TA 202A

Lecture 5

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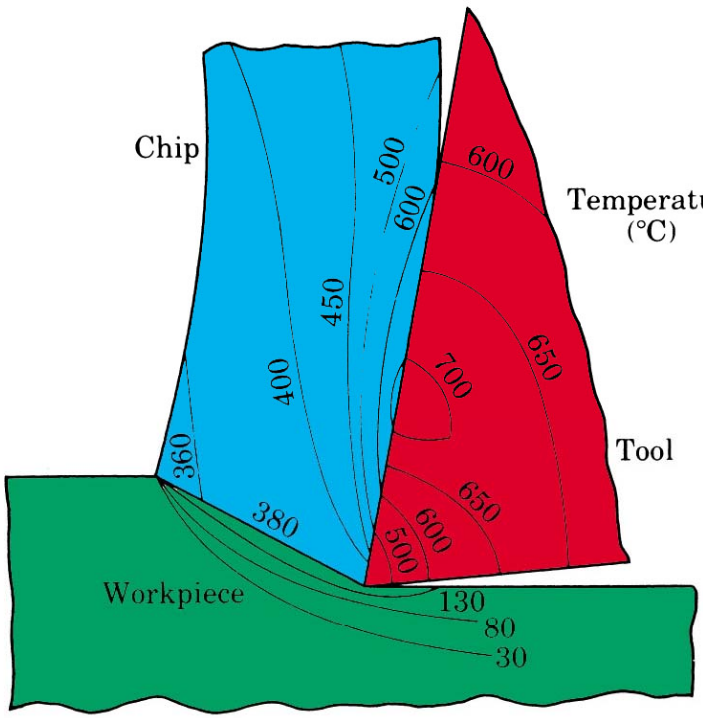
Factors Influencing Cutting Process

PARAMETERS	INFLUENCE AND INTER-RELATIONSHIP
CUTTING SPEED, DEPTH OF CUT, FEED, CUTTING FLUIDS	Forces, power, temperature rise, tool life, type of chip, surface finish.
TOOL ANGLES	As above, influence on chip flow direction, resistance to tool chipping.
CONTINUOUS CHIP	Good surface finish; steady cutting forces; undesirable in automated machinery.
BUILT-UP EDGE	Poor surface finish, thin stable edge can protect tool surfaces.
DISCONTINUOUS CHIP	Desirable for ease of chip disposal; fluctuating cutting forces; can affect surface finish and cause vibration and chatter.
TEMPERATURE RISE	Influences tool life, particularly crater wear, and dimensional accuracy of workpiece; may cause thermal damage to workpiece surface.
TOOL WEAR	Influences surface finish, dimensional accuracy, temperature rise, forces and power.
TOOL WEAR	Related to tool life, surface finish, forces and power

Temperature Distribution and Heat Generated

Approximately 98% of the energy in machining is converted into heat .This can cause temperatures to be very high at the tool-chip .The remaining energy (about 2%) is retained as elastic energy in the chip



Typical temperature distribution in the cutting zone. Note the steep temperature gradients within the tool and the chip.

G. Vieregge. *Source*

Cutting Tool Technology

Two principal aspects:

1. Tool material
2. Tool geometry

Three Modes of Tool Failure

- Fracture failure

  Cutting force becomes excessive and/or dynamic, leading to brittle fracture

- Temperature failure

  Cutting temperature is too high for the tool material

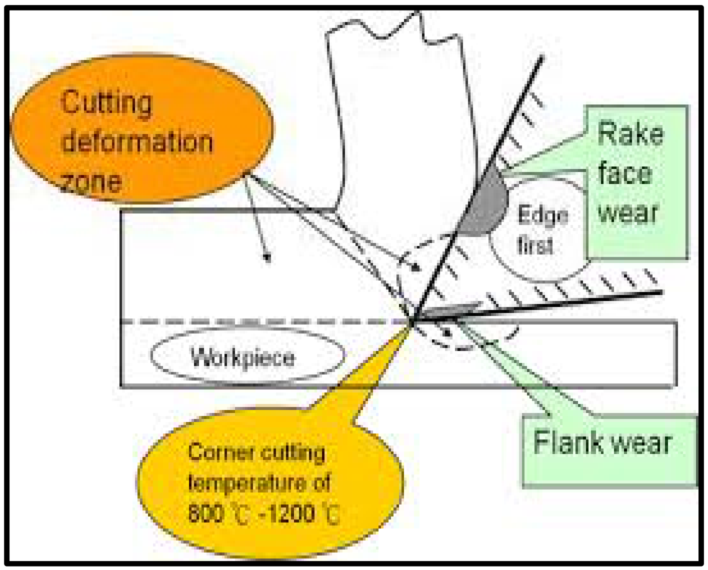
- Gradual wear

  Gradual wearing of the cutting tool

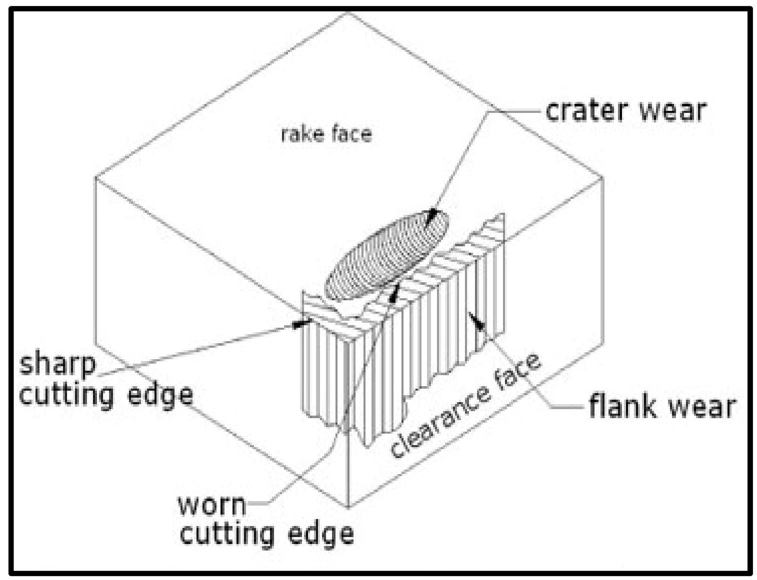
Process of Cutting Tool Failure

Cutting Tool Failure Mechanisms:

1. By Plastic deformation
2. By chipping due to mechanical breakage
3. Burning of the tool
4. By gradual wear



Typical wear pattern in cutting tool



Crater wear & flank wear

A tool that no longer performs the desired function can be declared as "failed"

Preferred Mode of Tool Failure

Gradual Wear

- Fracture and temperature failures are premature failures
- Gradual wear is preferred because it leads to the longest possible use of the tool
- Gradual wear occurs at two locations on a tool:

  Crater wear – occurs on top rake face

  Flank wear – occurs on flank (side of tool)

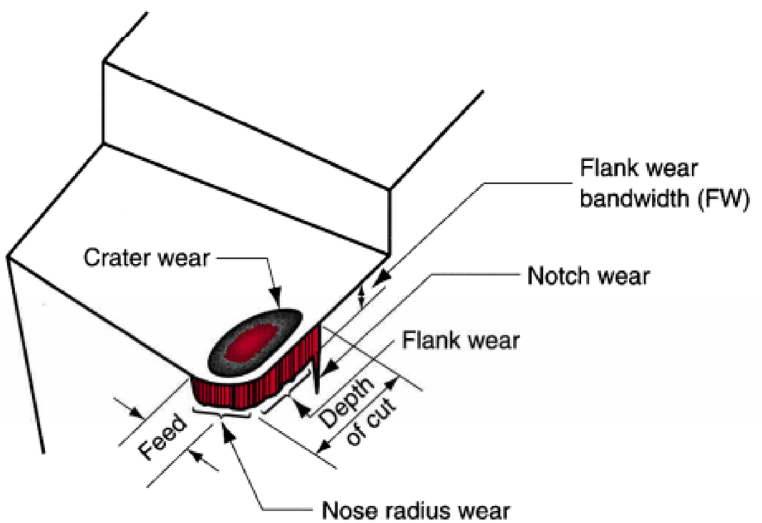


Diagram of worn cutting tool, showing the principal locations and types of wear that occur

FLANK WEAR: The progressive wear of a cutting tool first occurs on the flank face in the form of a wear land due to rubbing against the newly machined surface.

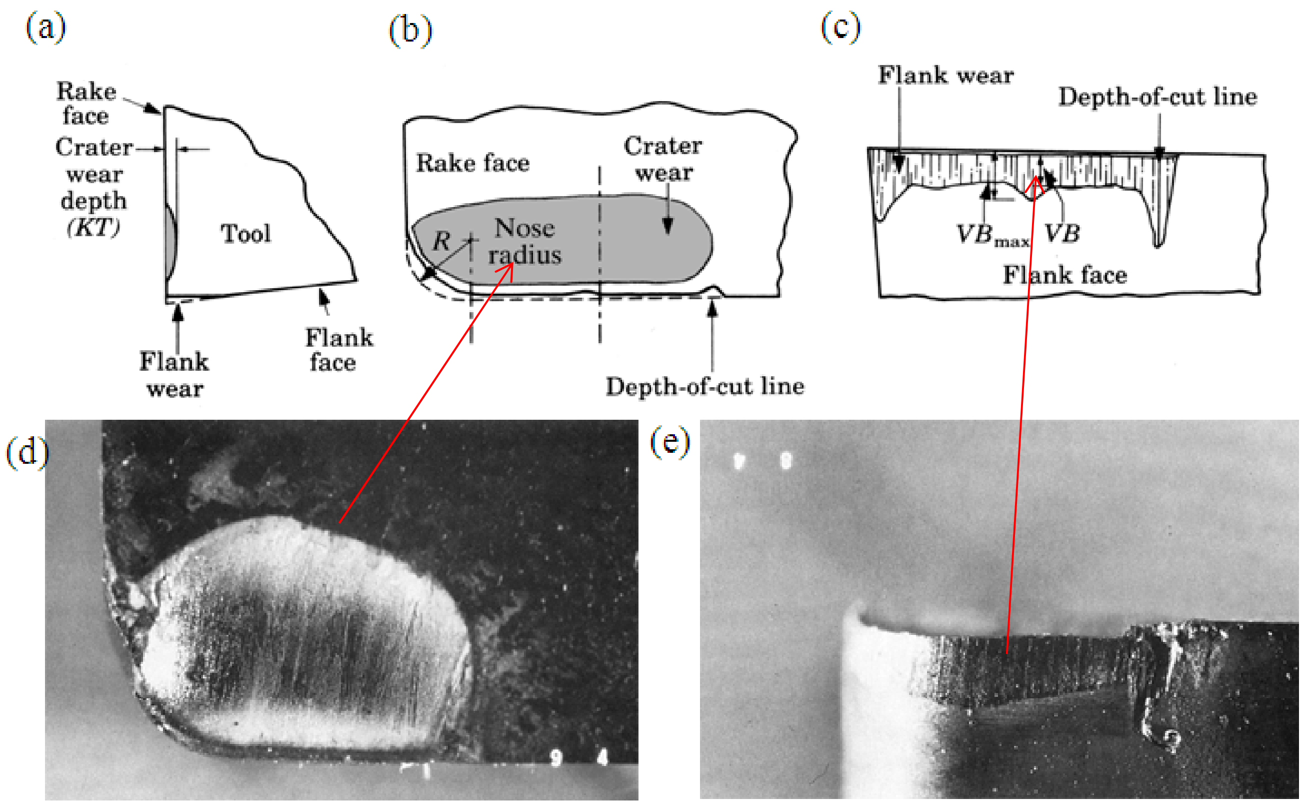
•Measured by the width of the wear band

CRATER WEAR: Cavity in the rake face caused by wearing due to chip sliding on rake surface.

- High stresses and temperatures at tool–chip contact contribute to the wearing action
- Measured either by its depth or its area

- Flank wear is measured by means of a measuring microscope.
- Crater wear can be evaluated by means of a surface analyser.

Flank and Crater Wear



(a) Flank and crater wear in a cutting tool. Tool moves to the left.

(b) View of the rake face of a turning tool, showing nose radius *R* and crater wear pattern on the rake face of the tool.

(c) View of the flank face of a turning tool, showing the average flank wear land VB and the depth-of-cut line (wear notch).

(d) Crater and (e) flank wear on a carbide tool.

Source: J.C. Keefe, Lehigh University.

Flank Wear and Time Relationship

Three stages of flank wear:

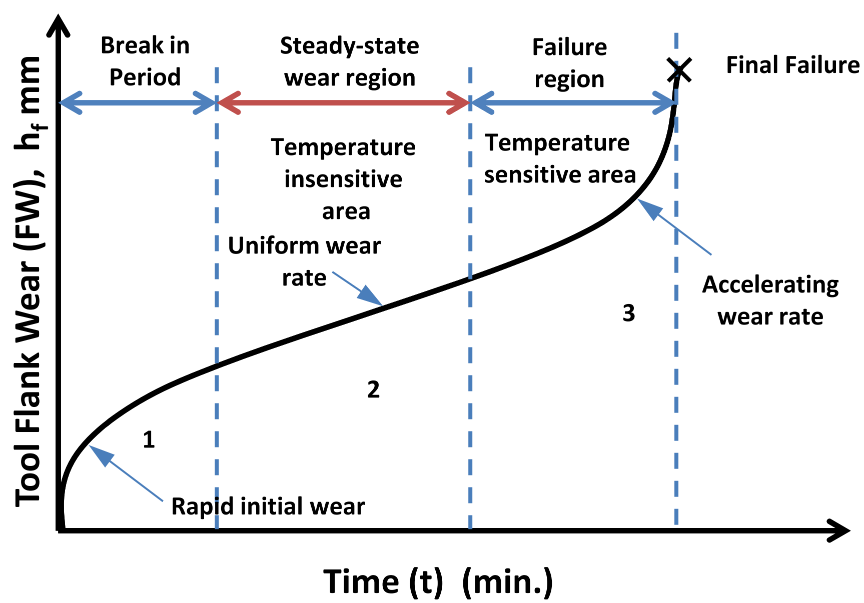
1. Rapid growth region (Break in region)
2. Steady state region (Temperature Insensitive region)
3. Catastrophe failure (Temperature sensitive region)

Flank wear characterised by wear land (or Height) h_f of wear band

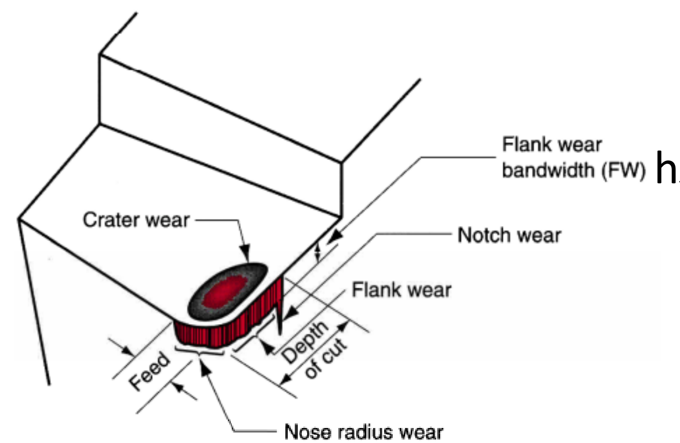
Flank wear formation depends on

* Cutting Conditions (f, d, V, tool angles)

* Properties of work material and tool material



Three stage flank wear curve



Flank wear (FW) is used here as the measure of tool wear. Crater wear follows a similar growth curve

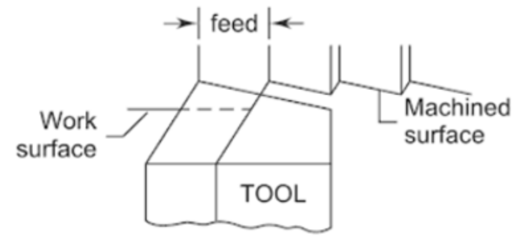
Tool wear Index, feed marks and surface finish

Type of wear depends MAINLY on cutting speed

- If cutting speed increases, predominant wear may be "CRATER" wear else "FLANK" wear.
- Failure by crater takes place when index h_k reaches 0.4 value, before flank wear limit of h_f = 1mm for carbide tools is attained.

$$h_k = \frac{C}{(l/2)+f} \qquad Where, C = Depth,\ l = Width,\quad f = Distance,\ For\ HSS\ \ h_k = 0.6$$

Surface Roughness (Represented by index R_{CLA} or R_{max}):



For turning with sharp cutting tool (Ideal cutting):

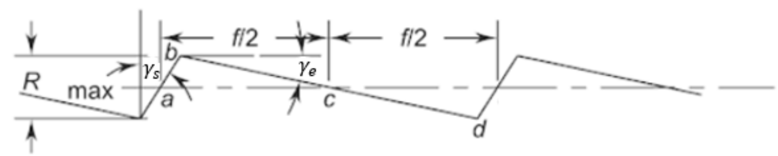
$$R_{\max} = \frac{f}{\cot\lambda + \cot\gamma_e}$$

$$R_{CLA} = \frac{R_{\max}}{4} \qquad CLA = Centre\ Line\ Average$$

$Where,\ f = Feed$

$\gamma_e = End\ cutting\ edge\ angle$

$\lambda = principal\ cutting\ edge\ angle = 90^\circ - \gamma_s$



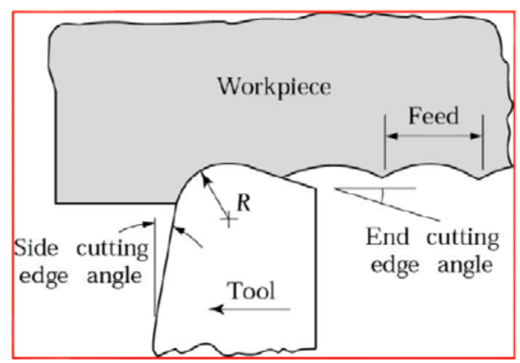
In actual turning (Cutting tool with nose radius):

$$R_{\max} = \frac{f^2}{8R} \qquad R_{CLA} = \frac{8f^2}{18\sqrt{3R}}\ (Empirical)$$

$$R_{CLA} = \frac{R_{\max}}{4}$$

$Where,\ f = Feed$

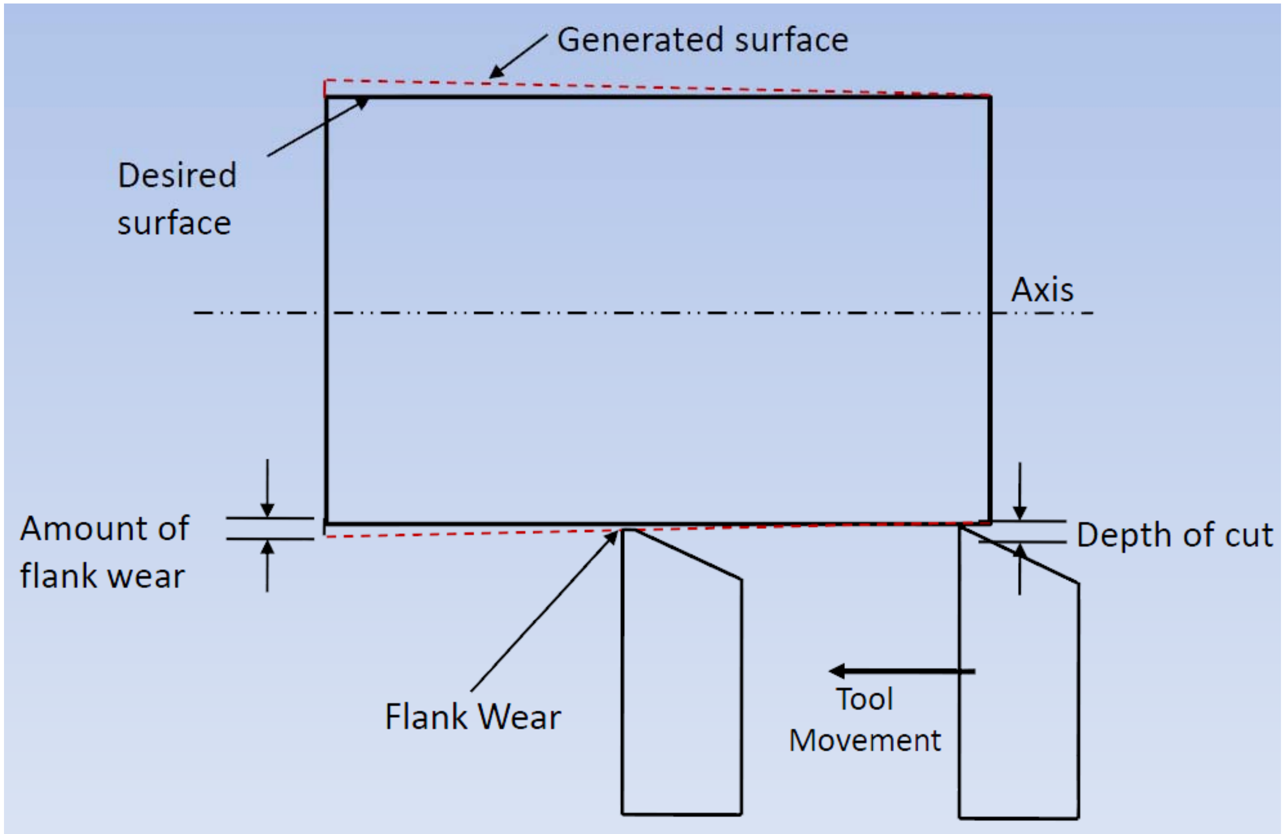
$R = Tool\ Nose\ Radius$



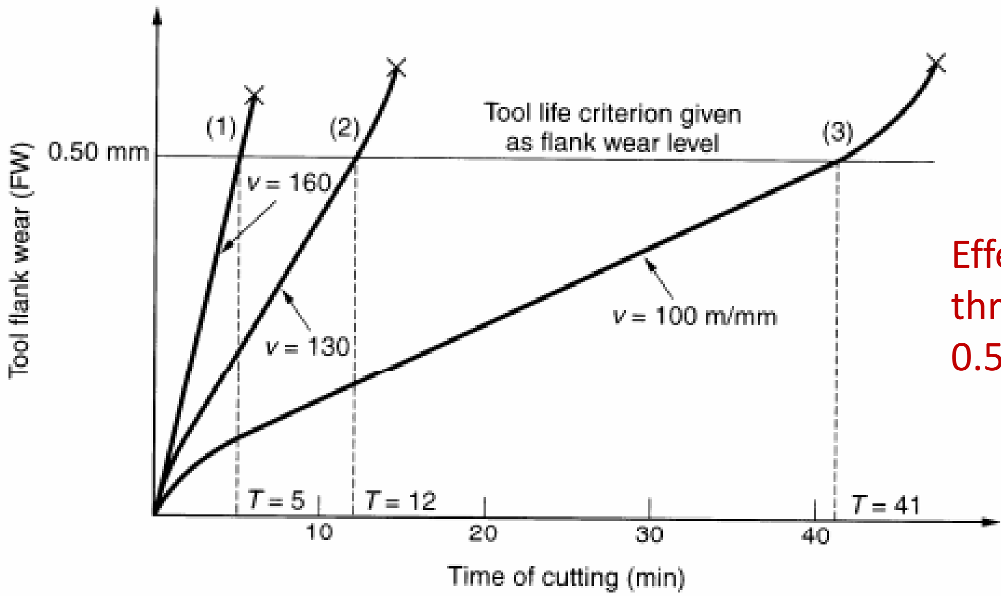
Effect of tool wear on machined surface

Flank wear affects:

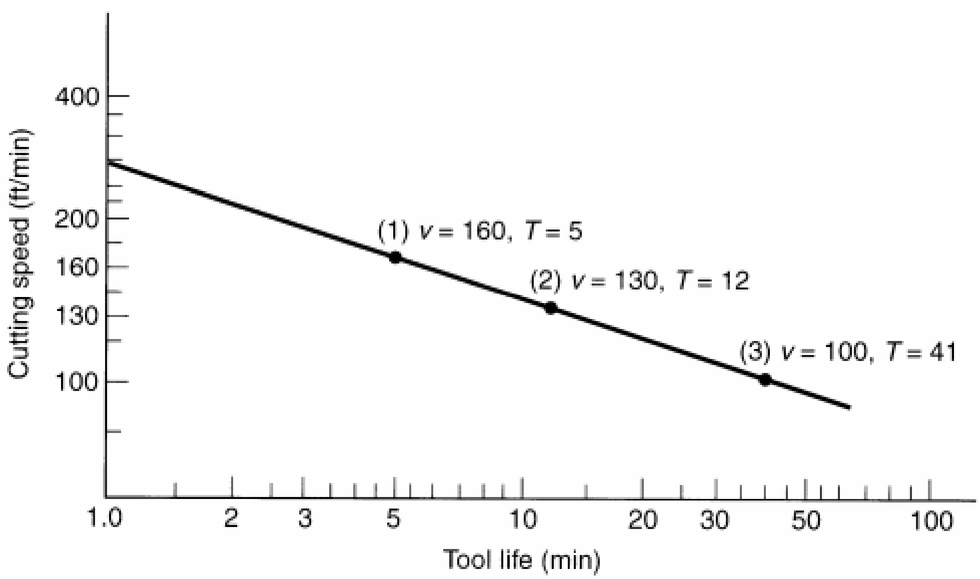
* Dimensional accuracy
* Process stability
* Surface finish



Effect of tool wear on machined component dimensions (Exaggerated view)



Effect of cutting speed on tool flank wear (FW) for three cutting speeds, using a tool life criterion of 0.50 mm flank wear



Natural log-log plot of cutting speed vs tool life

Tool Life & Machinability

Tool no longer performs desired function → **Failed** → **Re-sharpen and use it again.**

Tool Life:

- **Useful life of a tool** expressed in terms of time from the start of a cut to the termination point (defined by failure criterion). Sometimes, also expressed in terms of no. of the parts machined.

Taylor's Tool Life Equation

$$vT^n = C$$

where v = cutting speed; T = tool life; and n and C are parameters that depend on feed, depth of cut, work material, tooling material, and the tool life criterion used

- n exponents for conditions tested
- C Taylor's constant-represents cutting speed for 1 minute as tool life

Tool Life & Machinability

Taylor's tool life equation does not account for:

Feed (f),

Depth of cut (d),

Tool geometry (Rake Angle α).

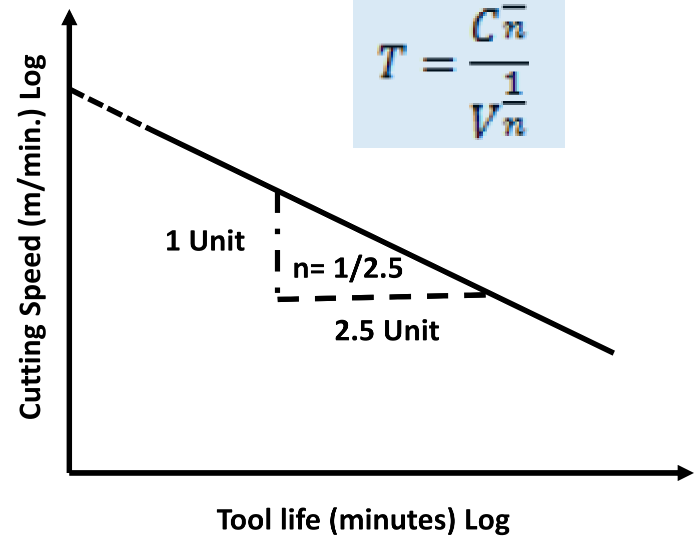
$\boxed{VT^n = C}$ (n<1), C is very large

Taking logarithm on both sides

LogV + nlogT= LogC

This becomes a straight line on the log-log scale

$$T = \frac{C^{\frac{1}{n}}}{V^{\frac{1}{n}}}$$



Modified Taylor's tool life equation

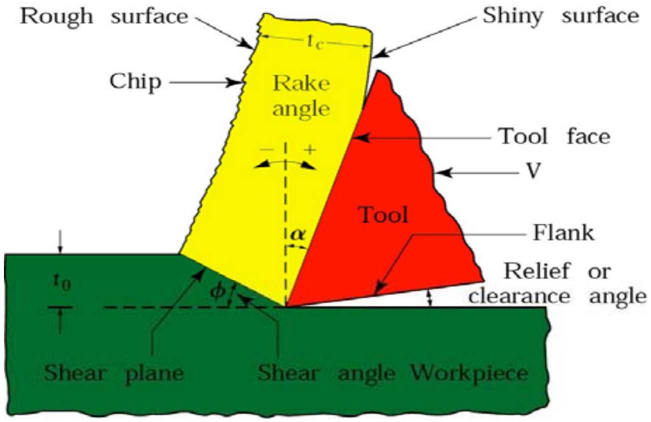
$V\,T^n\,f^{n_1}\,d^{n_2} = C$

n, n_1, n_2: Constants depend upon tool material (= 0.1 to 0.4).
C: constant that depends on tool-work material combination and tool geometry (>100)

Tool Wear & Tool Life

Effect of Tool Geometry: Rake angle

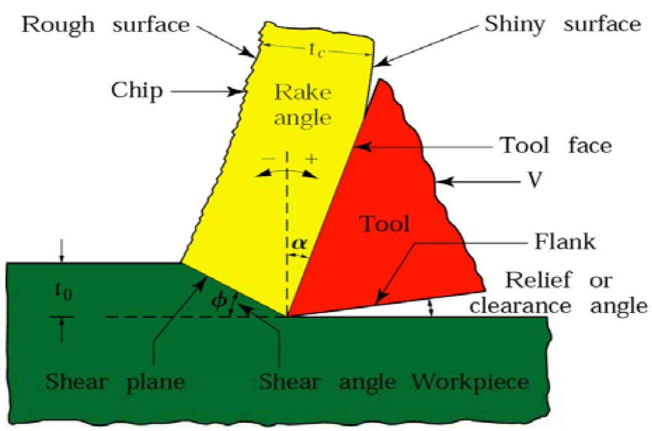
- Increasing the Rake Angle reduces the cutting force and the cutting temperature resulting in increased tool life.
- However, for large rake angle, tool edge is weakened resulting in increased wear due to chipping of the cutting edge.
- Increased wear is also due to larger temperature since the tool becomes thinner and the area available for heat conduction reduces.
- These conditions give an optimum rake angle which gives the maximum tool life.
- Higher is the strength of workpiece material, lower is the value of optimum rake angle.



Tool Wear & Tool Life

Effect of Tool Geometry: Flank angle

- Increasing the Flank Angle reduces rubbing between tool and the workpiece and hence improves the tool life.
- However, too high a value of flank angle weakens the tool and reduces its life.
- Optimum value of flank angles is also affected by the feed rates. Higher is the feed rate, lower is the optimum value.
- The flank angle, therefore, should be low if higher feed values are to be used.



Variables affecting tool life

- Cutting Conditions (V, d, f)
- Tool Geometry (all six angles, and nose radius)
- Workpiece Material
- Cutting fluid
- Machine tool
- Tool Material

MACHINABILITY

Mainly concerned with workpiece material properties not the tool properties. It depends on workpiece material properties. Good machinability means:

1. **Low tool wear**
2. **Good surface finish produced**
3. **Low cutting forces**

Machinability is defined as "The ease with which a given workpiecce material can be machined with a specified cutting tool"

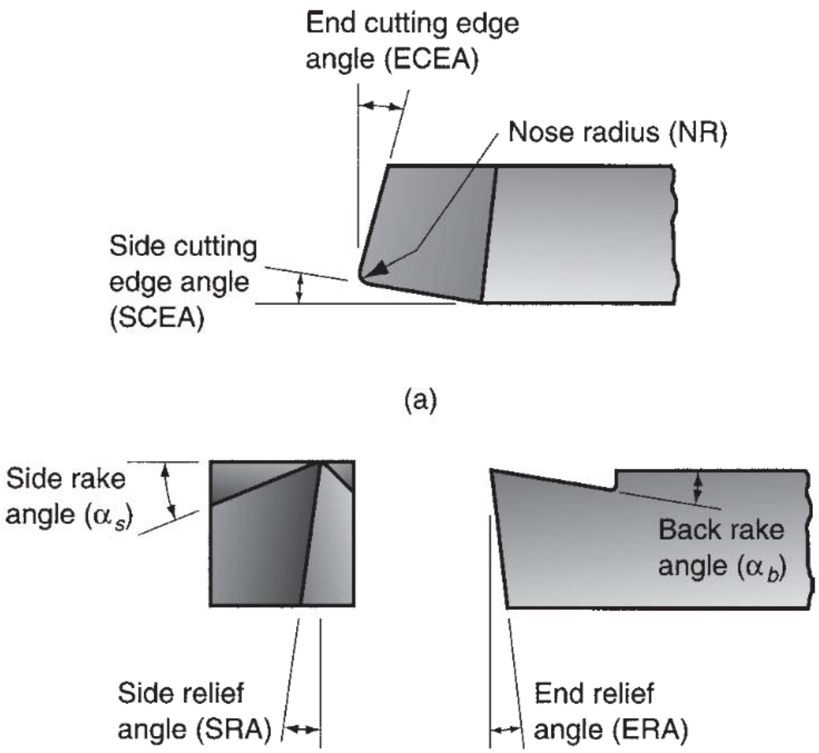
Tool materials

$$\boxed{VT^n = C}$$

Representative values of *n* and *C* in the Taylor tool life equation for selected tool materials.

		C			
		Nonsteel Cutting		Steel Cutting	
Tool Material	*n*	m/min	(ft/min)	m/min	ft/min
Plain carbon tool steel	0.1	70	(200)	20	60
High-speed steel	0.125	120	(350)	70	200
Cemented carbide	0.25	900	(2700)	500	1500
Cermet	0.25			600	2000
Coated carbide	0.25			700	2200
Ceramic	0.6			3000	10,000

Single-Point Tool Geometry



(b) Tool signature: α_b, α_s, ERA, SRA, ECEA, SCEA, NR

(a) Seven elements of single-point tool geometry

(b) the tool signature convention that defines the seven elements

Tool specification in American Standards Association (ASA) system:

$$\alpha_b - \alpha_s - \delta_e - \delta_s - \gamma_e - \gamma_s - r(mm)$$

Tool specification in Orthogonal Rake system (ORS):

$$i - \alpha_o - \delta_p - \delta_a - \gamma_a - \lambda - r(mm)$$

$$\lambda = 90^\circ - \gamma_s$$

i = inclination angle
α_o = orthogonal rake angle
λ = Principal cutting edge angle

δ_p = Principal flank angle
δ_a = Auxiliary flank angle
γ_a = Auxiliary cutting edge angle
r = Nose radius (mm)

Tool specification

Apart from tool material, one has to give tool angles and tool nose radius in the following sequence while going to purchase or asking some one to make a tool :

- Tool specifications (all six angles, and nose radius) :7-8-5-6-9-4-1mm

  This specification indicates the following:

  - **Back rake angle (7^0)**
  - **Side rake angle (8^0)**
  - **End clearance (relief) angle (5^0)**
  - **Side clearance (relief) angle (6^0)**
  - **End cutting edge angle (9^0)**
  - **Side cutting edge angle (4^0)**
  - **Nose radius (1 mm)**

Cutting Fluids

Any liquid or gas applied directly to machining operation to improve cutting performance.

Two main problems addressed by cutting fluids:

1. Heat generation at shear zone and friction zone
2. Friction at the tool-chip and tool-work interfaces

Other functions and benefits:

- Wash away chips (e.g., grinding and milling)
- Reduce temperature of workpart for easier handling
- Improve dimensional stability of workpart

Cutting Fluid Functions

Cutting fluids can be classified according to function

- Coolants - designed to reduce effects of heat in machining
- Lubricants - designed to reduce tool-chip and tool-work friction

Coolants

Water used as base in coolant-type cutting fluids

- Most effective at high cutting speeds where heat generation and high temperatures are problems
- Most effective on tool materials that are most susceptible to temperature failures (e.g., HSS)

Lubricants

- Usually oil-based fluids
- Most effective at lower cutting speeds
- Also reduces temperature in the operation

Cutting fluids should have high specific heat and good thermal conductivity, a chemical constituent to form weak junctions, should have a low viscosity and small molecular size, non corrosive and inexpensive.

At a very high speed, coolant is ineffective.

Dry Machining

- No cutting fluid is used
- Avoids problems of cutting fluid contamination, disposal, and filtration

Problems with dry machining:

- Overheating of the tool
- Operating at lower cutting speeds and production rates to prolong tool life
- Absence of chip removal benefits of cutting fluid in grinding and milling

Recap of this Topic

- Factors influencing Cutting Process
- Process of Cutting Tool Failure
- Tool wear and Tool life
- Tool specification
- Cutting fluids and its functions

Next Topic

Abrasive Machining Processes

Abrasive Machining Processes

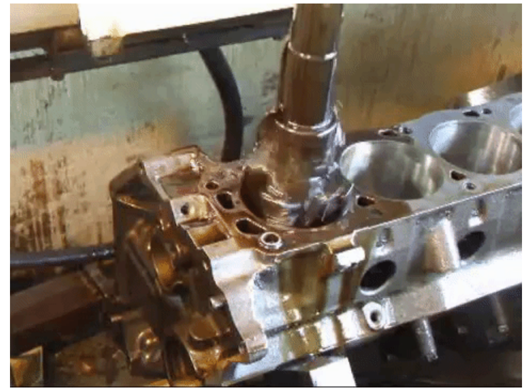
- Abrasive machining involves material removal by the action of hard, abrasive particles.
- Generally used as finishing operations after part geometry has been established by conventional machining

They are important because:

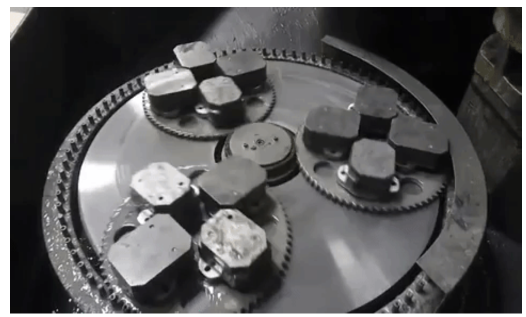
- They can be used on all types of materials ranging from soft metals to hardened steels and hard non-metallic materials such as ceramics and silicon.
- Extremely fine surface finishes (0.025 m).
- For certain abrasive processes, dimensions can be held to extremely close tolerances.

Types of Abrasive Machining Processes

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



Honing



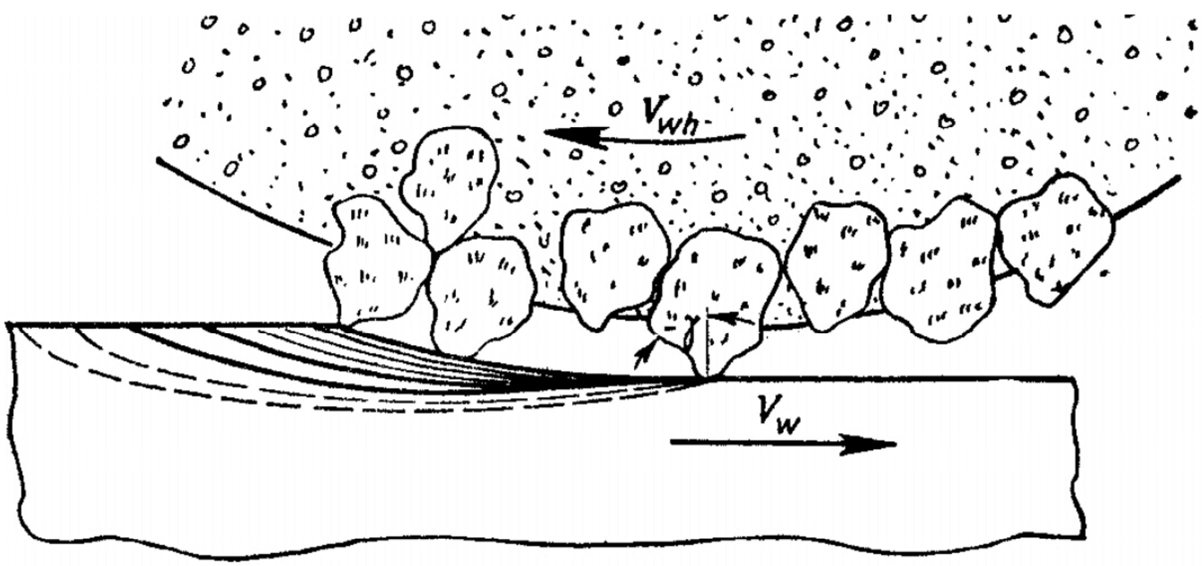
Lapping

Buffing

Grinding

Grinding Operation

- Grinding is the most common form of abrasive machining.
- It is a material cutting process which engages an abrasive tool whose cutting elements are grains of abrasive material known as grit.
- These grits are characterized by sharp cutting points, high hot hardness, chemical stability and wear resistance.
- The grits are held together by a suitable bonding material to give shape of an abrasive tool.



Grinding wheel and work-piece interaction

Difference between grinding and milling

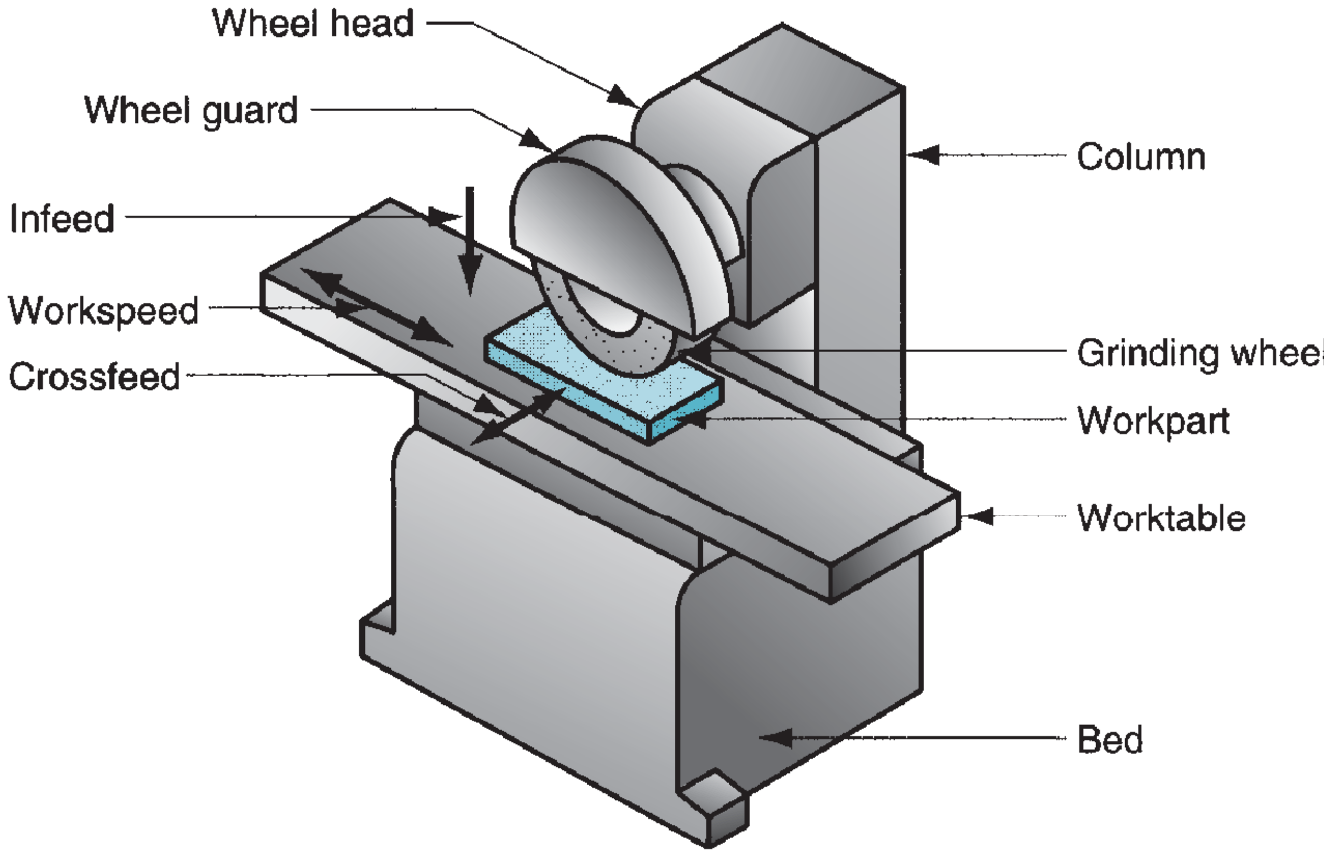
- The abrasive grains in the wheel are much smaller and more numerous than the teeth on a milling cutter.
- Cutting speeds in grinding are much higher than in milling.
- The abrasive grits in a grinding wheel are randomly oriented.
- A grinding wheel is **self-sharpening**.

  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.

Why Specific Energy in Grinding is high

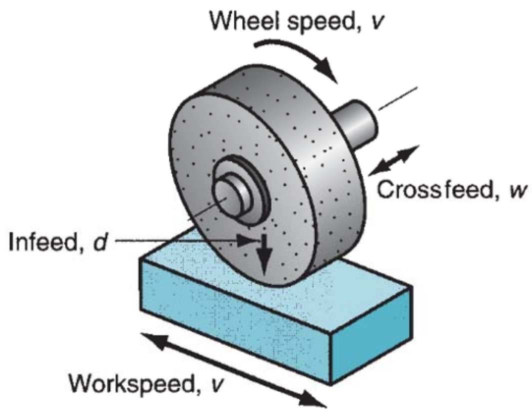
- *Size effect- small chip size causes energy to remove* each unit volume of material to be significantly higher- roughly 10 times higher
- Individual grains have extermely negative rake angles, resulting in low shear plane angles and high shear strains
- Not all grits are engaged in actual cutting

Surface Grinding

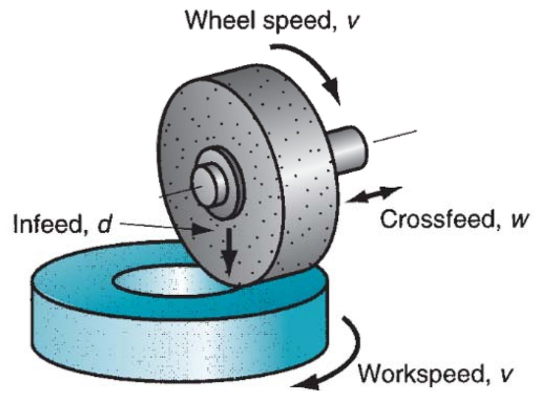


Horizontal Surface Grinding Machine

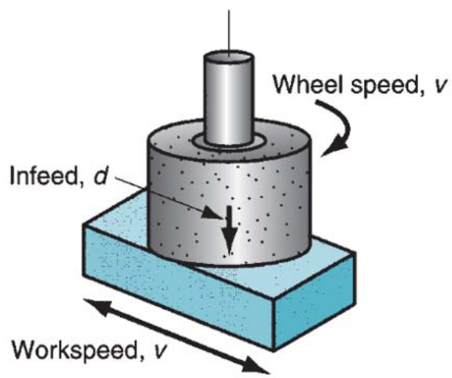
Surface Grinding Processes



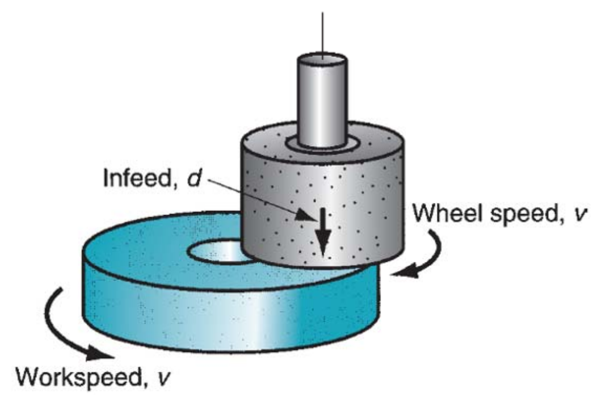
(a) Horizontal spindle with reciprocating worktable



(b) Horizontal spindle with rotating worktable

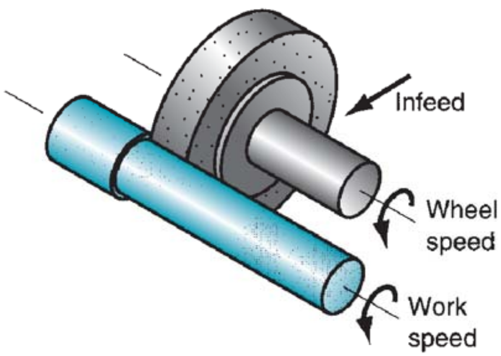


(c) Vertical spindle with reciprocating worktable

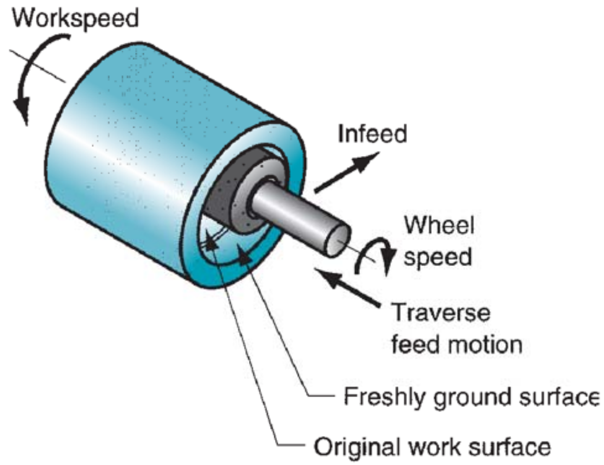


(d) Vertical spindle with rotating worktable

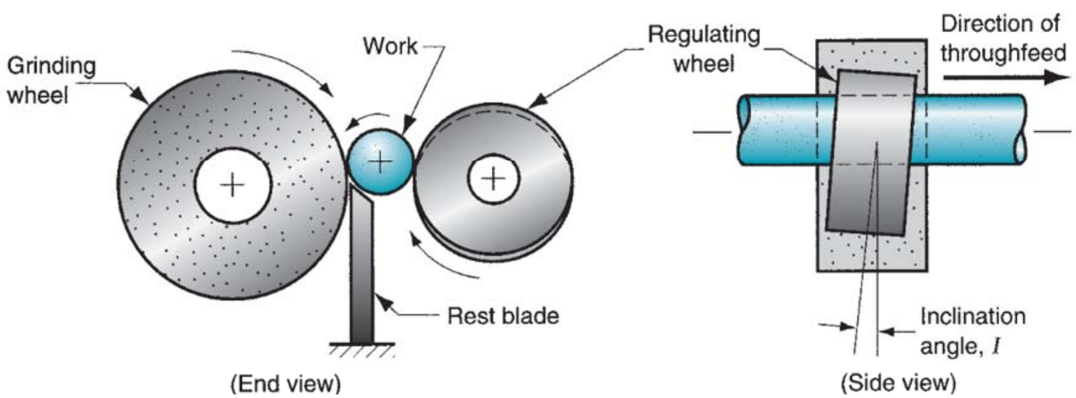
Cylindrical Grinding Processes



(a) External cylindrical grinding



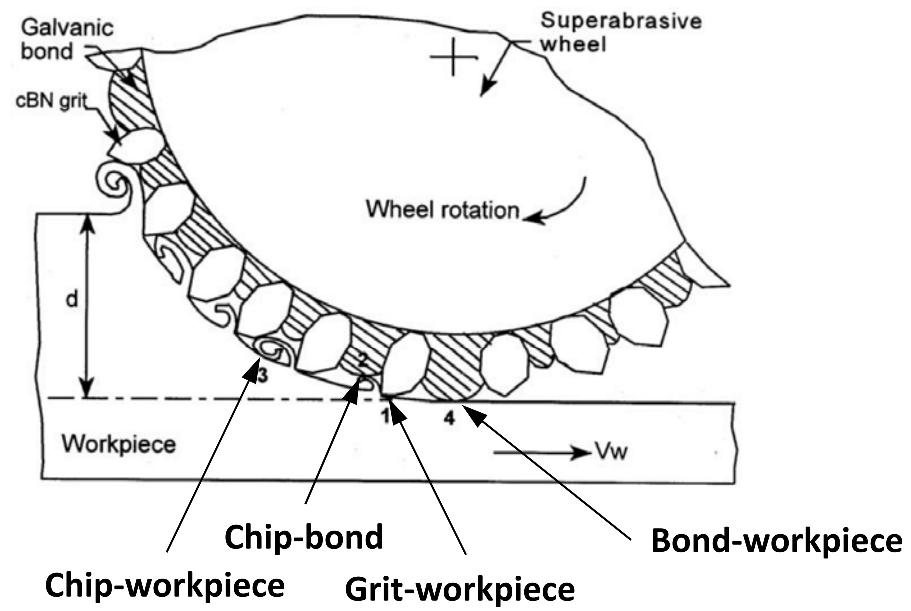
(b) Internal cylindrical grinding



External centreless cylindrical 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.

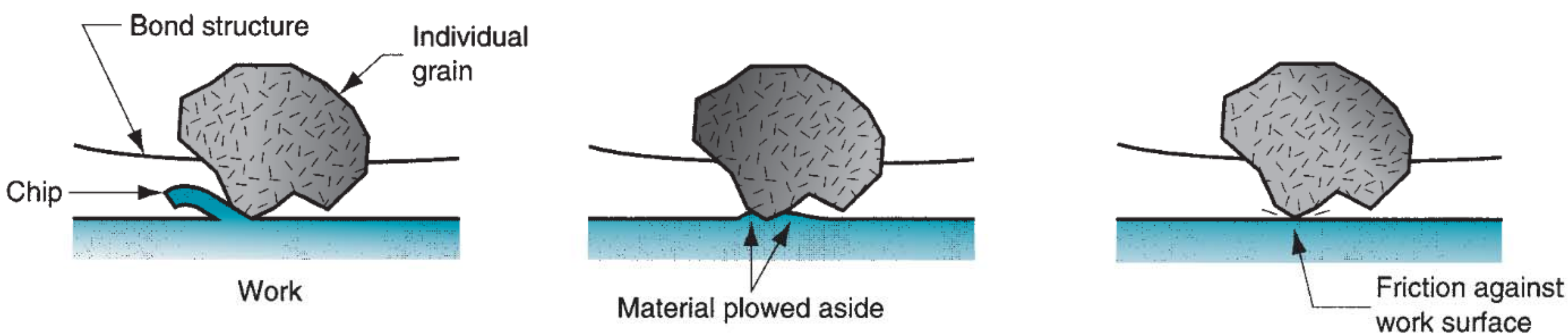
- ✓ Therefore, efforts should always be made to maximize gritworkpiece interaction leading to chip formation and to minimize the rest for best utilization of the available power.

Three types of grain action in grinding

Shearing: The grit projects far enough into the work surface to form a chip and remove material

Ploughing: The grit projects into the work, but not far enough to cause cutting; instead, the work surface is deformed and energy is consumed without any material removal

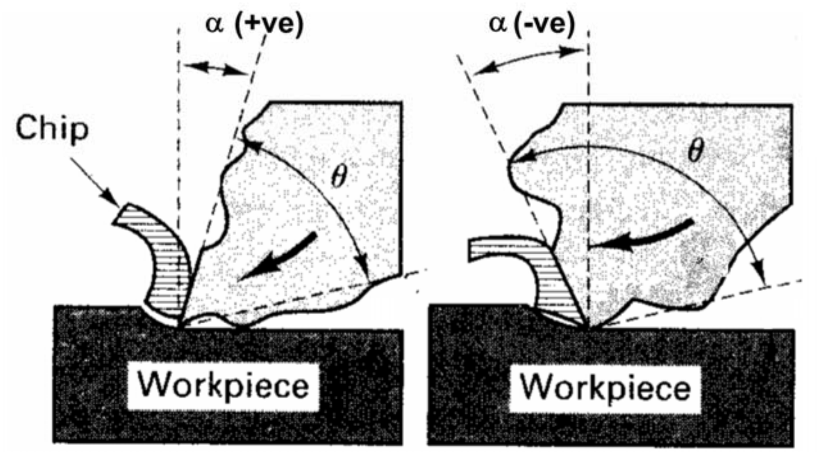
Rubbing: The grit contacts the surface during its sweep, but only rubbing friction occurs, thus consuming energy without removing any material



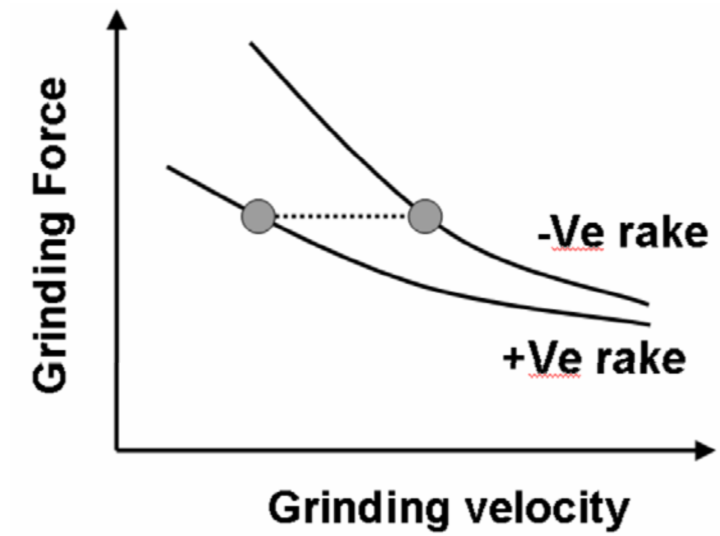
(a) Shearing (b) Ploughing (c) Rubbing

Grit projection: (a) > (b) > (c)

Effect of grinding velocity and rake angle on force

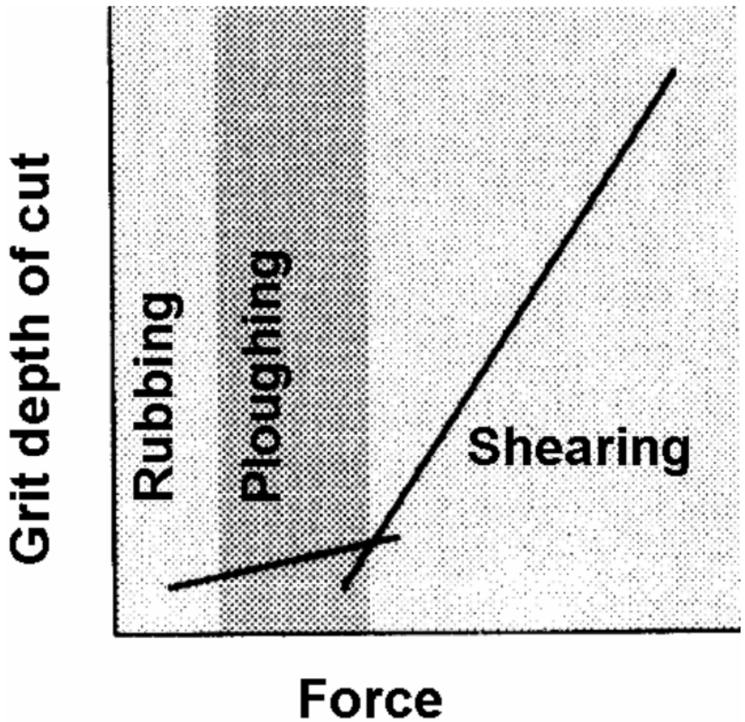


Variation in rake angle with grits
of different shape



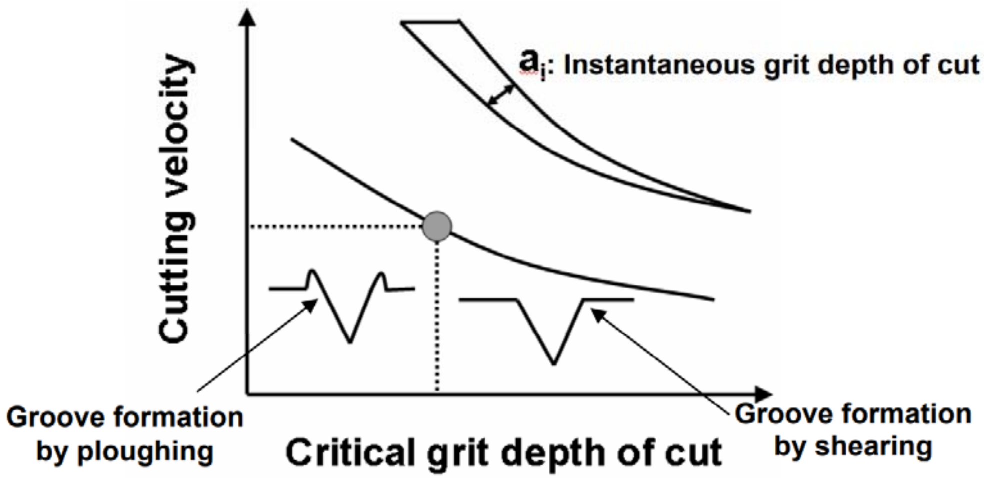
- The average rake angle is typically -60 degrees. consequently, grinding chips undergo much larger plastic deformation than they do in other machining process.
- A negative rake angle always leads to higher cutting force than what is produced with a cutting point having positive rake angle.
- It is interesting to note that the difference is narrowed at a high grinding velocity and the grinding force became virtually independent of the rake angle.
- This is one of the reasons of conducting grinding at a very high velocity in order to minimize the influence of negative rake angle.

Various stages of grinding with grit depth of cut



- At a small grit penetration only sliding of the grit occurs against the work piece. In this zone rise of force with increase penetration is quite high.
- With further increase of grit penetration, grit starts ploughing causing plastic flow of the material associated with high grinding force.
- With further increase of penetration, the grits 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 or 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.

Grinding wheel

A grinding wheel consists of abrasive particles and bonding material.

- Abrasive particles accomplish cutting
- Bonding material holds the particles in place and establishes the shape and structure of the 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 the cutting edge of the grain becomes dull, so a new sharp edge is exposed

Abrasive Materials

Commonly used abrasives in abrasive machining are:

- ❑ Conventional abrasive
  - Aluminum oxide (Al_2O_3)
  - Silicon carbide (SiC)
- ❑ Super abrasives
  - Cubic boron nitrite (CBN)
  - Diamond

Grain Size

- Grain size is expressed in terms of SIEVE NUMBER (S_n), which corresponds to the number of openings per inch.
- The diameter of an abrasive grain, $D_g = \frac{0.6}{S_n}$ *inch*
- The larger the size of the grains, the more will be material removal, but surface finish will be worse.
- Small grain sizes produce better finishes, whereas larger grain sizes permit larger material removal rates.

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

- Harder work materials require smaller grain sizes to cut effectively
- Softer materials require larger grit sizes

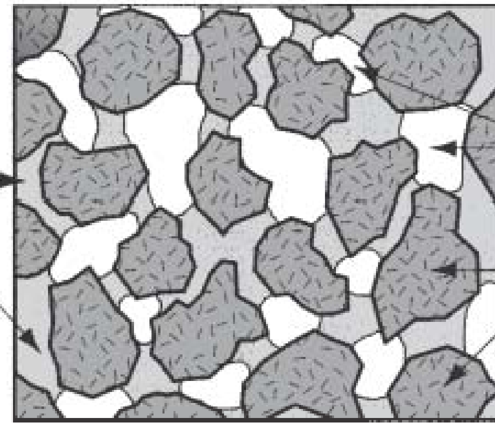
Bonding Material

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.

Wheel Structure



- Refers to the relative spacing of abrasive grains in wheel
- In addition to abrasive grains and bond material, grinding wheels contain air gaps or pores
- Volumetric proportions of grains, bond material, and pores can be expressed as:

$$P_g + P_b + P_p = 1.0$$

- Measured on a scale that ranges between "dense" and "open"
- 0…..16 – Dense (Closed) to Open structures
- Open structure means P_p is relatively large and P_g is relatively small - recommended when clearance for chips must be provided
- Dense structure means P_p is relatively small and P_g is larger - recommended to obtain better surface finish and dimensional control

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

Depends on the amount of bonding material in wheel structure (P_b)

Grinding wheel specification

Marking system for diamond and cubic boron nitride grinding wheels as defined by ANSI Standard B74.13-1977

XX D 150 P YY M ZZ 3

Depth of abrasive = working depth of abrasive section in mm (shown) or inches, as in Figure 25.2(c).

Bond modification = manufacturer's notation of special bond type or modification.

***Bond type*:** B = Resin, M = metal, V = Vitrified.

***Concentration*:** Manufacturer's designation. May be number or symbol.

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

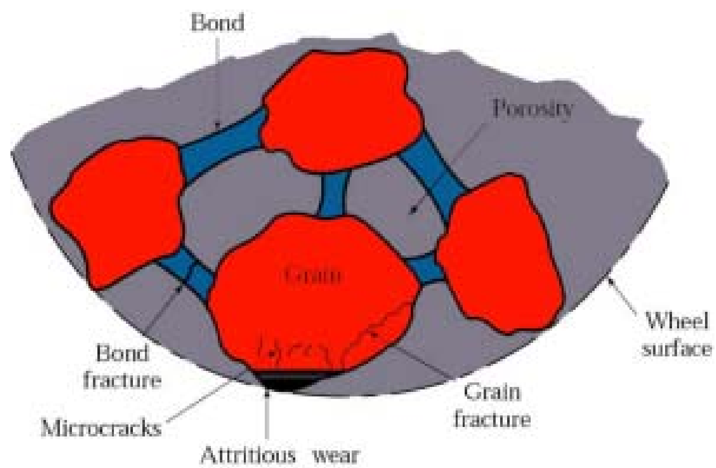
***Grain size*:** Coarse = grit sizes 8 to 24, Medium = grit sizes 30 to 60, Fine = Grit sizes 70 to 180, Very fine = grit sizes 220 to 600.

***Abrasive type*:** D = diamond, B = cubic boron nitride.

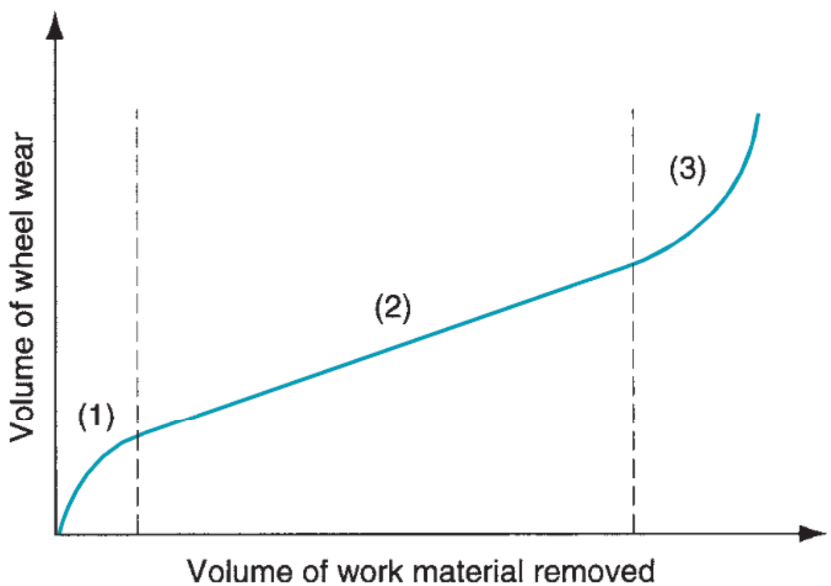
***Prefix*:** Manufacturer's symbol for abrasive (optional).

Causes of Grinding Wheel Wear

- Grain fracture: *When a portion of the grain breaks off*, but the rest of the grain remains bonded in the wheel.
  - Edges of the fractured area become new cutting edges
  - Tendency to fracture is called friability
- Attritious wear: Dulling of the individual grains, resulting in flat spots and rounded edges.
  - Analogous to tool wear in conventional cutting tool
  - Caused by similar mechanisms including friction, diffusion and chemical reactions
- Bond fracture: The individual grains are pulled out of the bonding material.
  - Depends on wheel grade, among other factors
  - Usually occurs because grain has become dull due to attritious wear and resulting cutting forces become excessive



Grinding wear profile and Grinding ratio



Grinding Ratio:

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

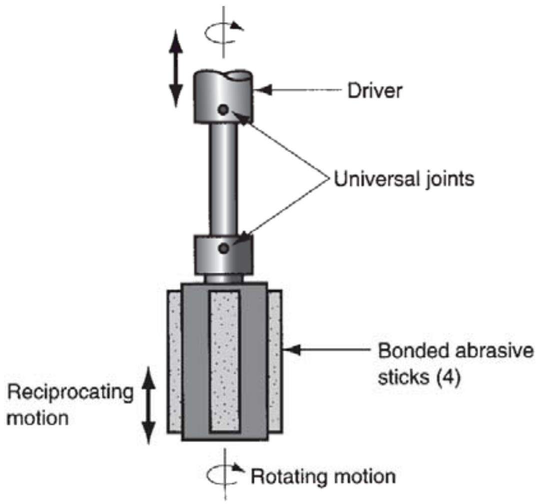
GR = Grinding ratio
V_w = Volume of work material removed
V_g = Corresponding volume of grinding wheel worn

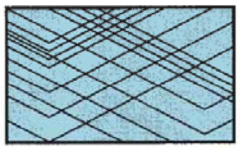
- Vary greatly (2-200 or higher) depending on the type of wheel, grinding fluid, and process parameters
- Higher forces decrease the grinding ratio

(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.

Honing

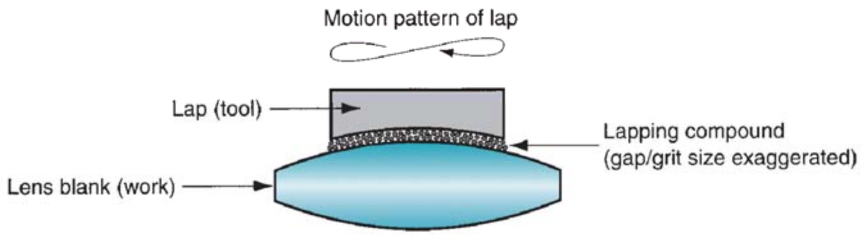
- Honing is an abrasive process performed by a set of bonded abrasive sticks using a combination of rotational and reciprocating motion.
- Applications: Finishing of bores of internal combustion engines, bearings, hydraulic cylinders, and gun barrels etc.
- Surface finishes of around 0.12 mm
- creates a characteristic cross-hatched surface that tends to retain lubrication





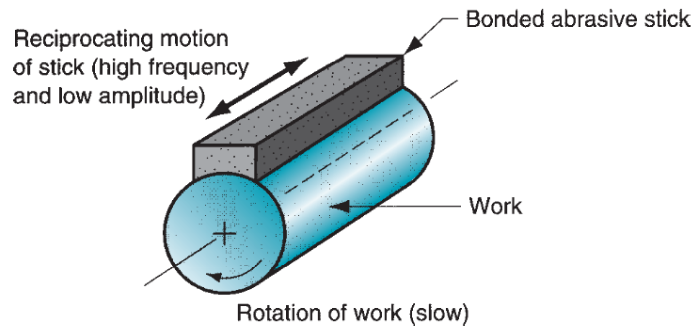
Lapping

- Lapping produces surface finishes of extreme accuracy and smoothness.
- Uses a fluid suspension of very small abrasive particles between the workpiece and the lapping tool (Lap).
- *Lapping compound- fluid with abrasives*, general appearance of a *chalky paste*.
- Typical grit sizes between 300 and 600.
- Application: Production of optical lenses, metallic bearing surfaces, gages etc.



Superfinishing

- Similar to honing-uses a bonded abrasive stick pressed against surface and reciprocating motion.
- Differs from honing:
  - Shorter strokes
  - Higher frequencies
  - Lower pressures between the tool and the surface
  - Lower workpiece speed
  - Smaller grit sizes



Polishing

- Polishing is used to remove scratches and burrs and to smooth rough surfaces by means of abrasive grains attached to a polishing wheel rotating at high speed.
- Wheel material: Canvas, leather, felt, and even paper etc.

Buffing

- Buffing is similar to polishing in appearance, but its function is different. Buffing is used to provide attractive surfaces with high luster.
- Wheels material: Same as in polishing but wheels are generally softer.

Usual part geometries for honing, lapping, superfinishing, polishing, and buffing.

Process	Usual Part Geometry	Surface Roughness µm	Surface Roughness µ-in
Grinding, medium grit size	Flat, external cylinders, round holes	0.4–1.6	16–63
Grinding, fine grit size	Flat, external cylinders, round holes	0.2–0.4	8–16
Honing	Round hole (e.g., engine bore)	0.1–0.8	4–32
Lapping	Flat or slightly spherical (e.g., lens)	0.025–0.4	1–16
Superfinishing	Flat surface, external cylinder	0.013–0.2	0.5–8
Polishing	Miscellaneous shapes	0.025–0.8	1–32
Buffing	Miscellaneous shapes	0.013–0.4	0.5–16

Recap of this Topic

- Basics of Abrasives
- Grinding wheel
- Grinding wheel wear
- Other Abrasive processes

Next Lecture

Unconventional material removal processes