GRINDING

Abrasive machining:

•The oldest machining process - "abrasive shaping" at the beginning of "Stone Era".

•Free sand was applied between two moving parts to remove material and shape the stone parts.

Grinding:

• Removing of metal by a rotating abrasive wheel. (Very high speed, Shallow cuts)

• the wheel action similar to a milling cutter with very large number of cutting points.

•Grinding was first used for making tools and arms.

SURFACE GRINDING:

Depth of Cut: 2-5 thou, 50-125 microns

Work Table → reciprocates beneath the wheel, Longitudinal feed

Wheel → crossfeed (Transverse feed) and infeed

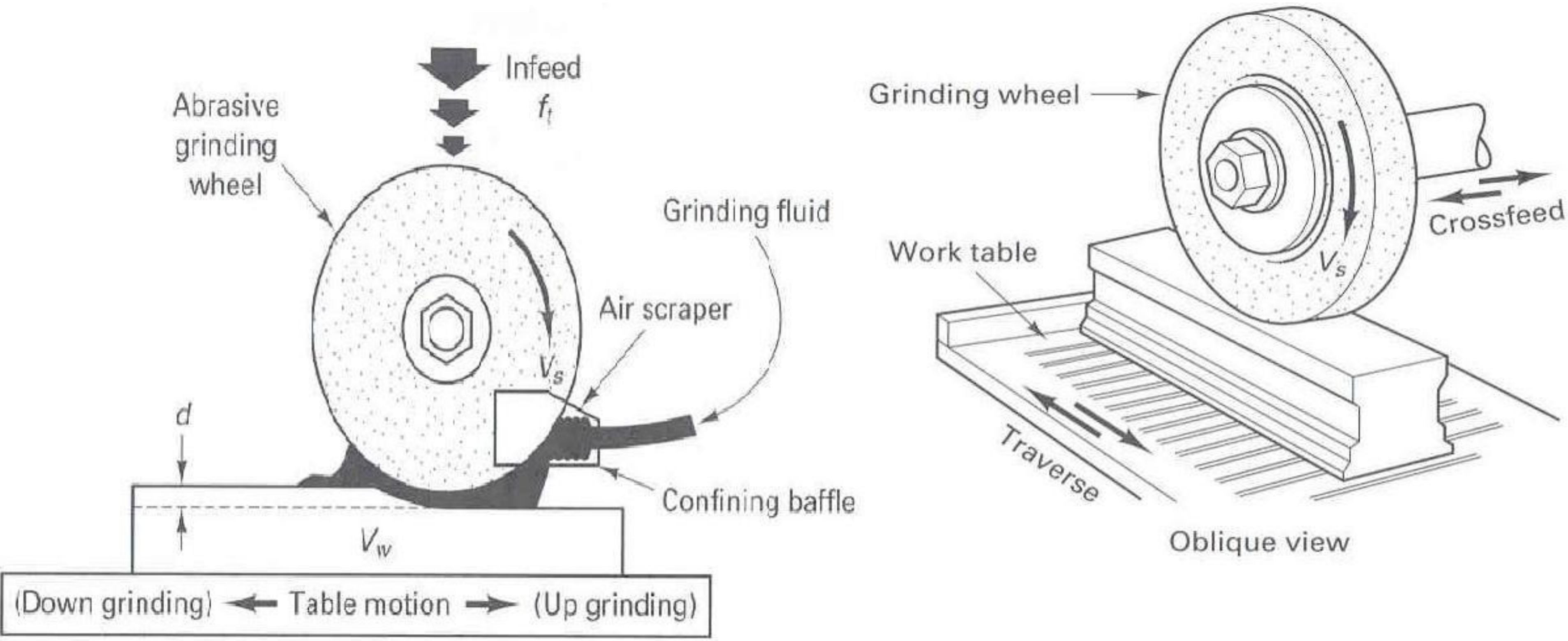


FIGURE 27-1 Schematic of a surface grinding, showing infeed and cross-feed motions along with cutting speeds, V_S, and workpiece velocity, V_W.

What makes the grinding different?

Large number of cutting edges that are very small and made of abrasive grits.

The cutting edges cut simultaneously.

Very fine and shallow cut are only possible → good surface finish (<Ra=0.8) and dimensional accuracy

→ Finishing and important Operation

Abrasive grits are extremely hard → very hard material can be machined.

→ e.g. hardened steel, glass, carbides, ceramics etc.

Features with strict tolerance and surface finish are machined by grinding.

→ e.g. Turbine Blade Fir-tree, Bearing seat diameters,

tool making, tool repair, etc.

Mesh sizes: 4 → 240 for grinding

240 → 600 for honing & lapping

The shape of the grain affects accuracy of the grain screening

GRINDING WHEELS

Abrasive bonded together in a disk (wheel)→ three main factors influence the performance of the grinding wheel:

a) Abrasive material

b) Bonding material

c) Structure

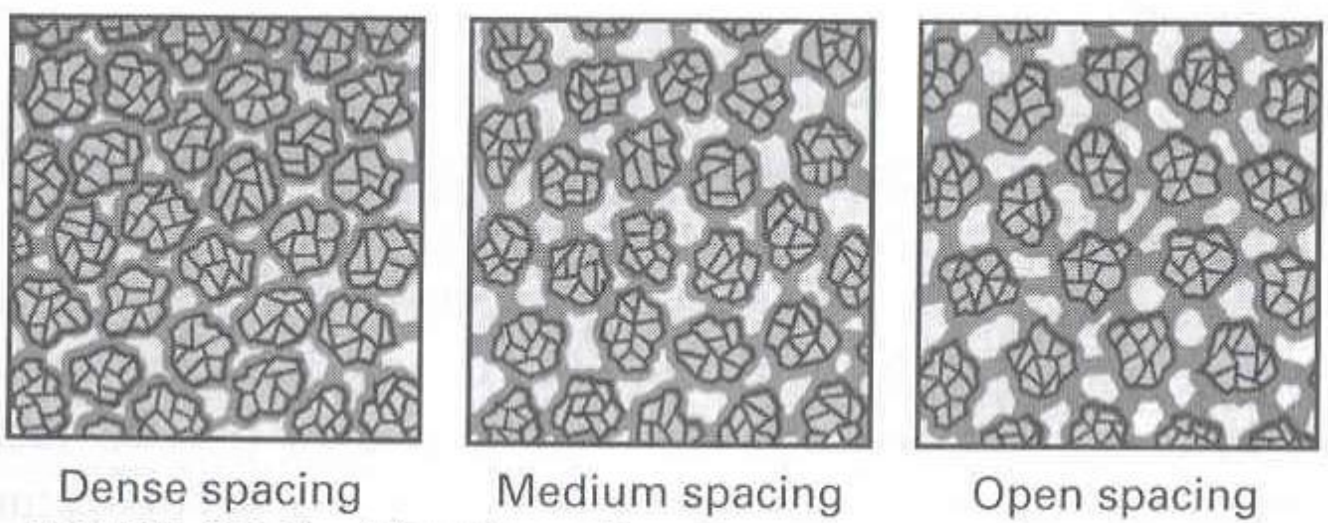


FIGURE 27-7 Meaning of grinding wheel “structure”.

Abrasives **different for:**

Grinding (Bonded wheel)
Honing (Bonded, very fine)
Snagging (Bonded, belted)
Lapping (Free abrasives)

Abrasive grains are bonded together to form tools (wheels)

Abrasive → NATURAL & MANUFACTURED

A. NATURAL ABRASIVES – *Sand*

1. Sand stone (quartz) – wheels **→ used for hand grinding– *cheap***
(SiO_2 + impurities) → is not uniform and does not wear evenly.

2. Corundum and Emery **– better uniformity** and **good for production**
(Natural Al_2O_3 and Al_2O_3+Fe_3O_4+impurities)

3. Diamond and garnets
– **abrasive material (Hardest)**
- most expensive (Carbon)
- hardness 10 on Mohr's scale

B. MANUFACTURED ABRASIVES

1. **Silicon Carbide (carborundum)** – discovered in 19^{th} century during an attempt to get precious gems.
   Hardness Mohr's Scale of 9.5.
   Produced at $2300^{0}C$ during a long period of time.
   Very sharp but brittle.
2. **Aluminium Oxide (Alundum)** – made of bauxite (AlO) – slightly softer than SiC but tougher.
3. **Cubic Boron Nitride (CBN)** – recently – hard (9.5) and tough
   – very good high temperature properties

SIZING OF ABRASIVE GRAINS:

Determined by the maximum number of openings in 1" length of the screen in a mechanical sieving machine.

- Graded into sizes specified by number → 4 to 600

  grade numbers 4 – 600 → the number of meshes in 1" that generates the mesh screen

Ranges of grades:

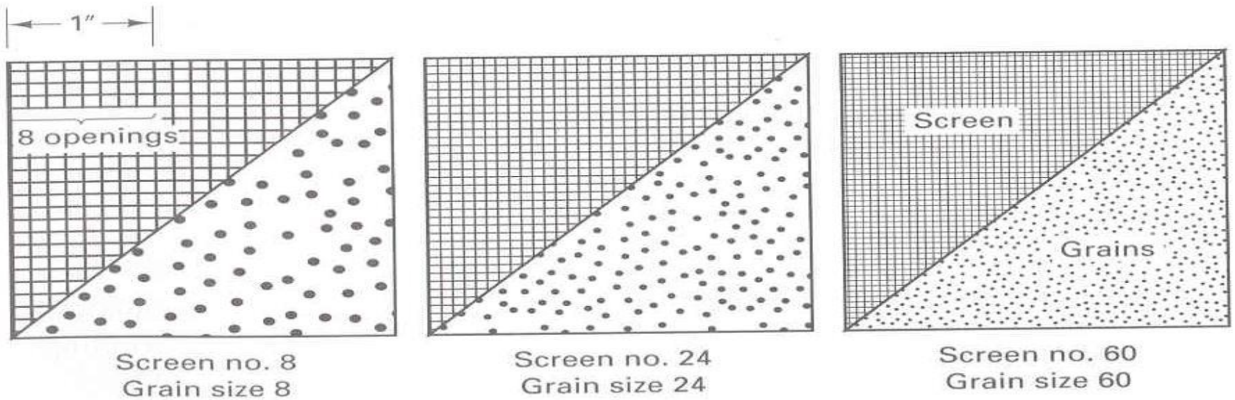
Grade numbers (S): 4 → 24 Coarse

30 → 60 Medium

70 → 600 Fine

The average diameter of the grain ~ 0.7/S (Grid 600→0.03mm size, 4→4.4mm size)

FIGURE 27-3 Typical screens for sifting abrasives into sizes. The larger the screen number (of openings per linear inch), the smaller the grain size.



MANUFACTURE OF WHEELS:

Grains mixed with bonding material;

Moulded or cut **to proper shape and heated so that the bond melts.**

Heating (burning) process varies according to the type of bond used.

Bonding materials **- determine the max. allowed speed the wheels could work.**

- determine the rigidity and the strength (flexibility & toughens)

- the force required to dislodge the grains

- should have a similar wear rate as of abrasive grit.

Types of bonds:

1. VITRIFIED BONDS (75% of all wheels) – similar to firing pottery

- Clay with other ceramics are mixed with abrasive grains

- Wheels are formed from this mix and dried; then fired for 1-14 days

→ the bonding material becomes hard, strong and similar to glass

Characteristics: porous, strong, unaffected by water, or high temperature

SAFE SPEED 60m/s (12000 fpm)

STANDARD SPEED 33 m/s (6500 fpm)

2. SILICATE BONDS:

Sodium silicate mixed with abrasives.

Wheels: formed, dried and backed at 260^0 C for 1-3 days.

Speeds: 40-70 m/s

Milder and wear more rapidly.

Large wheels → are formed for tool grinding, therefore they do not deform too much during baking, as vitrified do.

3. RUBBER BONDS: **pure rubber, sulphur and vulcanising agents are mixed with grains. Rolled and vulcanised under pressure → very thin wheels/sheets can be produced/because of the elasticity of the bond.** Speeds upto (45-80 m/s) is used for cutting off/hot circular saws.

4. BAKELITE OR RESINOID BONDS

synthetic resin is mixed with the grains. wheels are moulded and backed → the bond **very hard & strong,** speeds 48-80m/s → can remove metal rapidly but are **expensive**

SELECTION:

1. Size and shape of wheels – (standard) – the straight type ANSI

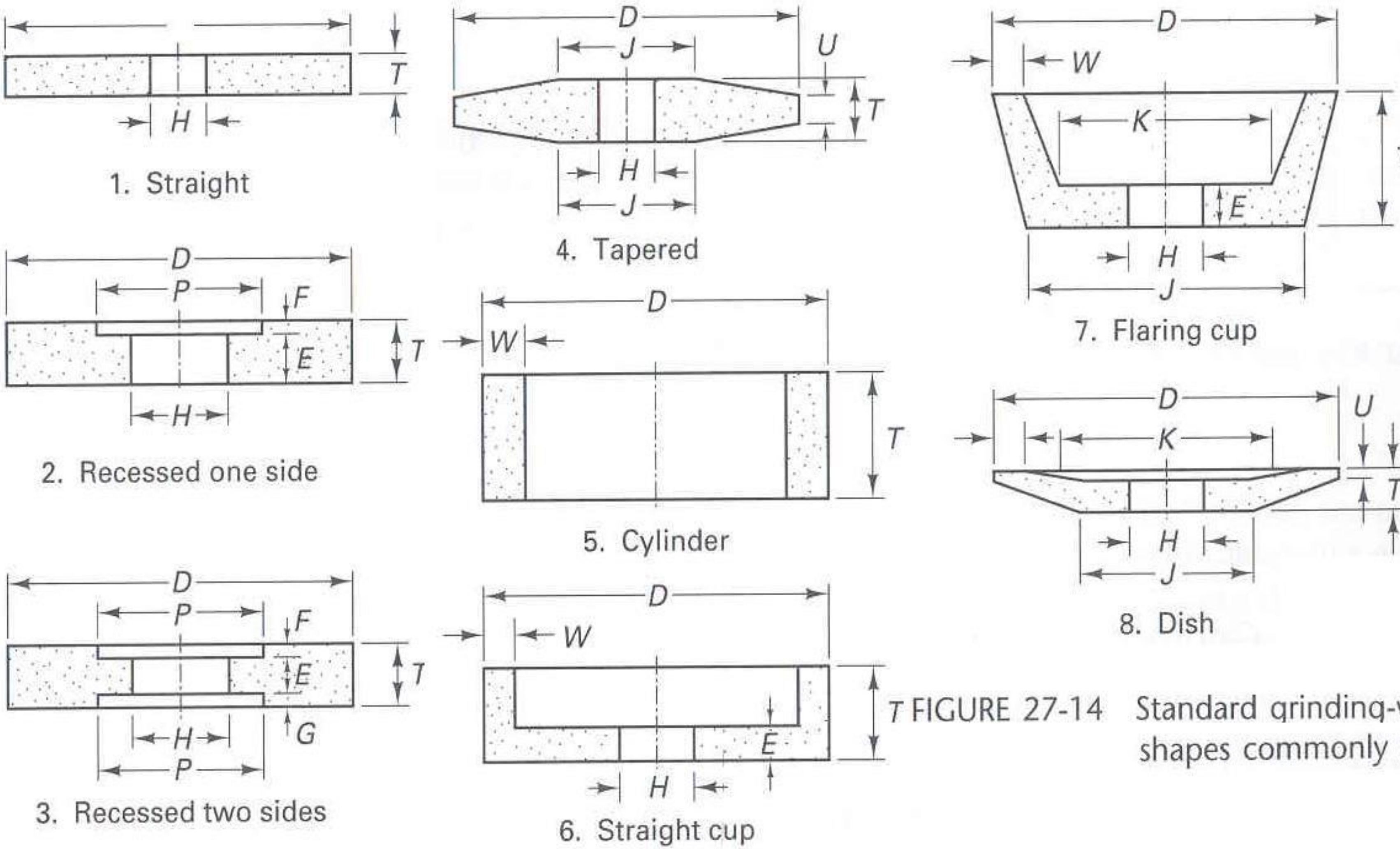


FIGURE 27-14 Standard grinding-wheel shapes commonly used.

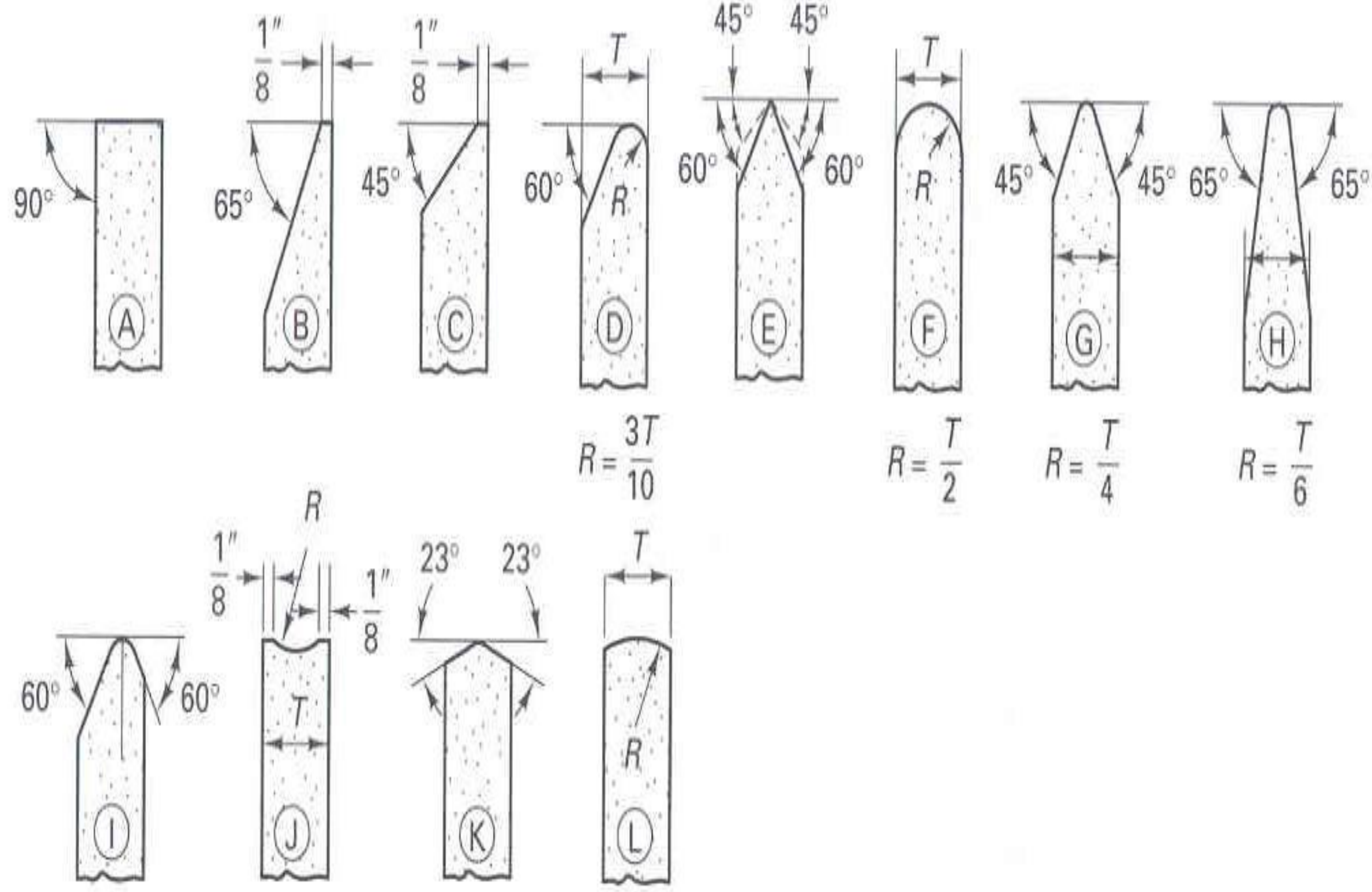


FIGURE 27-15 Standard face contours for straight grinding wheels.

2. Kind of abrasive, SiC or Al_2O_3 or CBN → selection depends on the characteristics of the metal that must be ground

SiC - materials with low tensile strength (cart iron, brass stone, rubber, cemented carbides)

Al_2O_3,CBN- materials with high tensile strength material such as: hardened steel, high speed steel, alloyed steel

3. Grain size of abrasive particles

Coarse wheels (<40 mesh screen size) – fast removal of material and for soft materials

Fine – grained wheels (>70 mesh screen size) – for finishing and hard & brittle materials

4. Grade or strength of bond

Grade → depends on the kind and hardness of bonding materials.

If bond is strong → capable to hold the abrasive grains → it is called a **HARD WHEEL**; Otherwise a **SOFT WHEEL.**

Hard wheels cut	Soft wheels cut
↓	↓
Soft materials	Hard materials

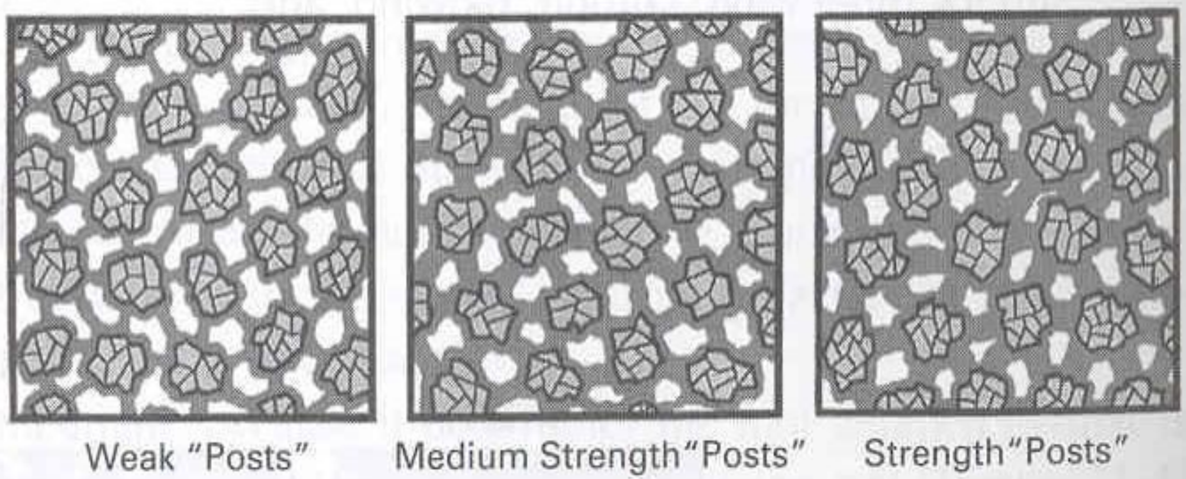


FIGURE 27-9 The grade of a grinding wheel depends on the amount of bonding agent on the holding of abrasive grains in the wheel. *(Courtesy of Carborundum Company.)*

5. Structure or grain spacing – refers to the number of cutting edges per unit area of wheel face or to the space available between grains.

* **Soft materials require wide spacing**
* **Fine finish requires close spacing**

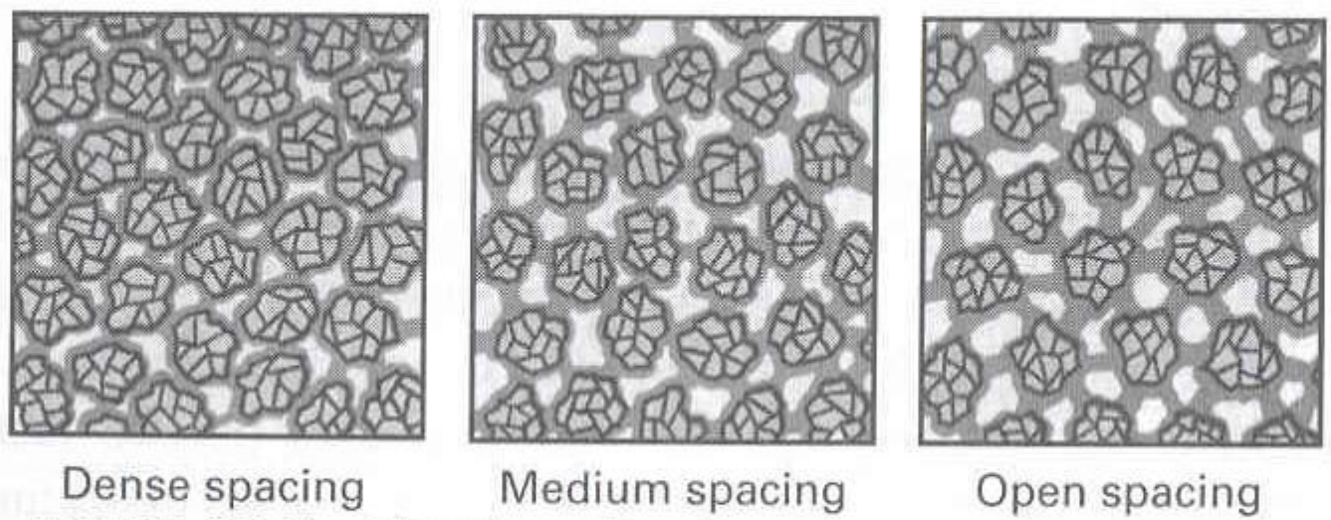


FIGURE 27-7 Meaning of grinding wheel "structure".

6. Kind of bond material

→ usually, vitrified bond is required

→ for thin wheels or high speeds → different kind of bonds

A STANDARD COMPEREHENSIVE MARKING SYSTEM CHART DEVELOPED BY ANSI

STANDARD MARKING SYSTEM CHART
ANSI STANDARD B74,13 – 1970

Sequence: Prefix	1 Abrasive type	2 Grain size	3 Grade	4 Structure	5 Bond type	6 Manufacturer's record
51	A	36	L	5	V	23

PREFIX	ABRASIVE TYPE	ABRASIVE (GRAIN) SIZE				GRADE			STRUCTURE	BOND TYPE	MANUFACTURER'S RECORD
		COARSE	MEDIUM	FINE	VERY FINE	SOFT	MEDIUM	HARD	DENSE TO OPEN		
Manufactuer's symbol indicating exact kind of abrasive *(use optional)*	A – Aluminum Oxide C – Silicon Oxide	8 10 12 14 16 20 24	30 36 46 54 60	70 80 90 100 120 150 180	220 240 280 320 400 500 600	A E B F C G D H	I M J N K O L P	Q V R W S X T Y U Z	1 9 2 10 3 11 4 12 5 13 6 14 7 15 8 16 etc. *(use optional)*	B – Resinold BF – Resinold reinforced E – Shellac O – Oxychloride R – Rubber RF – Rubber reinforced S – Silicate V – Vitrifed	Manufacturer's private marking to identify wheel *(use optional)*

FIGURE 27-13 Standard marking system for grinding wheels (ANSI standard B74. 13-1970).

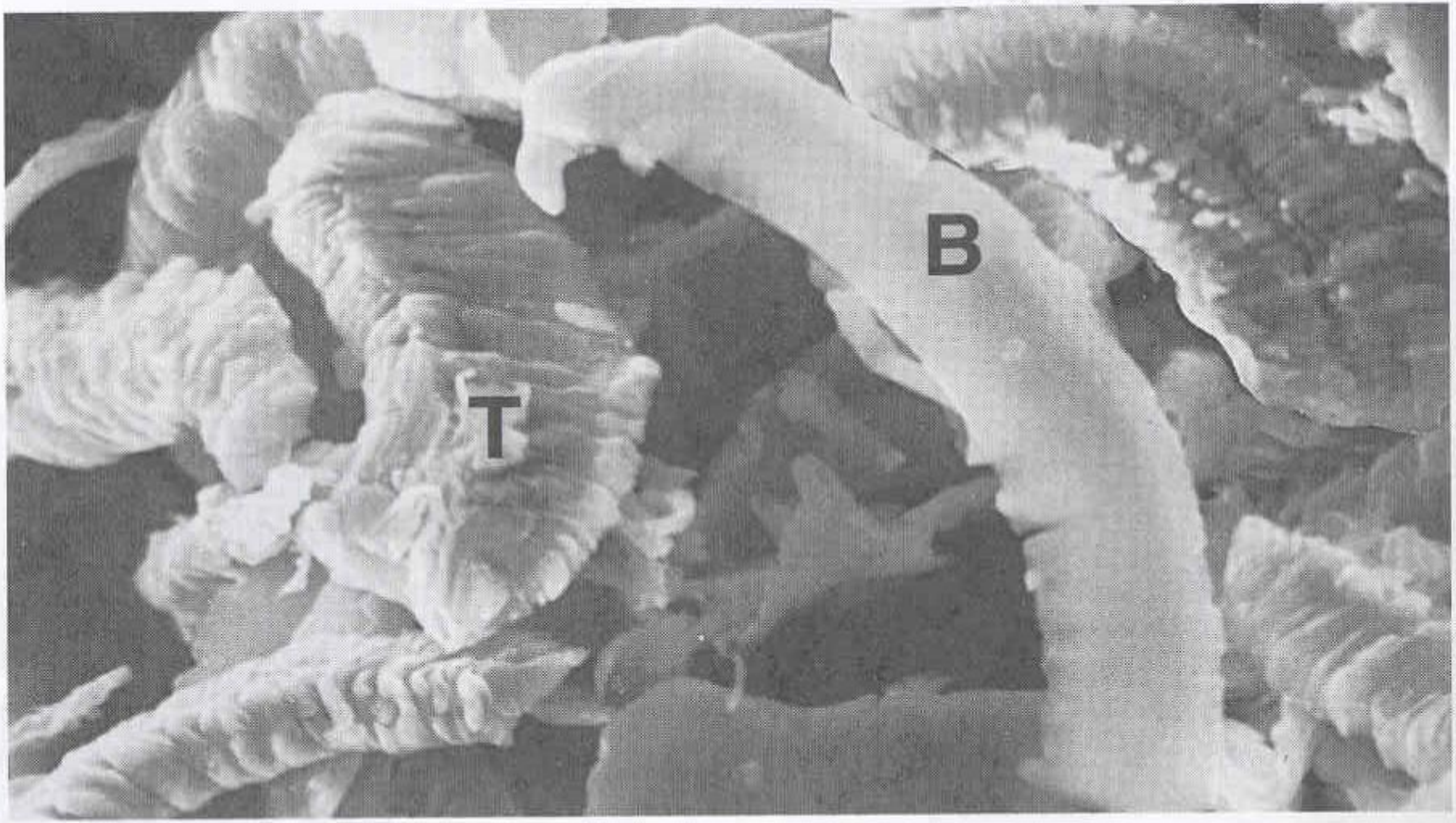


FIGURE 27-8 SEM micrograph of stainless steel chips from a grinding process. The tops (T) of the chips have the typical shear-front-lamella structure while the bottoms (B) are smooth; 4800×.

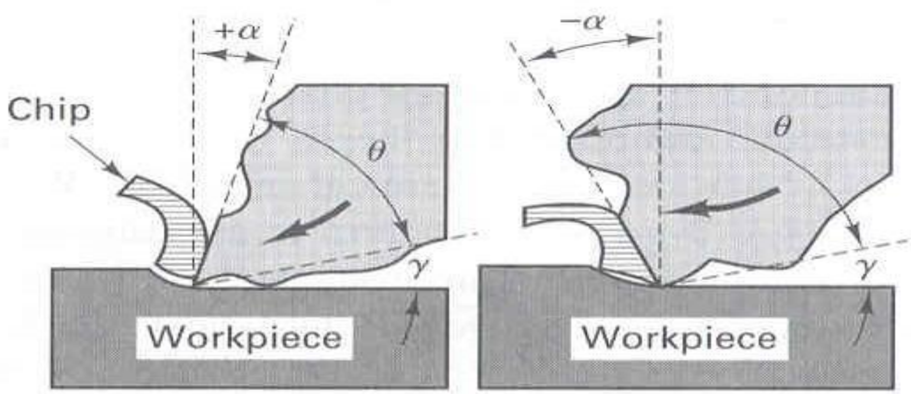
Only 2-5% of the surface area of the grain is useful.

CUTTING PROCESS:

Cutting action of grinding wheel:

Structure of the wheel decides its cutting action.

- Each cutting edge produces small chips in similar action as single point action
- Edge dull → the large friction forces remove the dull grain→ the old grain is replaced by a new one.
- Grade or strength of bond controls removal of grains → the kind of bond and the amount of bond is important.



Rake angle: +45° to –60°

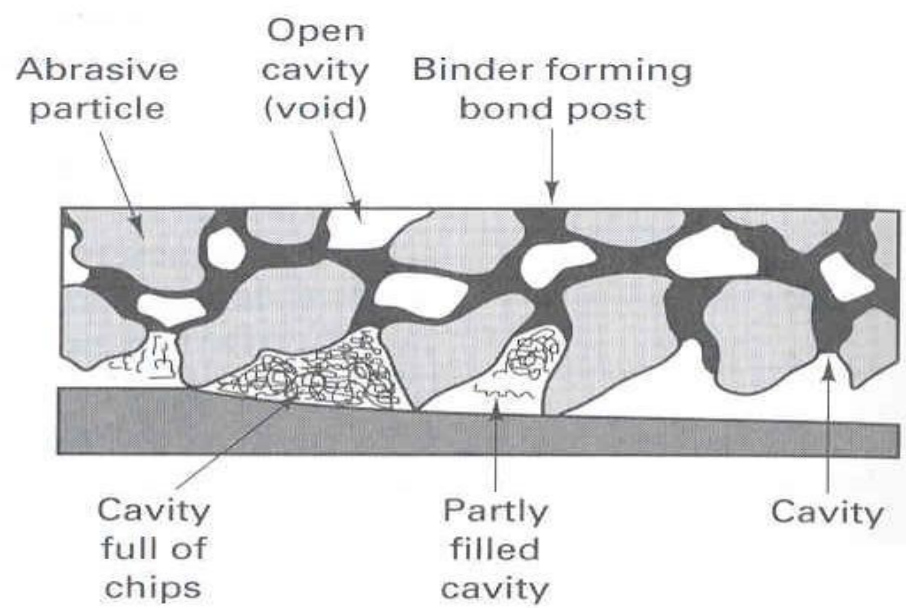


FIGURE 27-4 The rake angle of abrasive particles can be positive, zero, or negative. The cavity or voids between the grains must be large enough to hold all the chips during the cut.

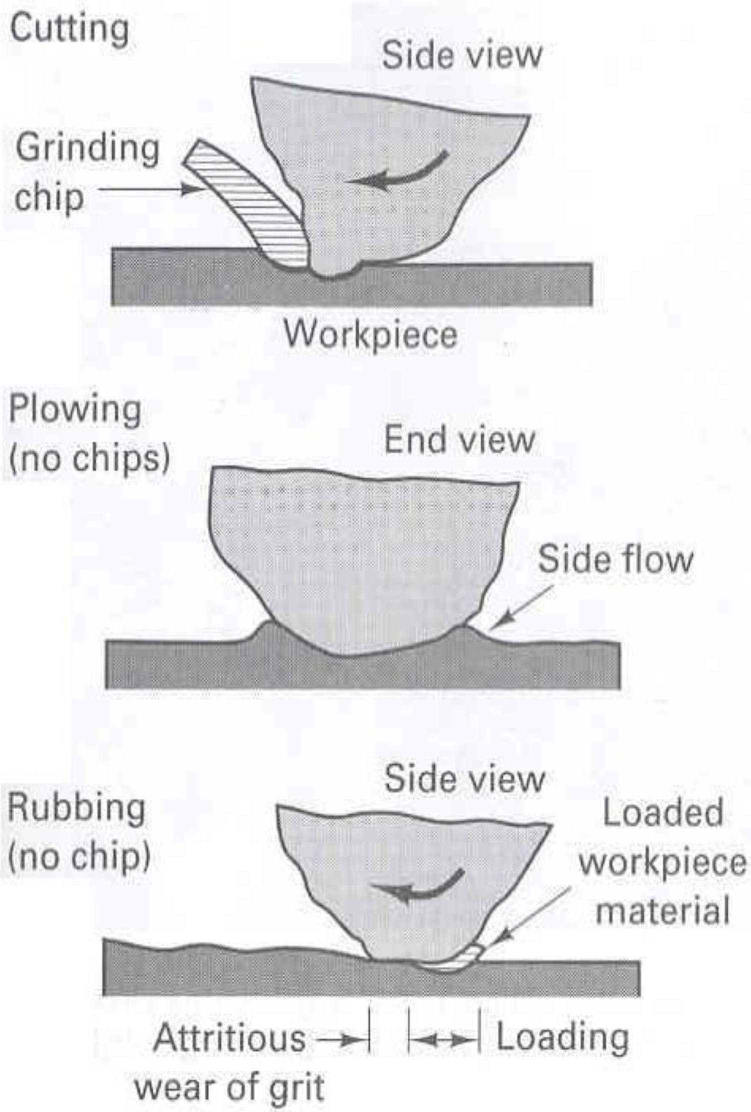


FIGURE 27-5 The grits interact with the surface three ways: cutting, plowing, and rubbing.

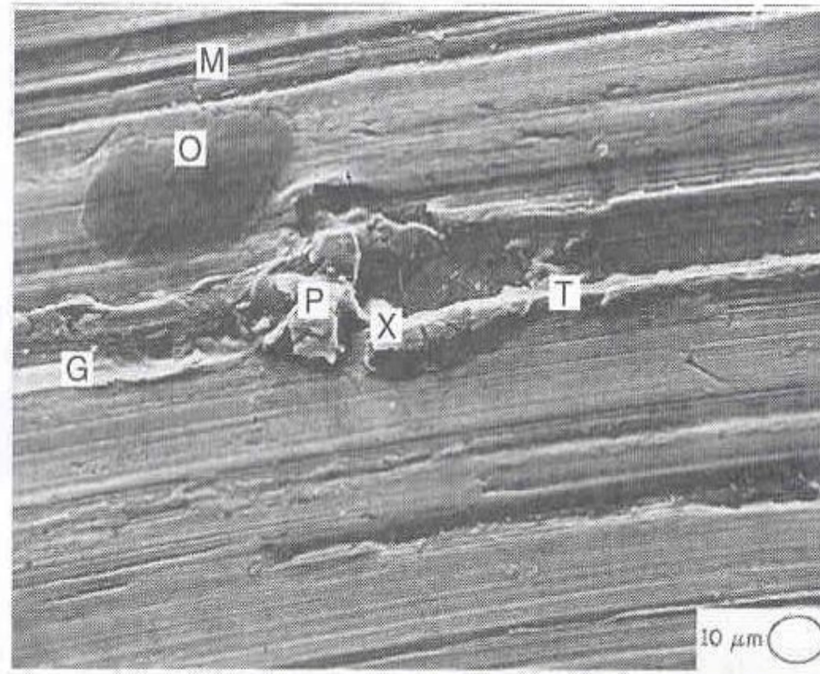


FIGURE 27-6 SEM micrograph of a ground steel surface showing a plowed track (T) in the middle and a machined track (M) above. The grit fractured, leaving a portion of the grit in the surface (X), a prow formation, (P), and a groove (G) where the fractured portion was pushed farther across the surface. The area marked (O) is an oil deposit.

- The ratio of material removal/ abrasive removal is 40:1 → 80:1 in volume

→ **the wheel looses its shape**

- Self-sharpening of a dull wheel may occur when deeper cuts are taken.

  * Optimal value of cut depth for which required cutting power becomes lower and the wheel wear rate provides the wheel with continuous replacement of dull grains with sharp edges grains→ natural regeneration THIS IS NO SUFFICIENT IN LONG RUN. To regenerate the grinding wheel → to provide a new sharp cutting edges when the wheel becomes dull.

DRESSING OF THE WHEEL → TRUING, reshaping the wheel to the initial form

- various tools are used the when wheel is **loaded (dirty)**

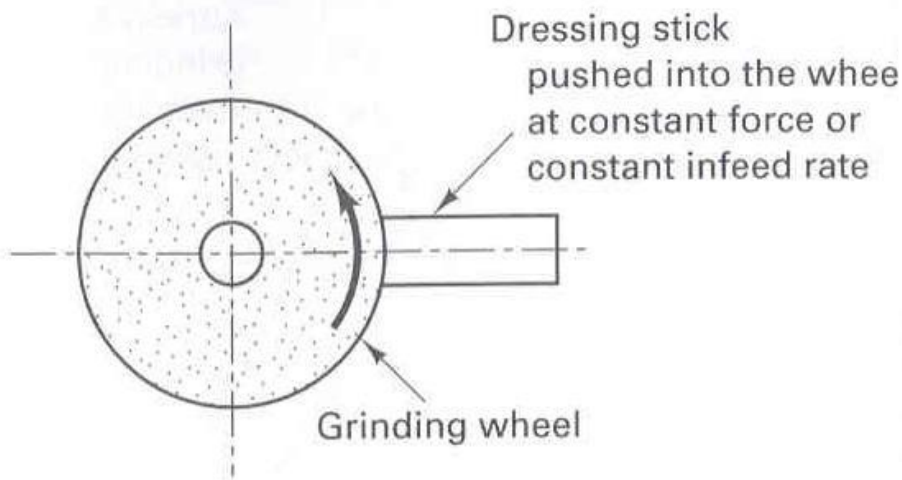


FIGURE 27-11 Schematic arrangement of stick dressing.

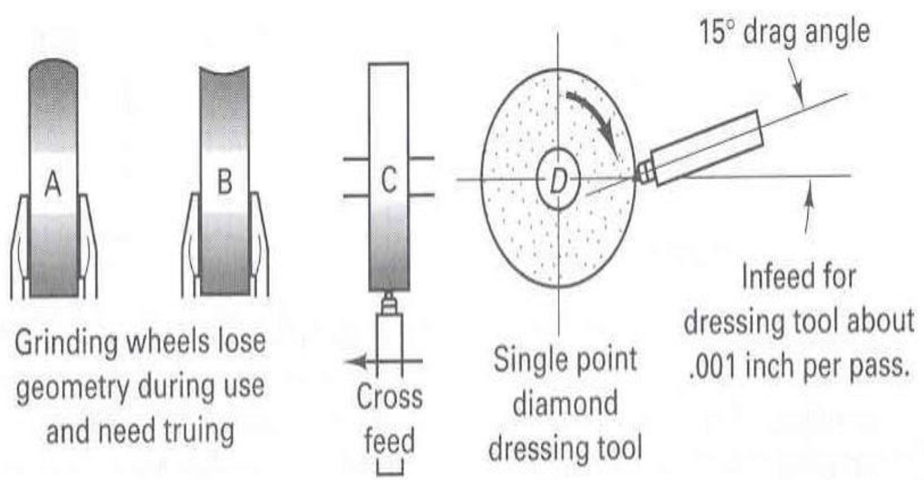


FIGURE 27-12 Diamond nibs may be used for truing wheels in batch operations.

CRUSH DRESSING:

A hard steel roll (with required profile) is pressed against the grinding wheel that revolves slowly → the crushing action dislodges the chips and improves the contour of the wheel.

• Some machines are equipped with crushing equipment (pre-installed)

HARD & SOFT WHEELS:

A hard wheel is becoming dull faster because it is not loosing grains

(which are strongly hold)

→ for hard materials, soft wheels are required.

• Speed of the work piece affects the cutting action of the grinding wheel.

PROBLEMS RELATED TO GRINDING

1. **BALANCING** :

   - The high wheel speed → new wheel to be balanced in special balancing machines.
   - Not balanced wheels affect the quality of the ground surface because of the vibrations (also can produce accidents when cracked)

2. **SAFETY PROBLEMS:**

   - Speed limit (marked on wheels) should be respected –-
   - Cracking of the wheel should be avoided (do not hit or drop)
   - Face of the operator protected against grain dislodging
     → safety glasses are mandatory
   - Wheel should be shielded – dust should be collected (vacuumed) and filtered

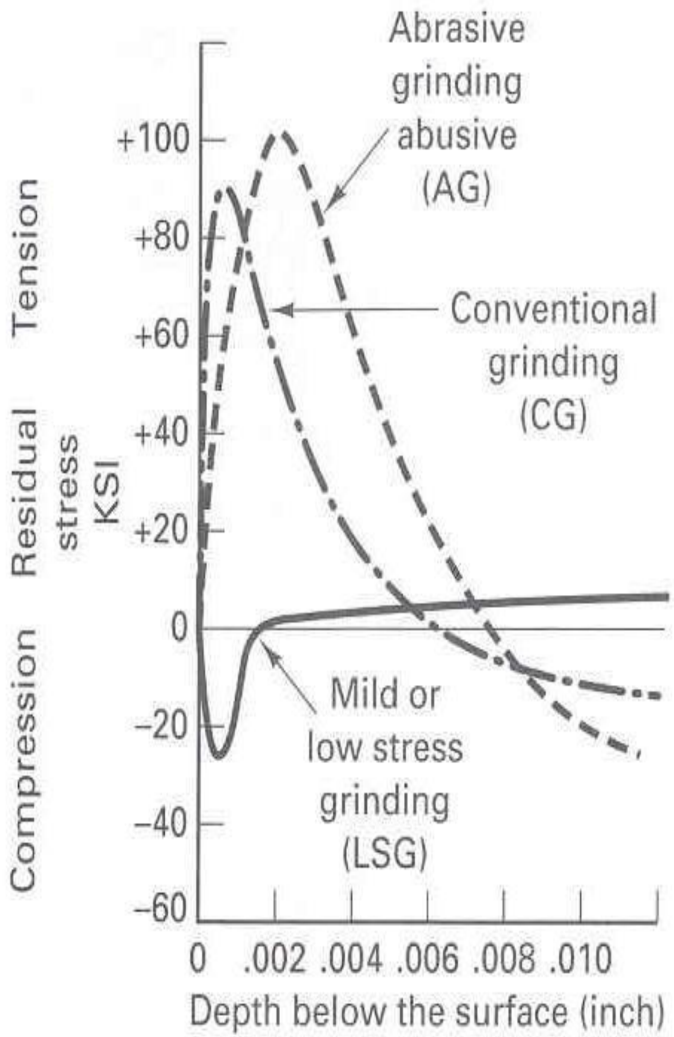
3. **RESIDUAL STRESS:**

   - Surface of the work builds up residual stress; low chip thickness → lower stress

4. **USE OF COLLANTS**:

   - cooling & lubrication & collect dust and chips
   - Sometimes, with out coolants, better finish is obtained (matter of experience)

5. **GRINDING- PRECISION OPERATION** → Samples with precision up to 0.25 micron



Grinding conditions

	Abusive AG	Conventional CG	Low stress LSG
Wheel	A46MV	A46KV	A46HV or A60IV
Wheel speed ft/min.	6,000 to 18,000	4,500 to 6,500	2500-3000
Down feed in/pass	.002 to .004	.001 to .003	.0002 to .005
Cross feed in/pass	.040 .060	.040 .060	.040-.060
Table speed ft/min	40 to 100	40 to 100	40 to 100
Fluid	Dry	Sol oil (1 : 20)	Sulfurized oil

FIGURE 27-10 Typical residual stress distributions produced by surface grinding with different grinding conditions for abrasive, conventional, and low stress grinding. Material 4340 steel. (*From M. Field and W. P. Koster, "Surface integrity in grinding," in* New Developments in Grinding, *Carnegie-Mellon University Press, Pittsburgh, 1972, p. 666.*)

GRINDING MACHINES (GRINDERS)

Two standard types of shapes: Cylindrical and Flat

The form of the work gives the type of the grinder

- Special grinders for tool grinding (other type of shapes)
- Grinders – heavy and rigid machines, with precise controls and special protection of moving parts.
- Requires skilled operators, unless automated for mass production

CYLINDRICAL GRINDERS

Differ according to the method of supporting the workpiece

1. The workpiece → is rotating between centers + dog or held in chuck
2. Centerless grinders : work is supported by the arrangement of: work rest; regulating wheel and grinding wheel.
   Both types → plain grinding wheels with grinding face on circumference
3. Plain center – type cylindrical grinders

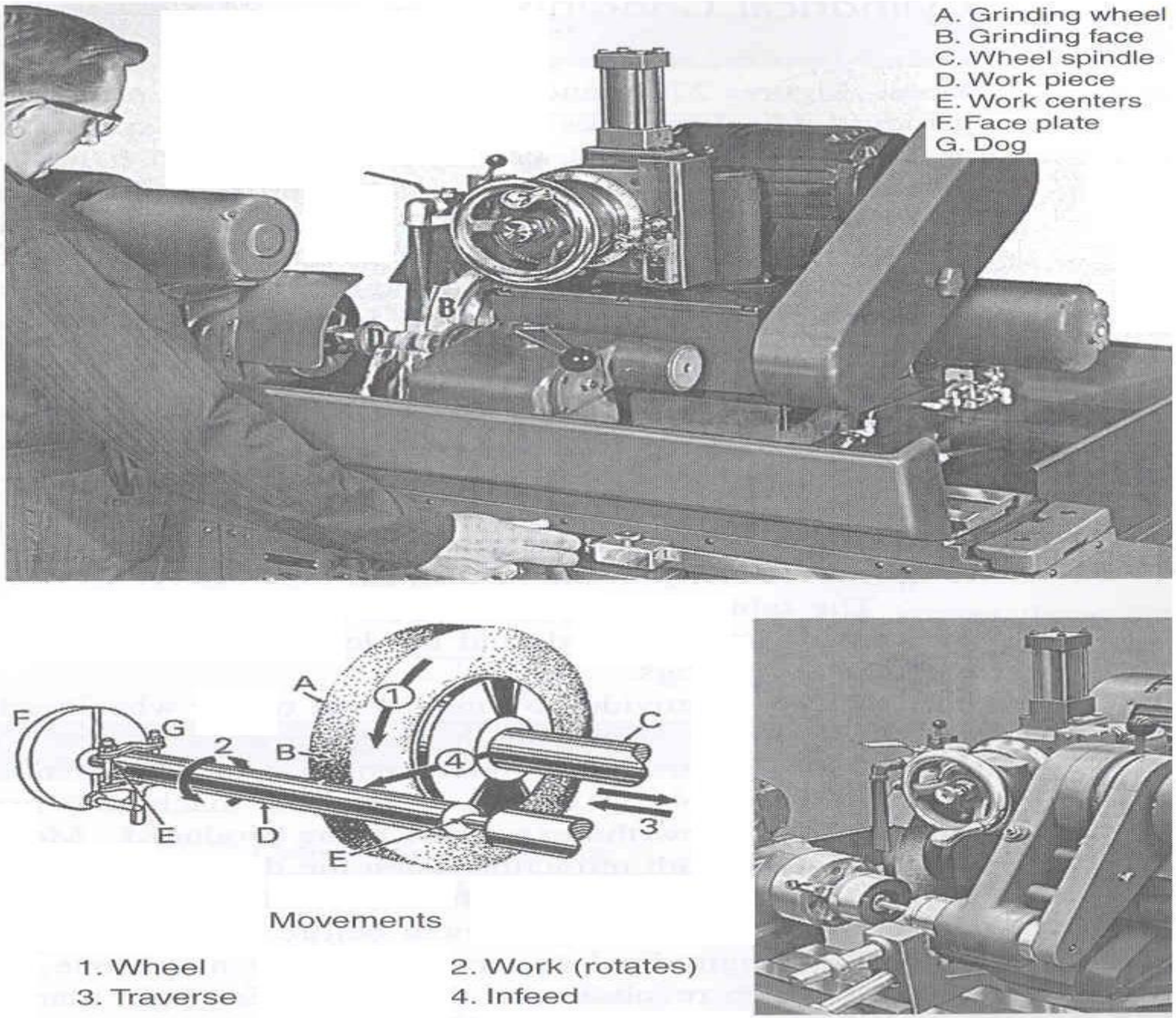


FIGURE 27-18 Cylindrical grinding between centers, *lower right:* Internal cylindrical grinding on same machine.

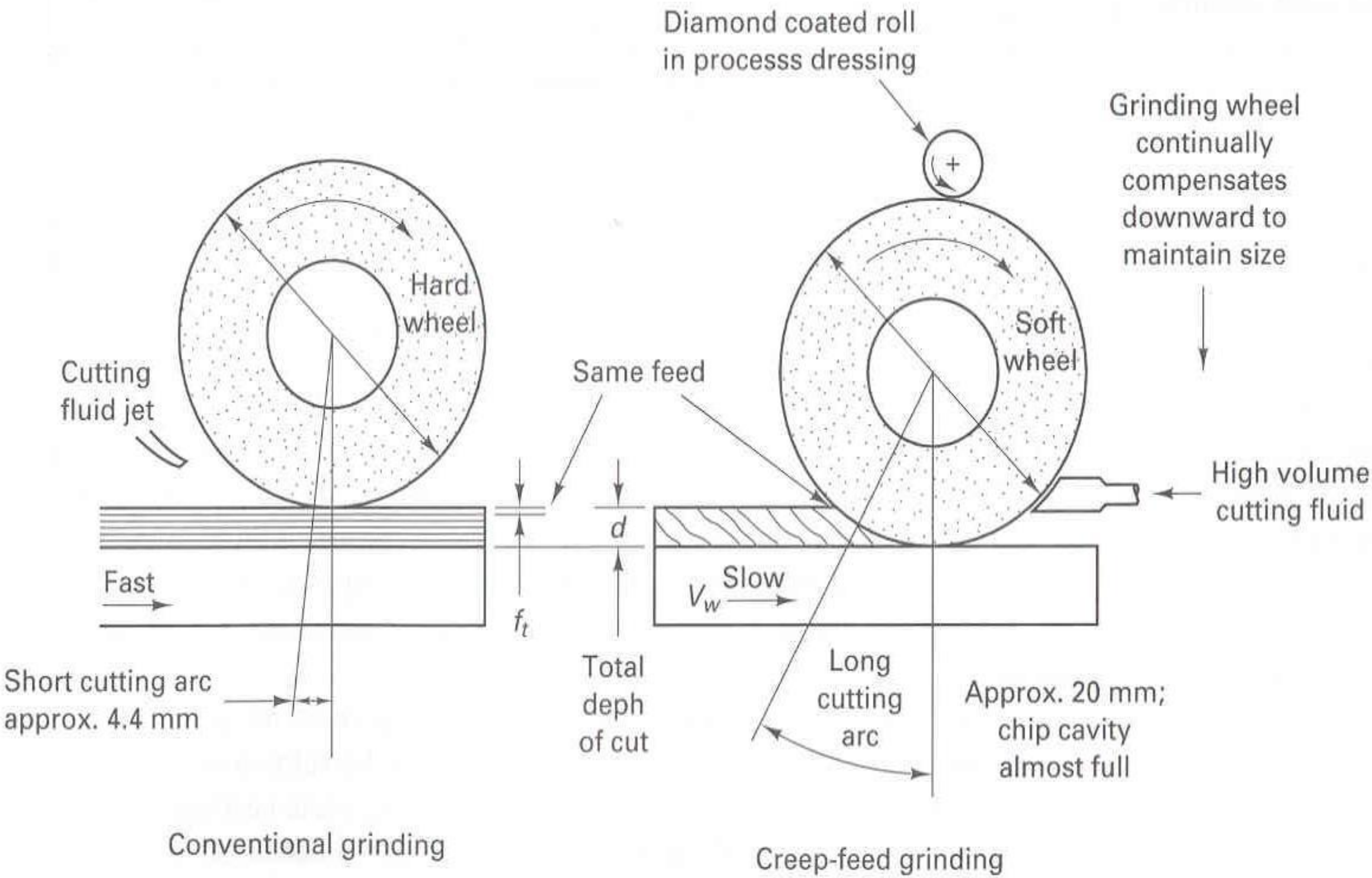


FIGURE 27-17 Conventional grinding contrasted to creep feed grinding. Note that crush roll dressing is indicated.

FIGURE 27-20 Grinding a bearing seat by means of a tool-post grinder on a lathe. *(Courtesy of Dunore Company.)*

FOUR MOVEMENTS:

A: Rotational speed of grinding wheel (28-33 m/s) [30m/s]
B: Slow rotation of workpiece (0.3 / 0.5 m/s) opposite direction
C: Horizontal transverse of work back and forth // to the axis of wheel
D: Infeed (allowance of surplus 0.25 mm)

Depth of cut :

ROUGHING, 0.05 mm
FINISHING, 0.005 mm or less

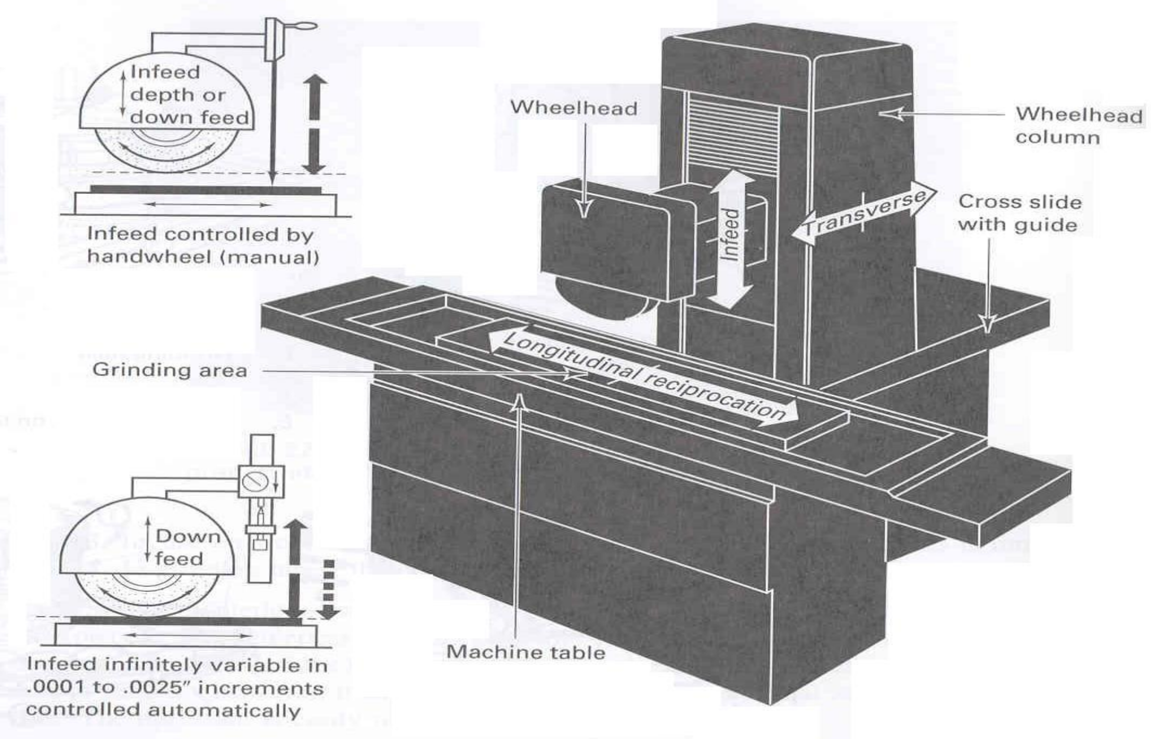


FIGURE 27-22 Horizontal spindle surface grinder, with insets showing movements of wheelhead.

E. Plunge cut → when the wheel is wider than the work.

→ no transverse movement is required (for form grinding → examples: threads)

- Work installed between the headstock & tailstock or between centers (+ dog)

- Headstock spindle may be driven by a belt drive or directly by an electric motor

- Tapered surfaces up to 10^0 (can be ground by the swiveling of the table with the centers ex: Morse and other tapers fixtures)

- UNIVERSAL CENTER – TYPE GRINDERS → fully swiveled table tapers > 10^0 – have additional spindle for **internal grinding**

- Roll grinders → for heavy pieces → the grinding wheel reciprocates and the workpiece only rotates.

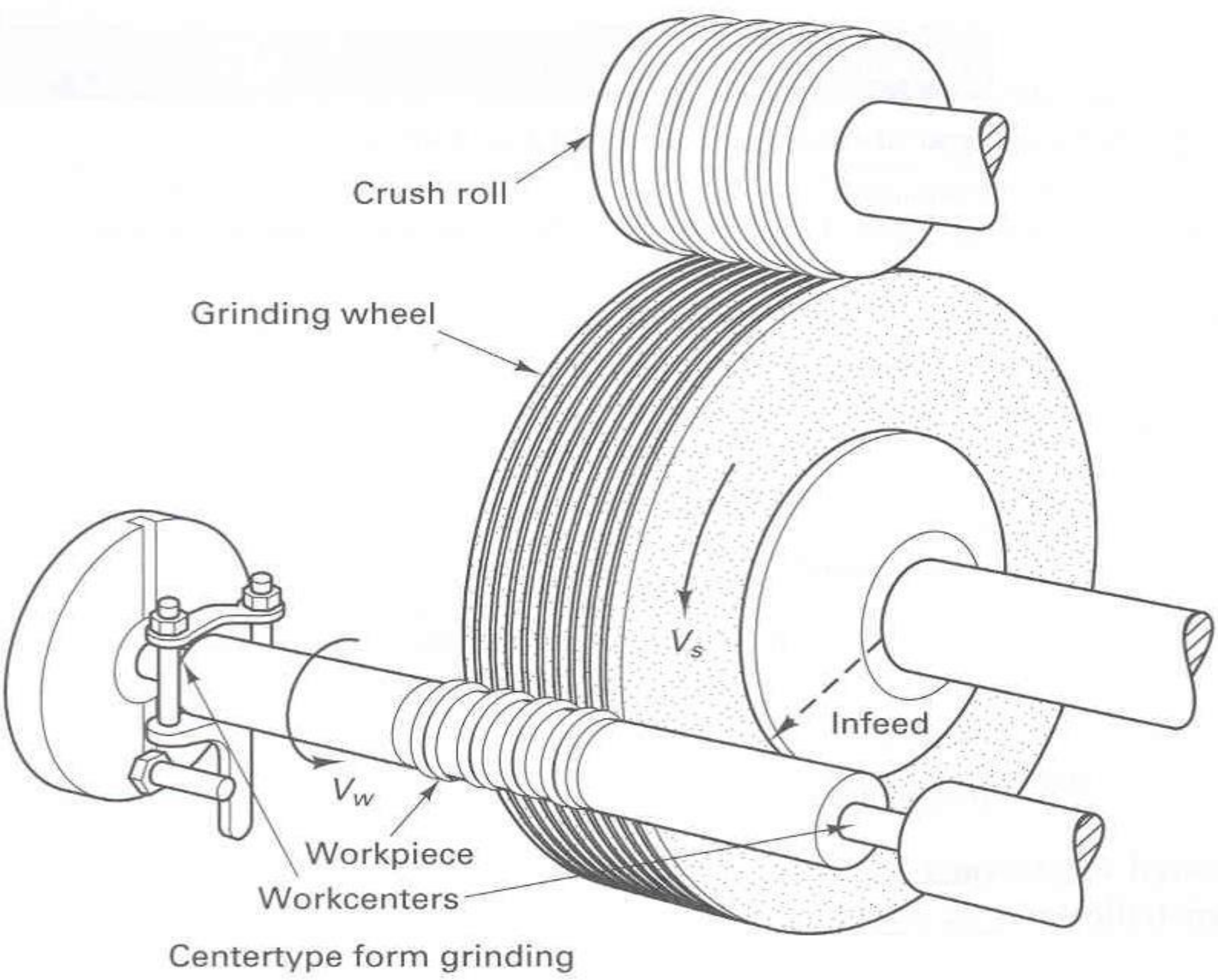


FIGURE 27-16 Plunge cut grinding of cylinder held between centers. Note that crush roll dressing is shown.

CENTERLESS GRINDERS

- Support and feed of the workpiece is provided by using two wheels (regulating and grinding) + work rest.

- Regulating wheel of rubber bonded abrasives. It rotates the work by friction, with a speed of 0.25 – 1 m/s. (much slower than the wheel)

- Both wheel rotate in the same direction to move the work.
- The work rest support the work. The axial movement of the work – piece is obtained by tilting regulating wheel at (5^0 – 7^0).

- Feed can be calculated F= Ø * RPM * sinØ <in/min>

- very productive and work must not be supported → automatic feed TYPES

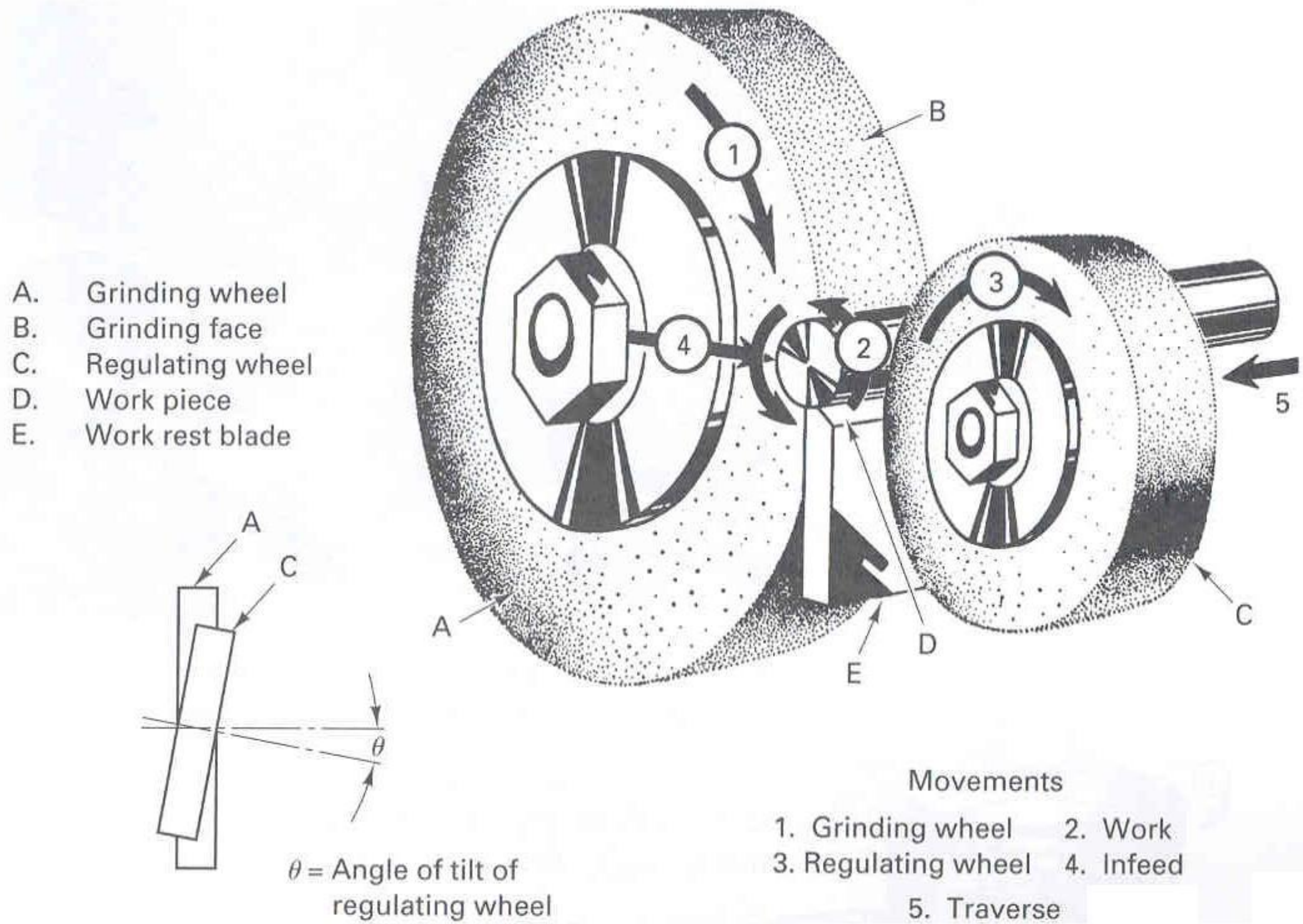


FIGURE 27-19 Centerless grinding showing the relationship between the grinding wheel, the regulating wheel, and the workpiece in centerless method. *(Courtesy of Carborundum Company.)*

A. THRU-FEED GRINDING → the piece of one diameter is fed on one side and is passed between the wheels → e.g. preparing for thread rolling

B. INFEED GRINDING → For form grinding:

To install the piece, the rest and the regulating wheel have to be moved back; when the work is in, the regulating wheel is adjusted to the required position

→ parts with multiple diameters can be ground;

→ for curved parts, wheel with a profile is used → ball grinding for bearing

C. END FEED GRINDING – both wheels are tapered → tapered work/stock bar is fed from one side, until reaches the stop.

ADVANTAGES OF CENTERLESS GRINDING

1. No mounting of workpiece required
2. Size of the work easily controlled
3. No deflection of the workpiece
4. Very reproductive process
5. No high skilled operators are required (only setters).

DISADVANTAGES

1. Pieces with flats and key-ways can not be ground
2. Concentricity and the cylindricity are not assured
3. Machines are very specialised (not universal)→ limited operations only.

INTERNAL GRINDIING

Cylindrical, multi-diameter and tapered holes can be ground.

METHODS:

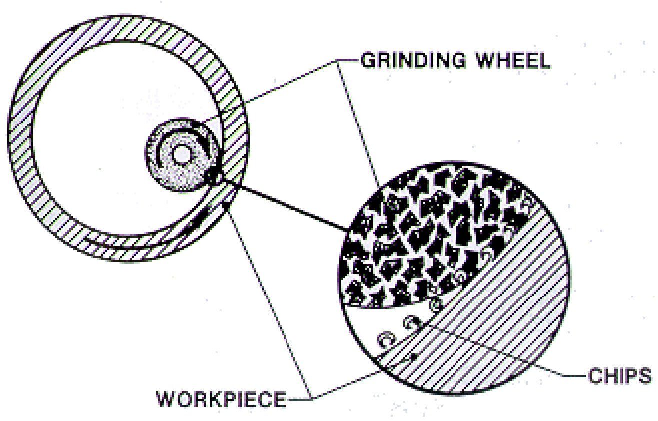
- Wheel – rotating ; work –rotating & reciprocating
- Wheel – rotating & reciprocating; work – rotating
- Wheel: rotating + planetary rotation; work – reciprocating

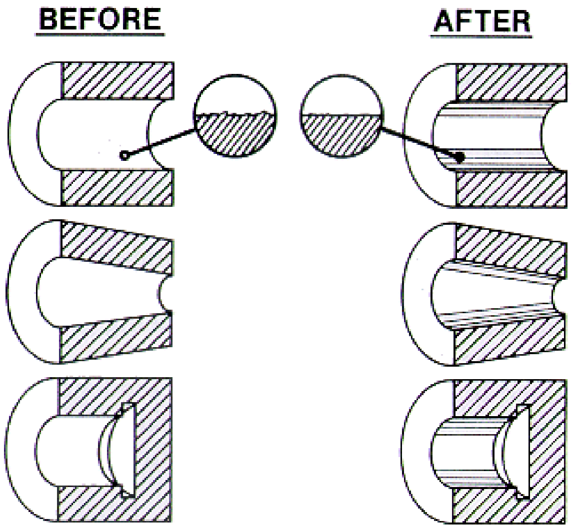
Centerless Internal Grinding :

Requirements: High speeds of spindle

Because small DIA of the wheel (for 30 m/s → 100,000 RPM)

- Depth of the cut 0.02 mm – to decrease forces.



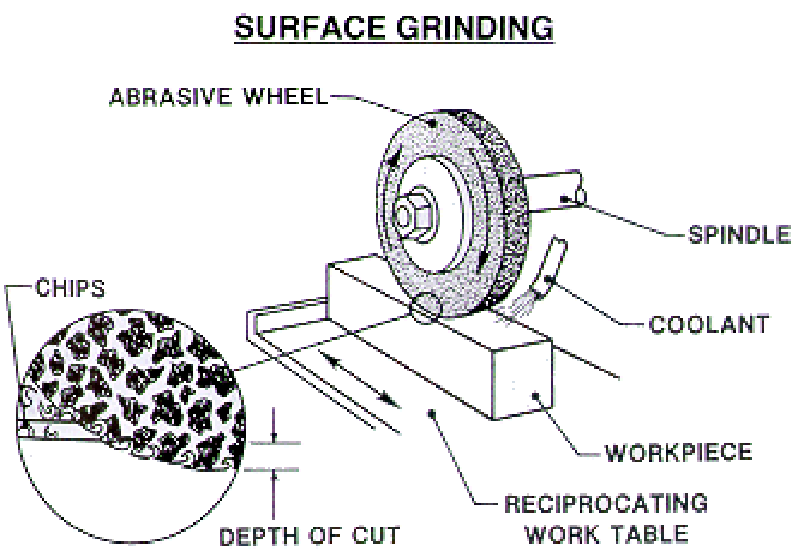


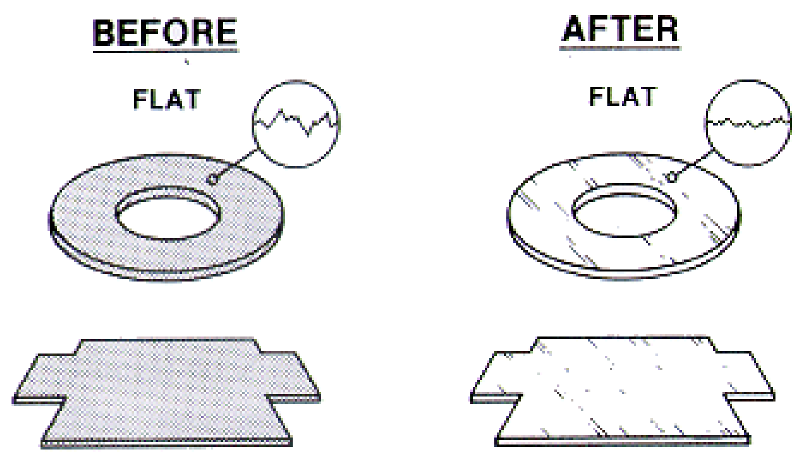
SURFACE GRINDING: Flat surface or irregular surfaces

WHEEL- Transversal feed at end of any table motion

- Another feed provided at the the end of each cut cycle
- Installed directly on the shaft of an electric motor

SIZE OF MACHINE: SIZE DESIGNATION → surface that can be ground; the wheel must meet the overall range of the piece





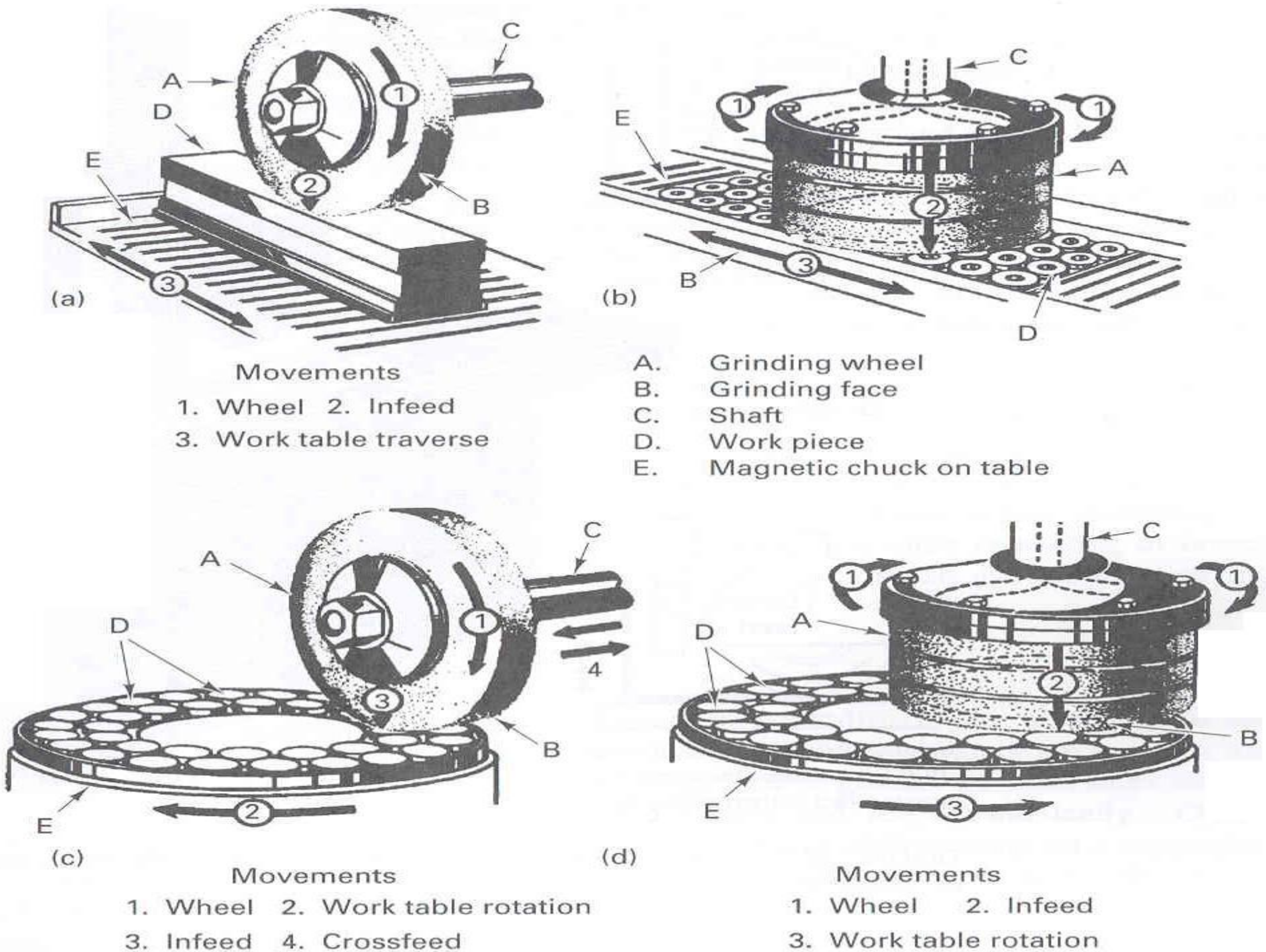


FIGURE 27-21 Surface grinding: (a) horizontal surface grinding with reciprocating table; (b) vertical spindle with reciprocating table; (c) and (d) both horizontal and vertical spindle machines can have rotary tables. *(Courtesy of Carborundum Company.)*

VERTICAL SPINDLE GRINDING MACHINE

- DIA of the wheel – large than the width of the work
- The spindle can be tilted for roughing grinding
- Segment type wheel

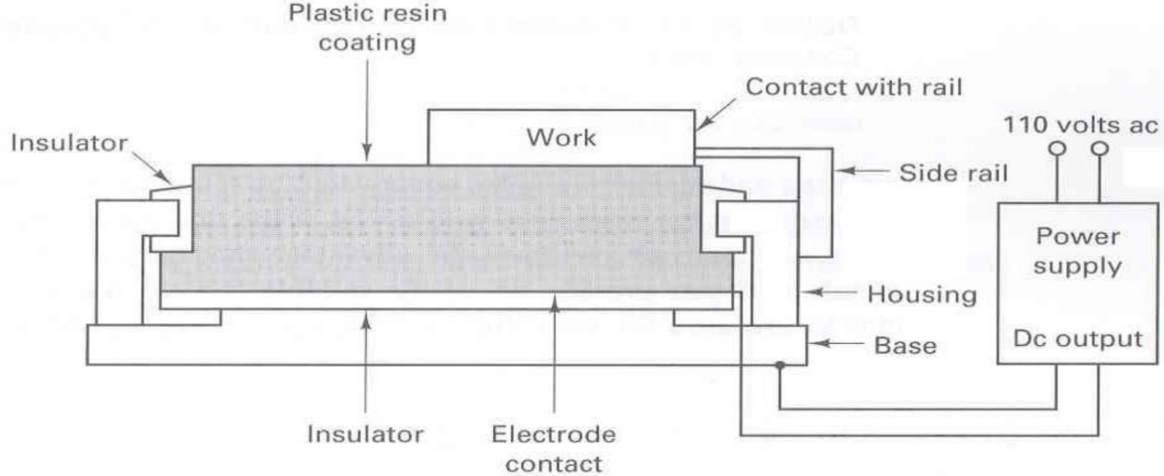


FIGURE 28-22 Principle of electrostatic chuck.

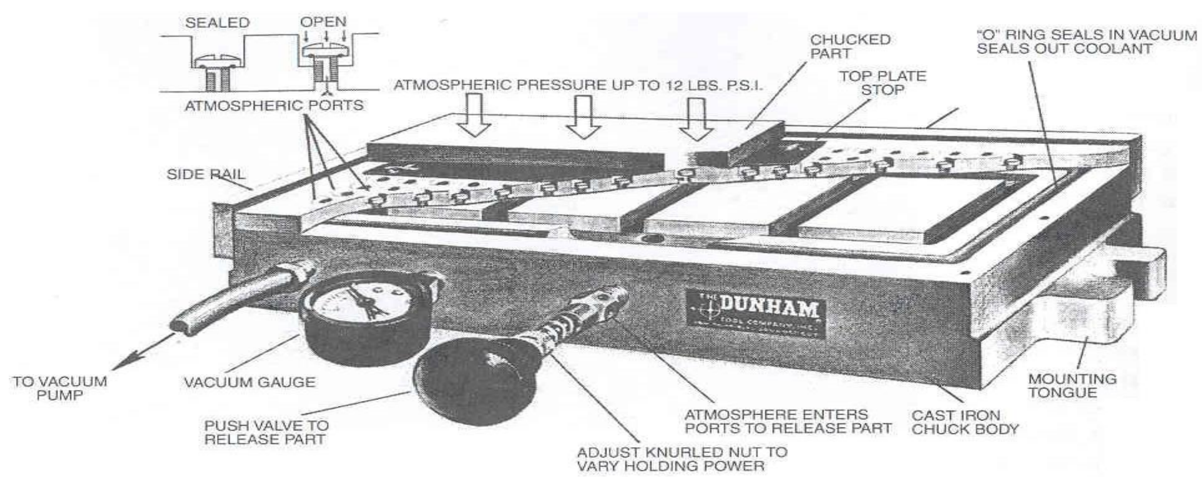


FIGURE 28-23 Cutaway view of a vacuum chuck. *(Courtesy of Dunham Tool Company, Inc.)*

DISC GRINDERS

- For hand grinding operations → work supported on the rest for large wheels

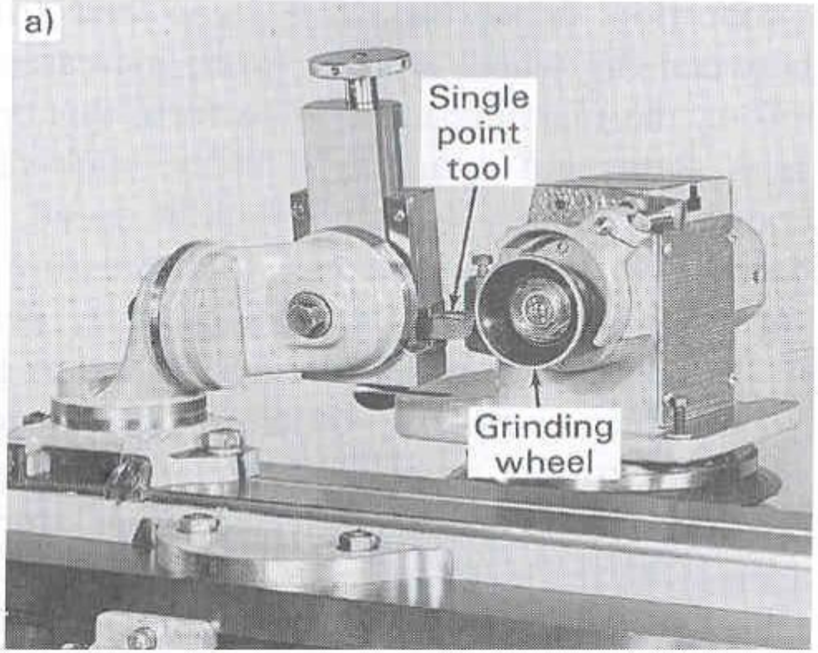
TOOLS & CUTTER GRINDERS

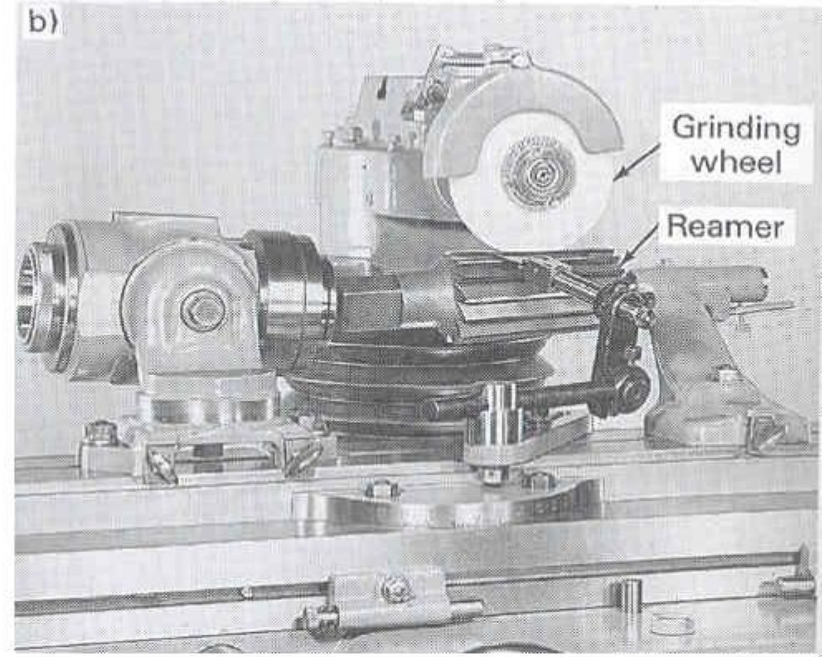
- Universal tool & cutter grinders for sharpening of more complicated tools → every machine shop will have this.

- Are simpler than the cylindrical grinders, do not have power feeds → high degree of flexibility

- Setting up for a tool grinding is complicated → sharpening is easy. Can be equipped with a projector.

- Jig grinders – with high accuracy and speed up to 175,000 RPM for small holes





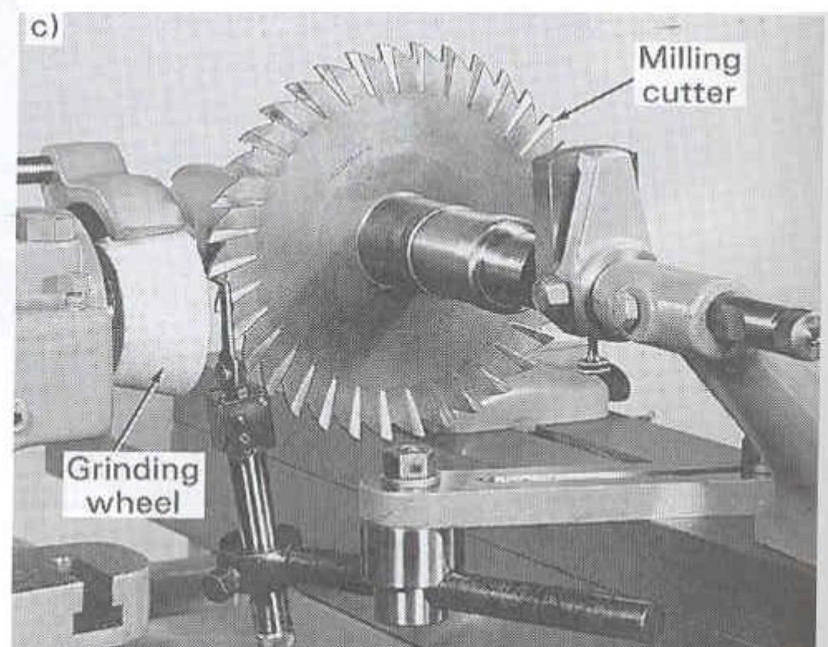


FIGURE 27-23 Three typical setups for grinding single- and multiple-edge tools on a universal tool and cutter grinder: (a) single-point tool is held in a device that permits all possible angles to be ground; (b) edges of a large hand reamer are being ground; (c) milling cutter is sharpened with a cupped Al_2O_3 grinding wheel.

SNAGGING – rough grinding used on rough castings

AIM: - to do metal grinding rapidly but not accurately.

Two types: Pedestal type grinder

Swing type grinder

MOUNTED WHEELS & POINTS →

used for deburring and finishing → to remove sharp edges.

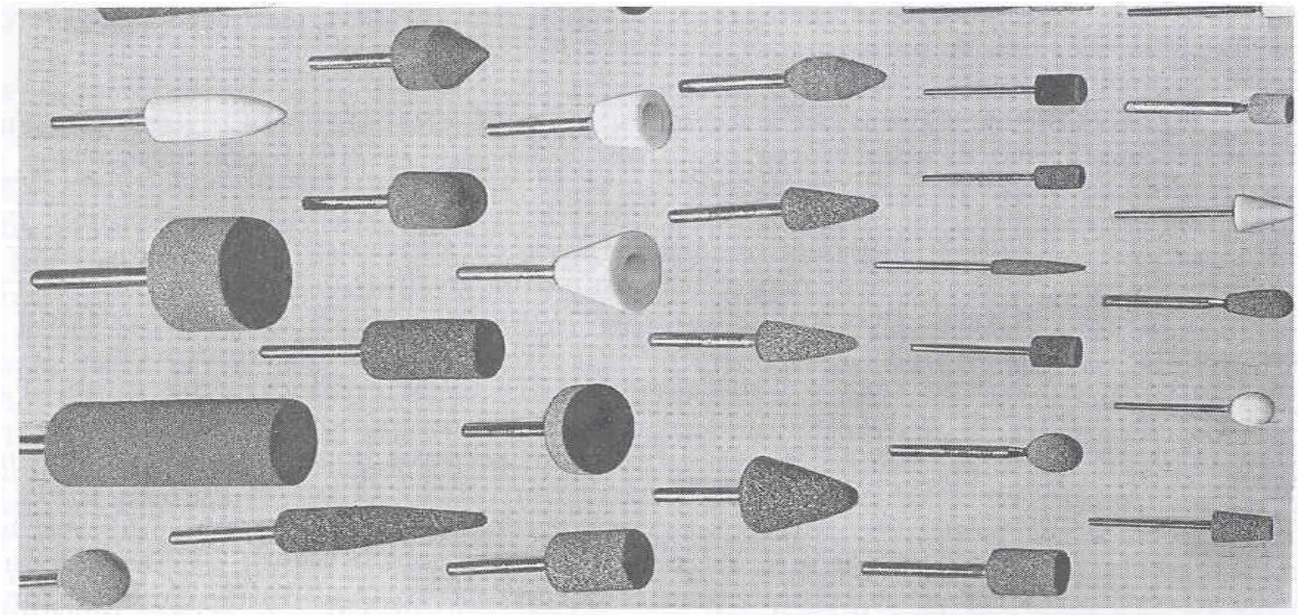


FIGURE 27-24 Examples of mounted abrasive wheels and points. *(Courtesy of Norton Company.)*

COATED ABRASIVES

Abrasive grains are glued to cloth or paper sheets.

Synthetic and natural abrasives are used .

The sheets are flexible:

Available in various shapes and work can be easily ground

ABRASIVE BELT GRINDER – the same

Self sharpening is not possible

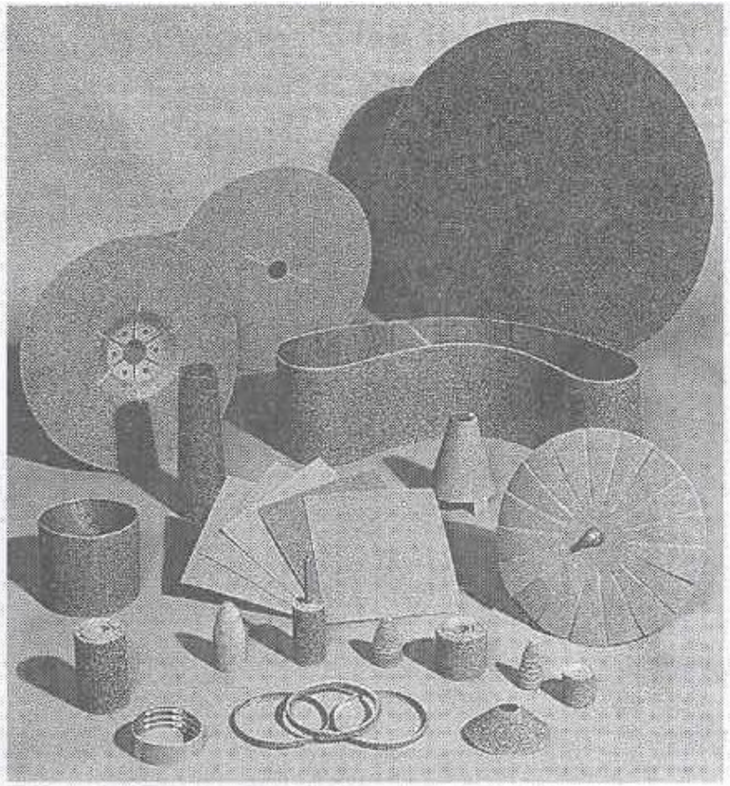


FIGURE 27-25 Examples of coated abrasives, belts and discs. *(Courtesy of Carborundum Company.)*

BARREL FINISHING:

The rubbing and sliding action is removing material from the surface of the rough material pieces (at random) →

The barrel can rotate and vibrate.

THREAD GRINDING – discussed

Threads in hardened steel, with a smooth finish; more accurate

HONING

Low velocity abrading process, using fine abrasives in stones.

Heat release and pressure are minimized (centrifugal force is used) → excellent shape and size.

TOOL – Metal mandrel with abrasive stones

Workpiece: The honing head is floating → no distortion of the part → the surplus of material is in the order of 0.1 mm (total).

Honing is applied when the scratches left after grinding have to be removed

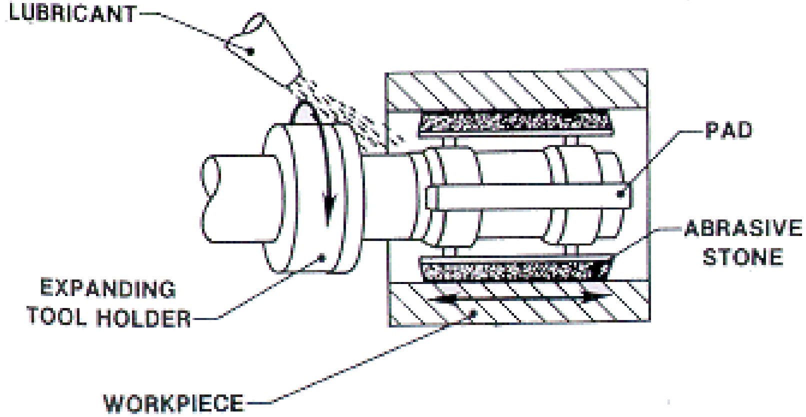
when geometrical shape of a bore has to be restored → greater amount of metal may be removed (0.5 mm).

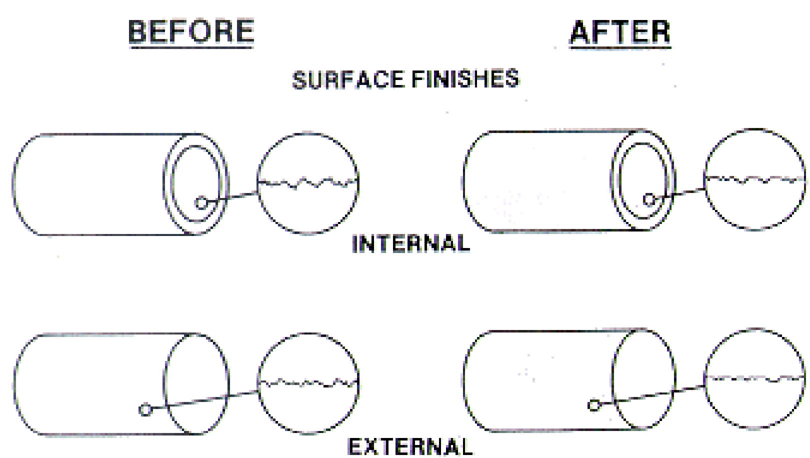
Special (thick) cutting liquids are being used with high viscosity.

- Horning – for hard metal parts
- Stones are rotating as well as reciprocating
- This gives a cross hatch surface finish →honing stones grid mesh 80-600 grains.

Honing machines – horizontal and vertical

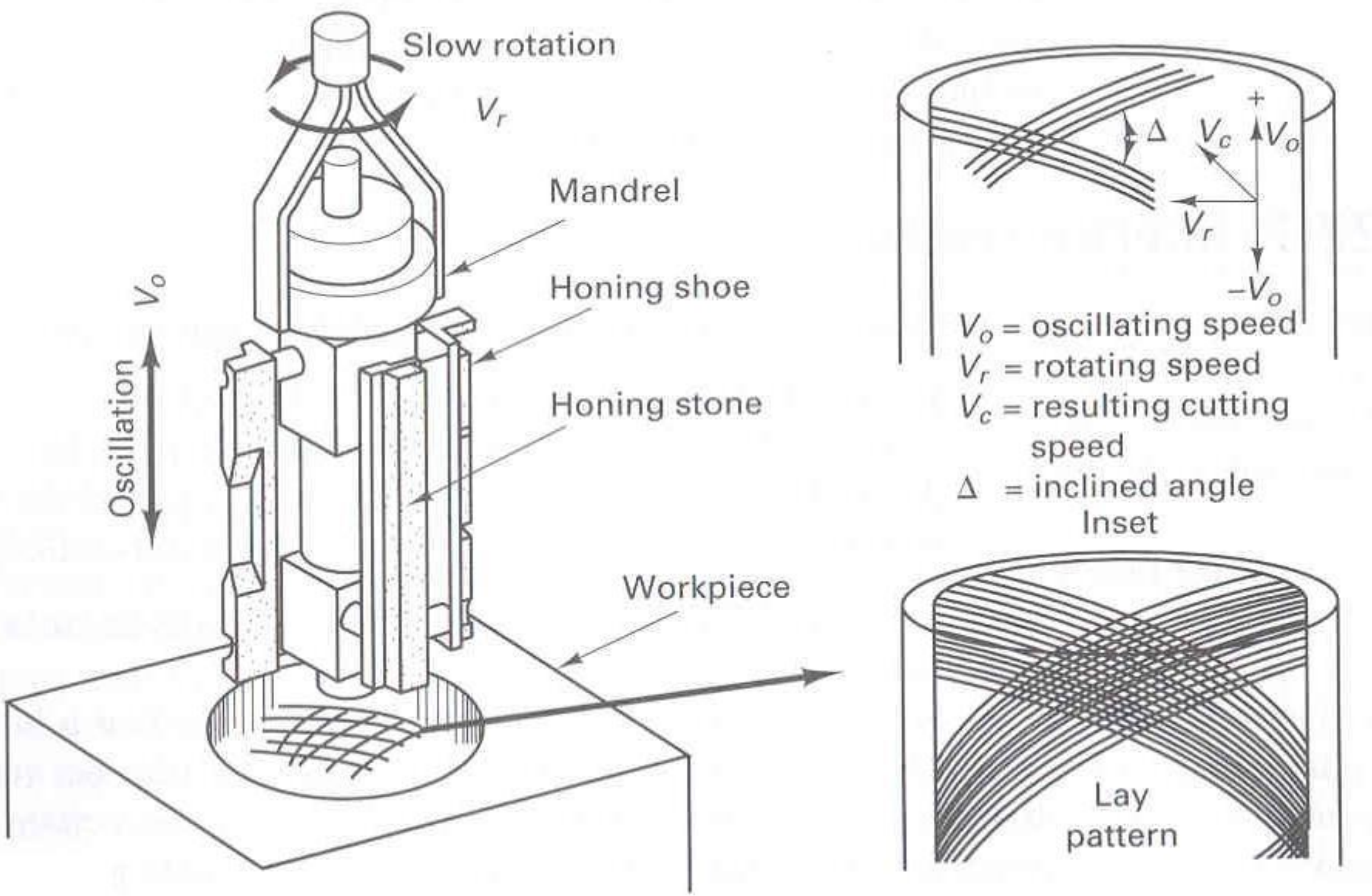
HONING


LUBRICANT
PAD
ABRASIVE
STONE
EXPANDING
TOOL HOLDER
WORKPIECE


BEFORE
AFTER
SURFACE FINISHES
INTERNAL
EXTERNAL

Workpiece – manual or power movement (Engine cylinders)

FIGURE 27-27 Schematic of honing head showing the manner in which the stones are held. The rotary and oscillatory motions combine to produce a crosshatched lay pattern.



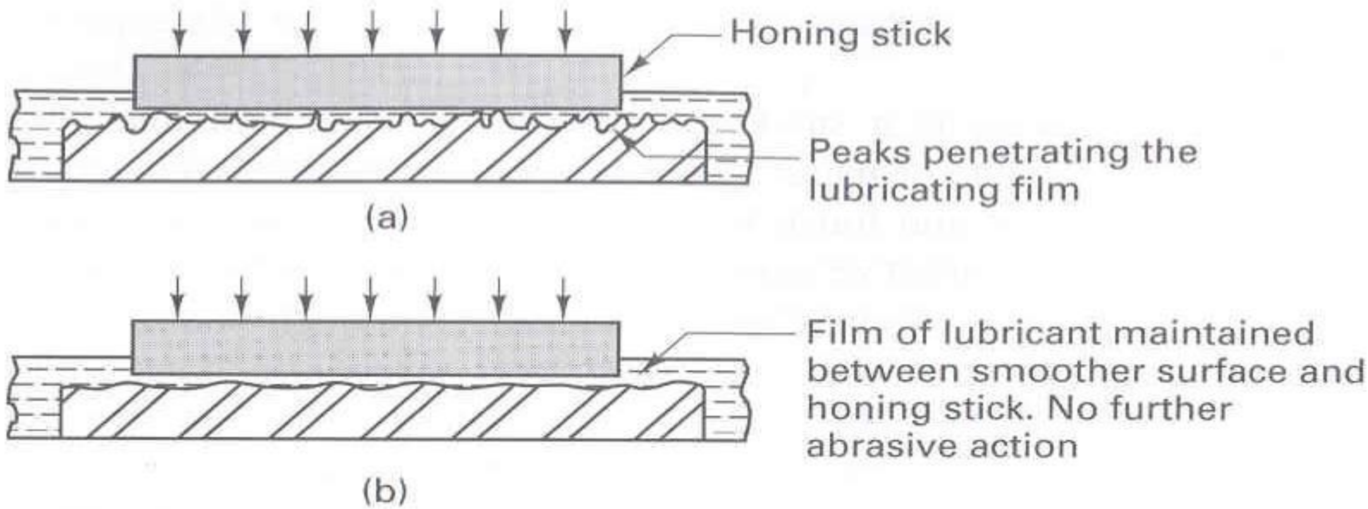


FIGURE 27-28 Manner in which a film of lubricant is established between the work and the abrasive stone in superfinishing as the work becomes smoother.

TABLE 27-6. Honing Reference Values

For:	Honing Parameters	Conventional Abrasives	Diamonds	CBN
High MRR	V_c (m/min)	20–30	40–70	35–90
	P_s (N/mm^2)	1–2	2–8	2–4
Best quality service	V_c (m/min)	5–30	40–70	20–60
	P_s (N/mm^2)	0.5–1.5	1.0–3.0	1.0–2.0

SUPER FINISH

Variation of honing but with much lighter pressure is applied

- higher frequency of oscillation ~ 400 cyc/min
- Super finish → a surface improving process – removing the undesirable fragments of metal left after machining
- Improvement of the quality of the surface – NOT the dimensions – removal of 10 micron max.
- Low pressure (10-40 psi)

TYPES:

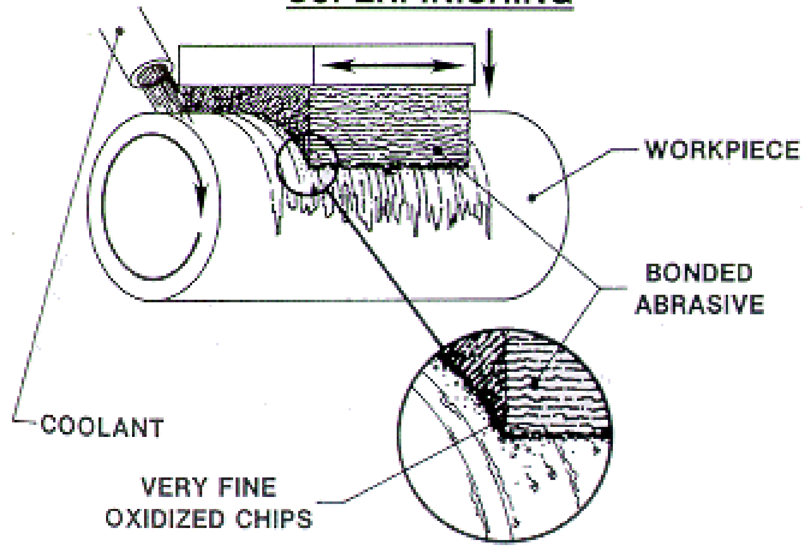
1. Semi-cylindrical abrasive stone –covers only a part of cylindrical surface of the piece **→ cylindrical super finish**

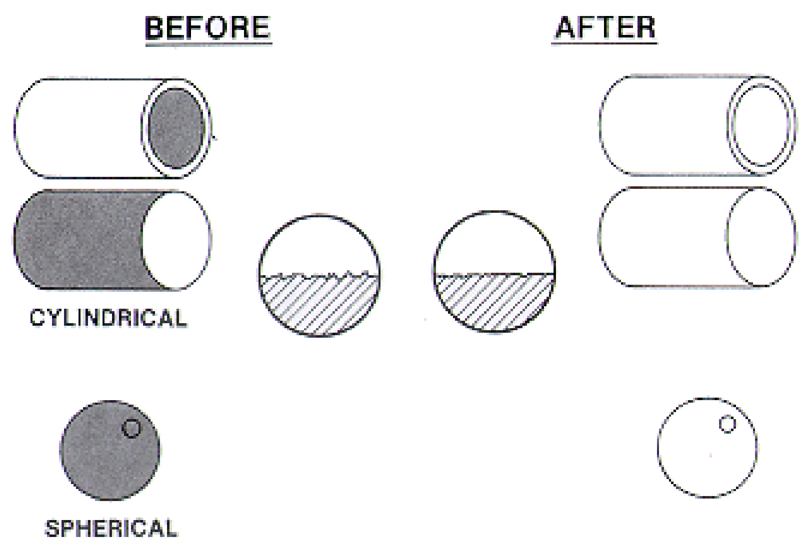
2. Rotating cup- shaped abrasive stone is used on the workpiece rotating on table → flat super finish

3. Low viscosity coolant is used in abundance → helps the abrasive process

Special machines were developed for super finish in mass production → example: for crank shaft pins

SUPERFINISHING





LAPPING

Differs from grinding, horning → uses free abrasives in grease

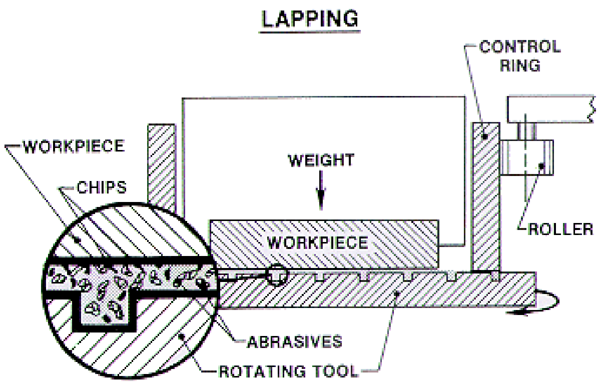
Purpose of lapping:

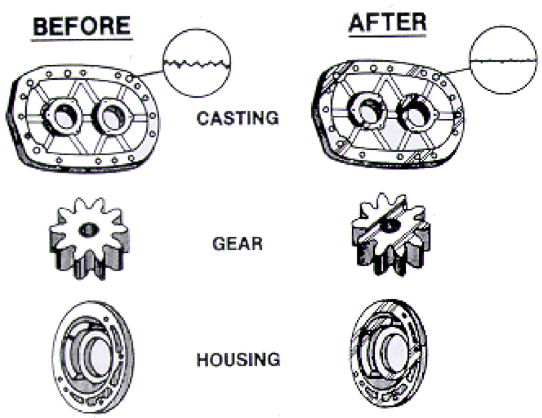
- Produces geometrically correct surfaces
- Correct minor imperfections of surfaces
- Improves dimensional accuracy
- Provides close fit between two surfaces

Total removal of metal – usually less than 30 microns.

• Flat, cylindrical & spherical surfaces can be lapped

Lap is used as a tool for free abrasives → lap is rotating against the lapped surface which has reciprocating motion





Loose abrasive in a vehicle like oil, grease or water are introduced between the tool & workpiece.

Lap has to be softer than the machined material

- It is made of soft iron of soft steel, brass or wood
- The abrasive particles – embedded in the surface of the lap and are cutting material on the surface of the workpiece
- Lap does not wear – has to be redressed however
- In lapping of carbide tools or diamonds → copper laps are used →size of abrasives 120-600 grid (mesh)
- Lapping by hand → abrasive as paste
- Lapping machines → horizontal machines used for flat lapping, it is a costly process.

ULTASONIC MACHINING

- Material removed through high velocity movement of abrasive particles, which are in the form of slurry
- The oscillating motion of the tool – frequencies 25-40 kHz causes cavitation phenomena and projects the abrasive particles against the workpiece
- Any desired contour of the hole can be produced by forming the tool to a desired shape.
- Holes in hard materials can be machined (ceramics, etc.)

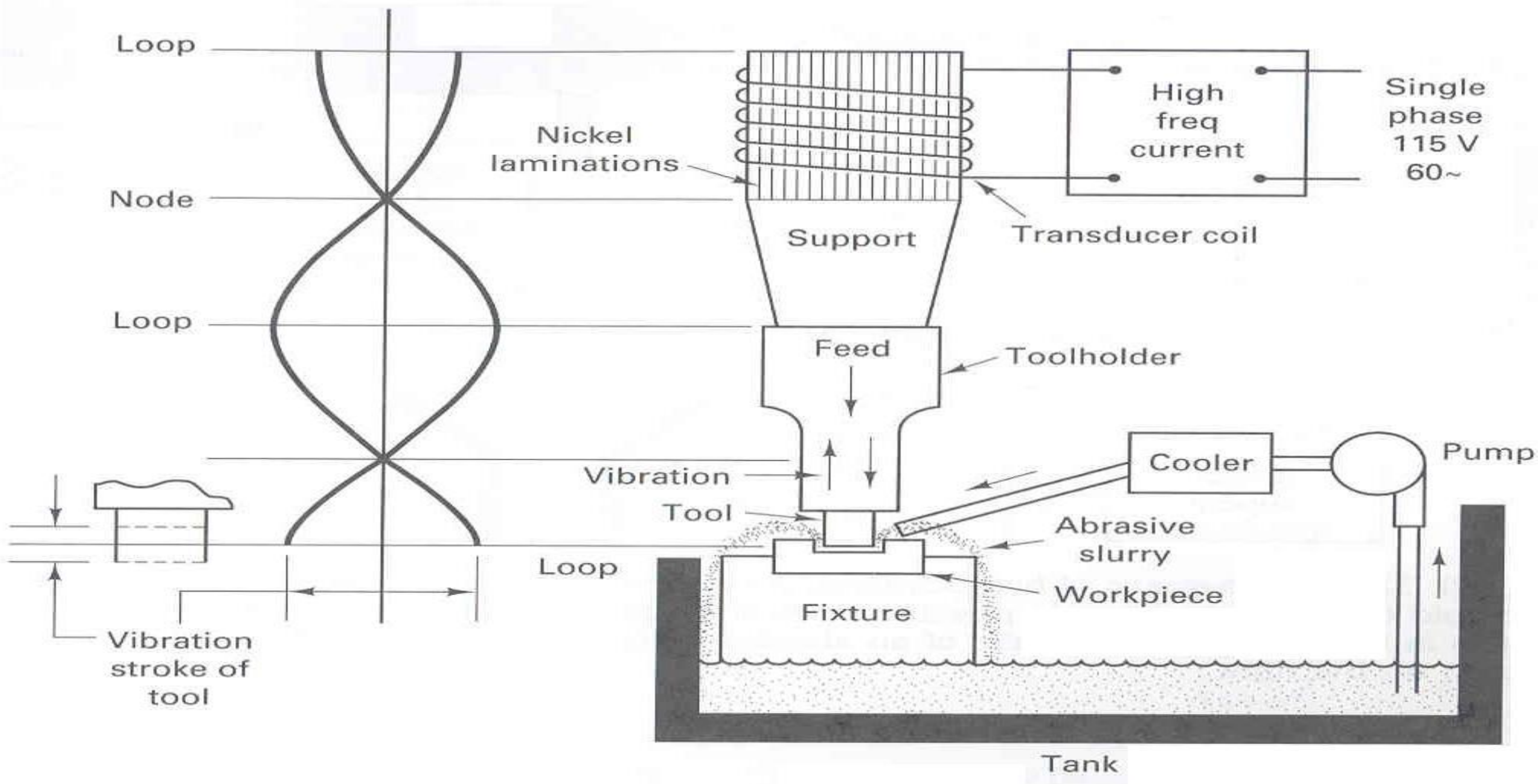


FIGURE 32-14 Sinking a hole in a workpiece by ultrasonic machining.