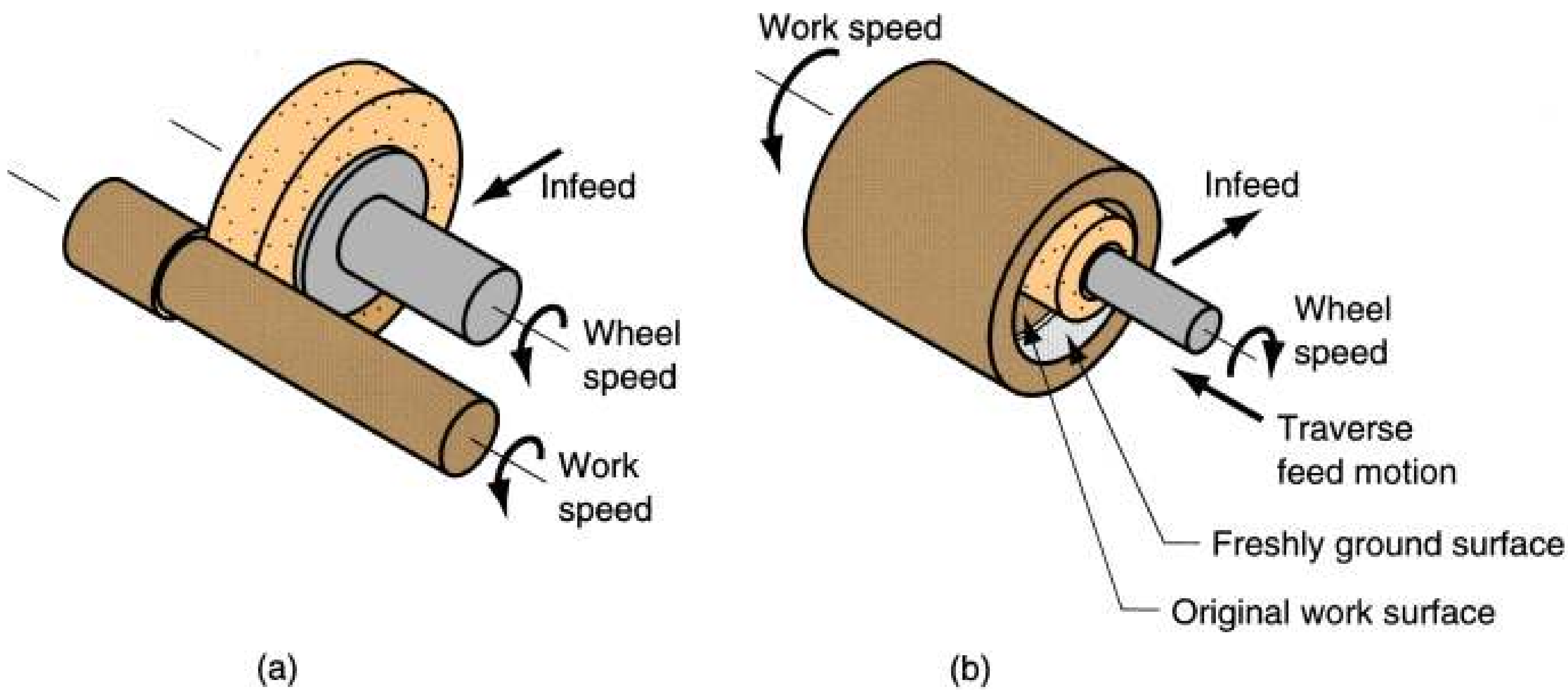
Vertical Surface Grinding

Surface Grinding



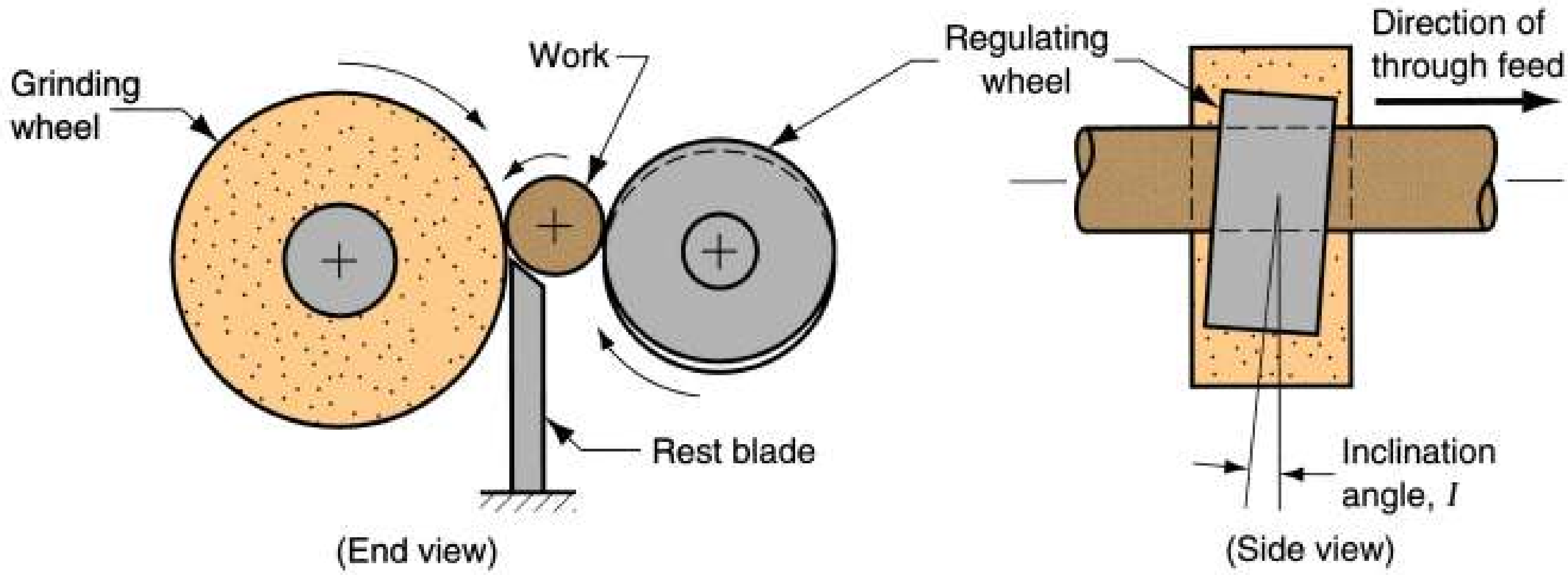
Horizontal Grinding Machine

Cylindrical Grinding



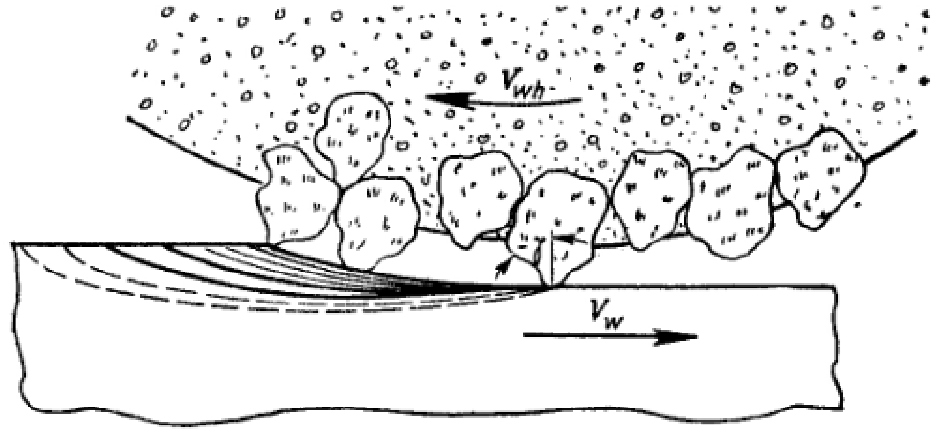
Two types of cylindrical grinding:
(a) external, and (b) internal

External Centerless Grinding



Grinding Wheel and Workpiece Interaction

- ➢Grit-workpiece (forming chip)
- ➢Chip-bond
- ➢Chip-workpiece
- ➢Bond-workpiece



✓ Except the grit-workpiece interaction, which is expected to produce chip, the remaining three undesirably increase the total grinding force and power requirement.

✓ Therefore, efforts should always be made to maximize grit-workpiece interaction leading to chip formation and to minimize the rest for best utilization of the available power.

Grinding Wheel Parameters

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

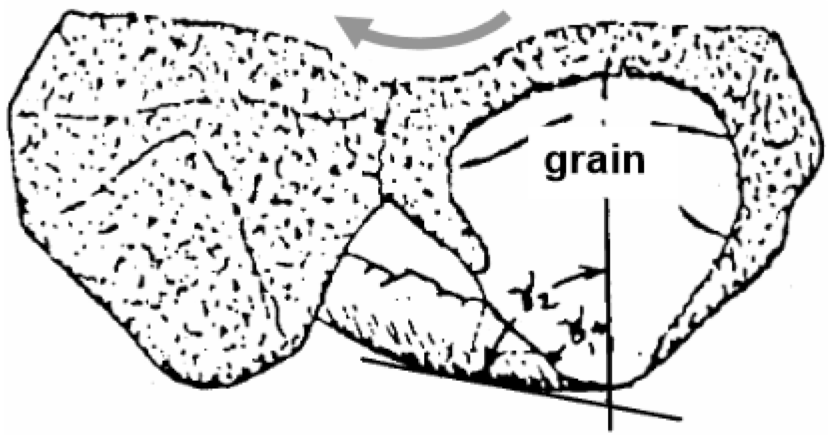
Abrasive Materials

General Properties

Hardness, wear resistance, toughness, friability

Abrasive	Description	Knoop Hardness
Aluminum oxide (Al_2O_3)	Most common abrasive material (Section 7.3.1), used to grind steel and other ferrous, high-strength alloys.	2100
Silicon carbide (SiC)	Harder than Al_2O_3, but not as tough (Section 7.2). Applications include ductile metals such as aluminum, brass, and stainless steel, as well as brittle materials such as some cast irons and certain ceramics. Cannot be used effectively for grinding steel because of the strong chemical affinity between the carbon in SiC and the iron in steel.	2500
Cubic boron nitride (cBN)	When used as an abrasive, cBN (Section 7.3.3) is produced under the trade name Borazon by the General Electric Company. cBN grinding wheels are used for hard materials such as hardened tool steels and aerospace alloys.	5000
Diamond	Diamond abrasives occur naturally and are also made synthetically (Section 7.5.1). Diamond wheels are generally used in grinding applications on hard, abrasive materials such as ceramics, cemented carbides, and glass.	7000

Effective grit geometry due to material loading at tip



- Grit geometry may undergo substantial change due to mechanical or chemical attrition leading to rounding or flattening of the sharp cutting points.
- This happens when the work material has hard or abrasive constituent.
- A chip material adhered to the tip of the grit because of some chemical affinity can also change the effective rake angle of the grit leading to high grinding force, temperature and poor performance of the grinding wheel.

SiC and Ferrous Materials

- SiC abrasives are harder than friable Al_2O_3 but they are usually inferior for grinding most ferrous materials.

- This is due to the dissociation of SiC to react with and adhere to iron at elevated temperatures. (Affinity of silicon or carbon for the workpiece)

- Therefore, SiC tends to work better than Al_2O_3 on some ferrous metals with excess carbon.

- Superiority of SiC on some cast irons is due to the presence of small amounts of SiC as a normal constituent in the iron, which would have a more drastic effect on the wear of the softer Al_2O_3.

Grain Size

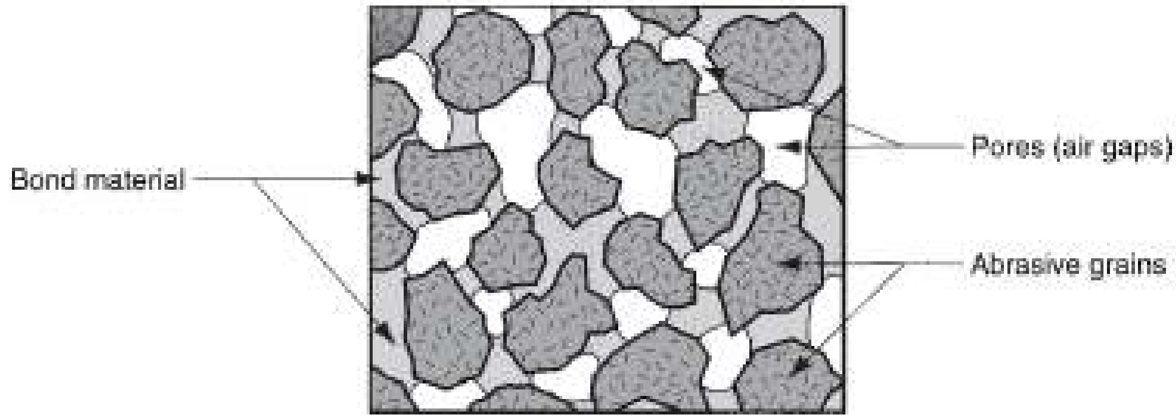
- Grain size is expressed in terms of a SIEVE NUMBER, S_n which corresponds to the number of openings per linear inch.
- The diameter of an abrasive grain is given by $D_g = \frac{0.6}{S_n}$
- The larger the size of grains, more will be material removal, but surface finish will be worse.

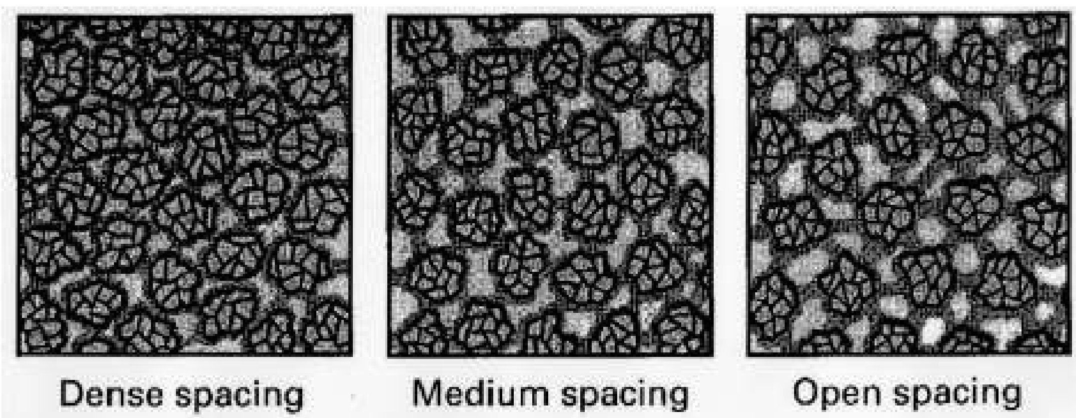
Sieve No.	Type of Grain
10-24	Coarse
30-60	Medium
70-180	Fine
220-600	Very Fine

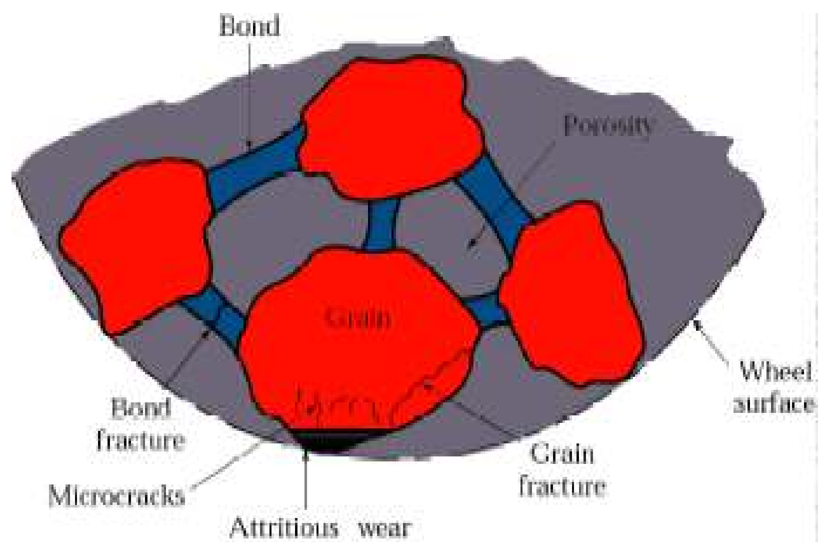
Grinding Wheel Structure

"Open" and "dense"

In what conditions these structures be provided?







Wheel Grade

Indicates the strength of the binding material.

When the work material is hard, the grains wear out easily and the sharpness of the cutting edges is quickly lost. This is known as WHEEL GLAZING.

To avoid this problem, a soft wheel should be used.

- **A-H – Soft Wheel**
- **J-P – Medium Wheel**
- **Q-Z – Hard Wheel**

Bonding Materials

- 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

Vitrified Bond (V) – Strong and Rigid, commonly used.

Resinoid (B) – Provides shock absorption and elasticity. They are strong enough.

Silicate (S) – Provides softness (grains dislodge quickly)

Shellac (E) – Used for making thin but strong wheels possessing some elasticity.

Rubber Bonds (R) – For making flexible wheels.

Metallic Bond (M) – For diamond wheels only.

Bonding Materials

Vitrified Bond (V) – Strong and Rigid, commonly used.

Resinoid (B) – Provides shock absorption and elasticity. They are strong enough.

Silicate (S) – Provides softness (grains dislodge quickly)

Shellac (E) – Used for making thin but strong wheels possessing some elasticity.

Rubber Bonds (R) – For making flexible wheels.

Metallic Bond (M) – For diamond wheels only.

Grinding Wheel Specification

30 A 46 H 6 V XX

Manufacturer's private marking for wheel (optional).

Bond type**:** B = Resinoid, BF = resinoid reinforced, E = Shellac, R = Rubber, RF = rubber reinforced, S = Silicate, V = Vitrified.

Structure**:** Scale ranges from 1 to 15: 1 = very dense structure, 15 = very open structure.

Grade**:** Scale ranges from A to Z: A = soft, M = medium, Z = hard.

Grain size**:** Coarse = grit sizes 8 to 24, Medium = grit sizes 30 to 60, Fine = grit sizes 70 to 180, Very fine = grit sizes 220 to 600.

Abrasive type**:** A = aluminum oxide, C = silicon carbide.

Prefix**:** Manufacturer's symbol for abrasive (optional).

Grinding Chips

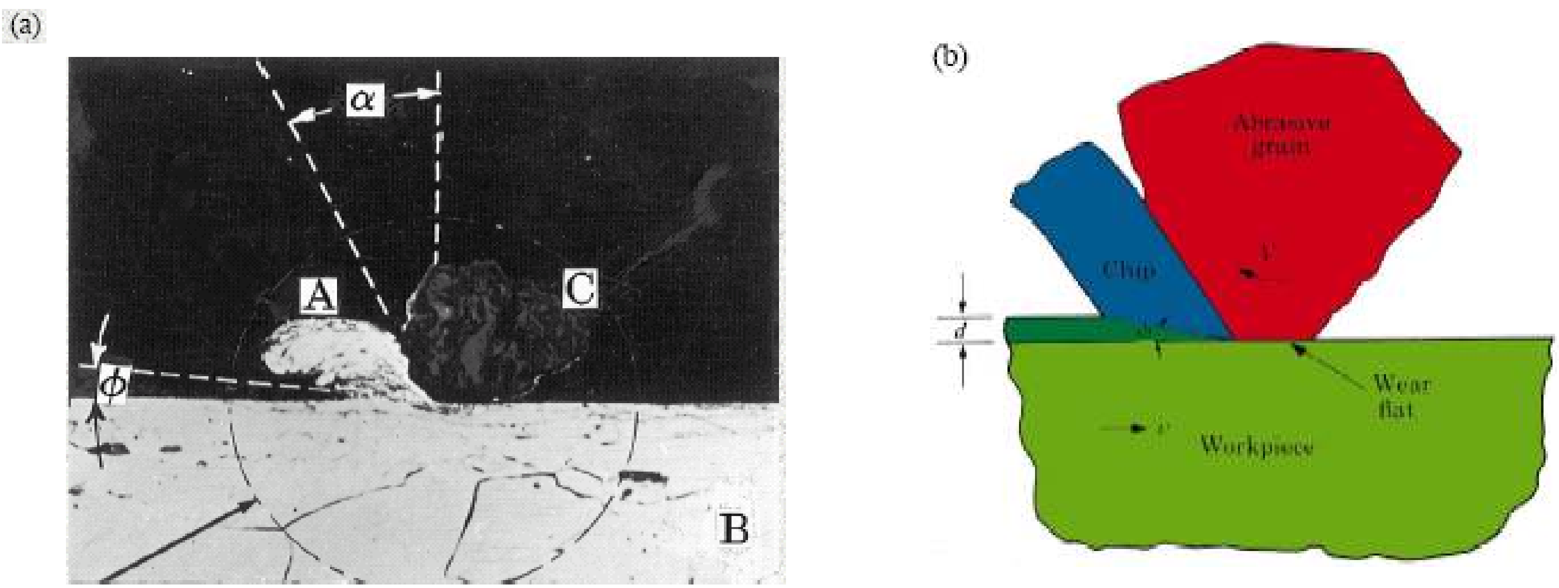
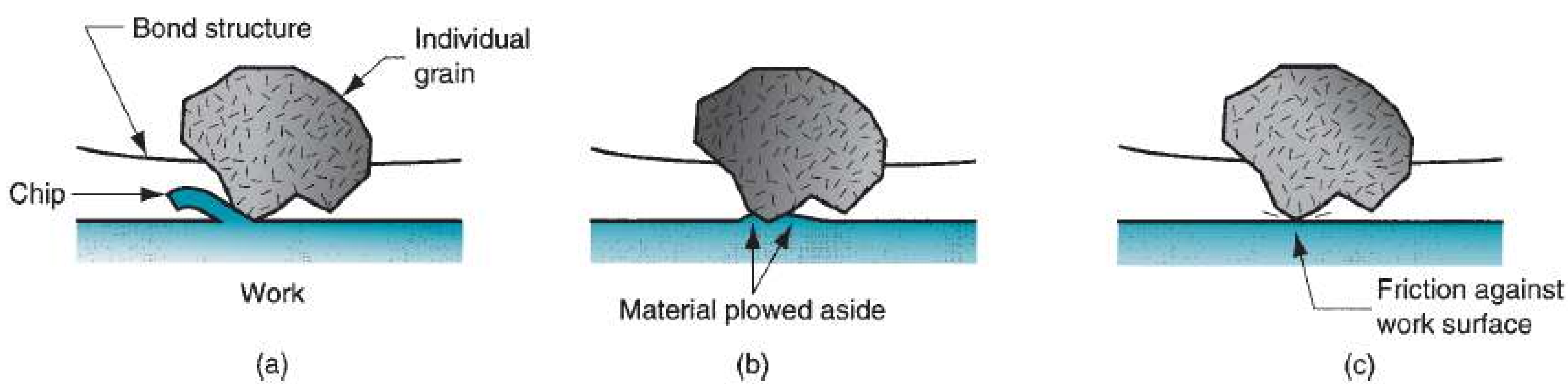


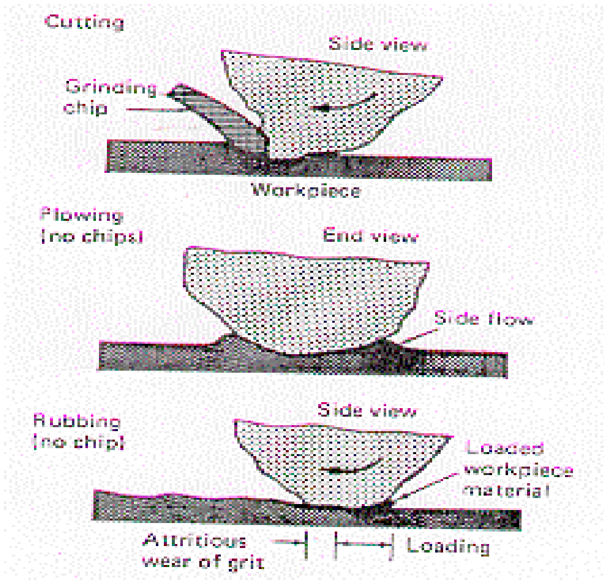
Fig: (a) Grinding chip being produced by a single abrasive grain. (A) chip, (B) workpiece, (C) abrasive grain. Note the large negative rake angle of the grain. The inscribed circle is 0.065mm in diameter. (b) Chip formation by an abrasive grain with a wear flat. Note the negative rake angle of the grain and the small shear angle

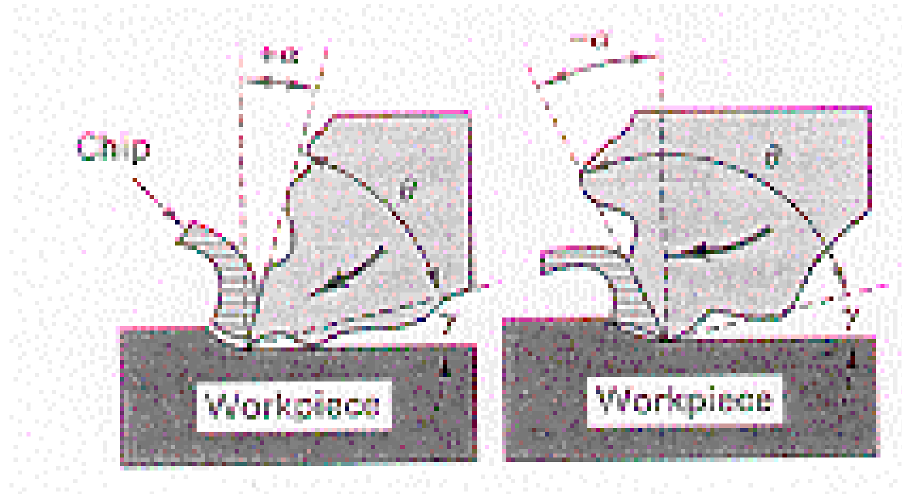
Chip Formation

- Chips in this process are formed by the same mechanism of compression and shear as other machining processes.
- As the grains or abrasives become dull, the cutting forces increase. The increase in the cutting force causes the grains to plow and rub rather than cut. As the plowing and rubbing increases, the grains fracture at the cutting edge to revile a new cutting edge.



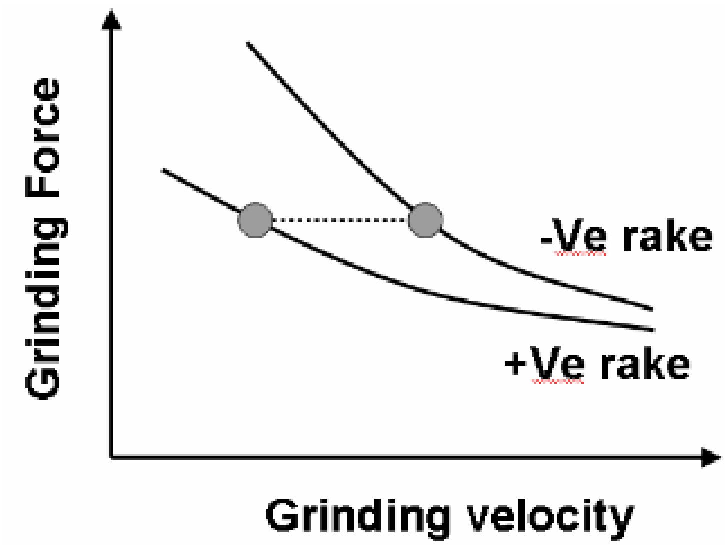
Chip Formation





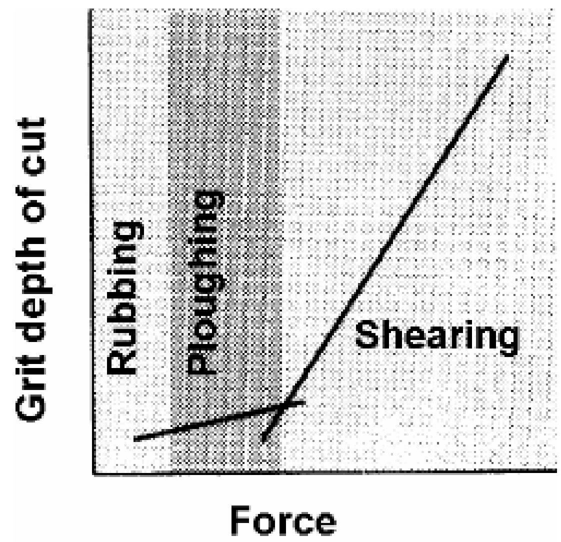
- The importance of the grit shape can be easily realized because it determines the grit geometry e.g. rake and clearance angle.
- The grits do not have definite geometry and the grit rake angle may vary from +45 to -60 or more.
- Grit with favorable geometry can produce chip in shear mode. However, grits having large negative rake angle or rounded cutting edge do not form chips but may rub or make a groove by plowing leading to lateral flow of the workpiece material.

Effect of grinding velocity and rake angle on force



- A negative rake angle always leads to higher cutting force.
- The difference is narrowed at a high grinding velocity and the grinding force becomes virtually independent of the rake angle.

Various Stages of Grinding with Grit Depth of Cut

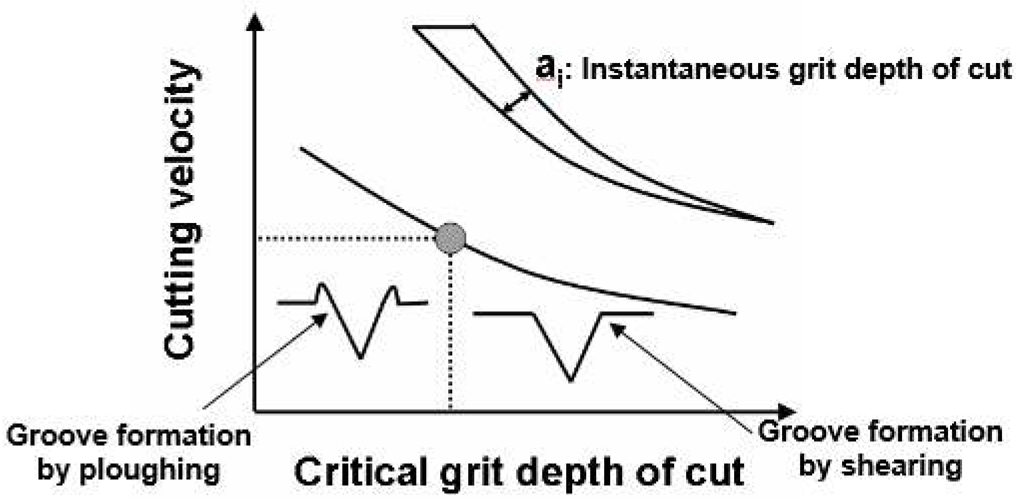


At a small grit penetration only sliding of the grit occurs against the workpiece. In this zone, rise of force with increase of grit penetration is quite high.

With further increase of the grit penetration, grit starts ploughing causing plastic flow of the material also associated with high grinding force.

With further increase of penetration, the grit start cutting and the rate of rise of force with increase of grit depth of cut is much less than what can be seen in the sliding and ploughing zone.

Variation of critical depth of cut with grinding velocity



Grinding is a combination of rubbing, ploughing and cutting (actual chip formation) .

A certain level of grit penetration into workpiece is required before chip formation can start.

Magnitude of critical grit depth of cut required to initiate cutting becomes less with the increase of grinding velocity.

Determination of the Density of Active Grains

Backer, Marshall and Shaw method: the grinding wheel is rolled over a glass plate covered with a layer of carbon black.

Peklenik and Opitz method: employs a thermocouple located at the surface of the workpiece. As each active grain passes, a thermocouple junction is formed between the wire and the workpiece and a pulse is obtained from the high temperature developed that can be counted using an oscilloscope.

Grisbrook method: the surface of the grinding wheel is viewed on a projection microscope, and the number of cutting points passing a line on the projection screen is counted as the wheel is rotated a given amount.

Testing of Grinding Wheels

Strength of a bond: pass a sintered metal carbide or diamond chisel over the wheel surface in such a way that it tears a layer of grains from the bond.
The forces required to separate a layer of grains from the bond are taken as a measure of the strength of the bond.

Hardness

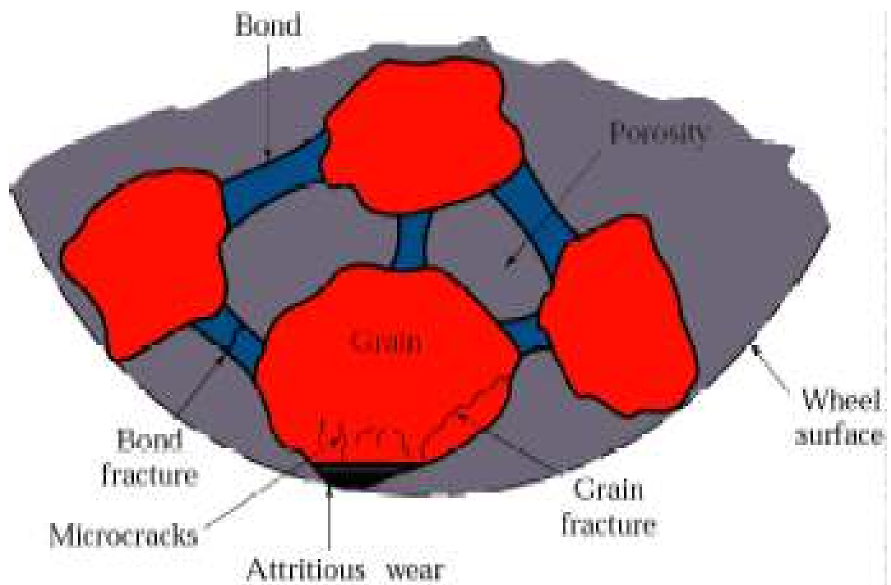
a) Drill the wheel with a hard spade-type drill with a constant force. The depth of penetration in a given time is a measure of wheel hardness.
b) Use an air/abrasive jet to break the bond. The depth of penetration of the jet erosion in a standard period of time is used to determine equivalent wheel hardness.
c) Measure the resonant frequency of an isolated wheel after a sharp blow with a rubber hammer and relate it to hardness.

Grinding Wheel Wear

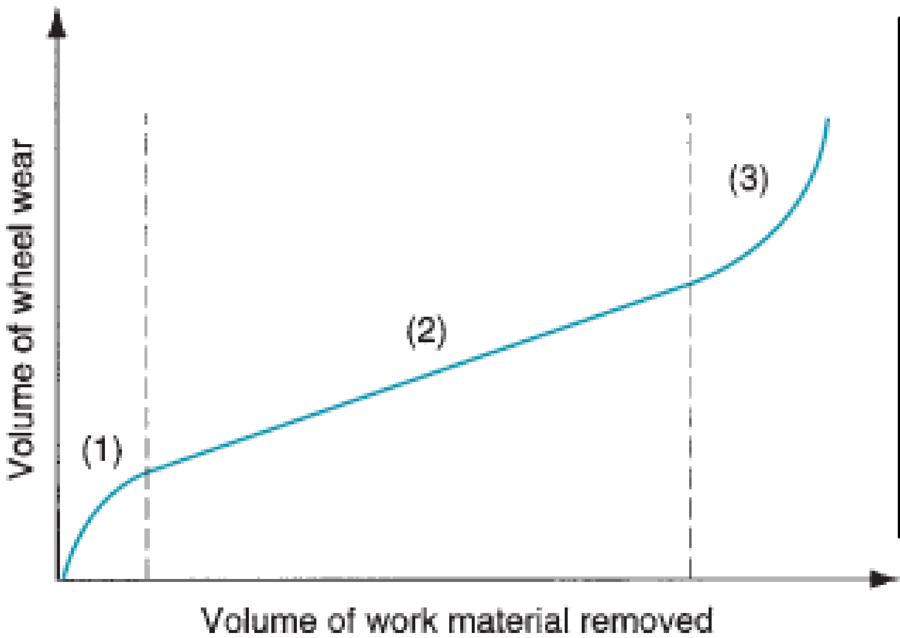
Grain fracture: a portion of the grain breaks off, but the rest of the grain remains bonded in the wheel.

Attritious wear: dulling of the individual grains, resulting in flat spots and rounded edges.

Bond fracture: the individual grains are pulled out of the bonding material.



Grinding Wheel Wear



$$G = \frac{\text{Volume of material removed}}{\text{Volume of wheel wear}}$$

Vary greatly (2-200 or higher) depending on the type of wheel, grinding fluid, and process parameters

Higher forces decrease the grinding ratio

(1): the grains are initially sharp, and wear is accelerated due to grain fracture.

(2): characterized by attritious wear, with some grain and bond fracture.

(3): the grains become dull and the amount of ploughing and rubbing increases relative to cutting.