CHAPTER IV: GRINDING

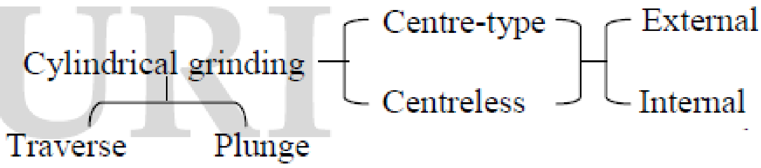
Introduction:

Grinding machines may be categorised into two major groups, (1) Rough grinders and (2) Precision grinders.
Rough grinders: Rough grinders are used for stock removal. These are further classified as: (i) Floor stand and bench grinder, (ii) Portable grinder, (iii) Abrasive grinder, and (iv) Swing frame grinder.

Precision grinders: Precision grinding machines are used where surface quality is the desired criterion. They are further classified as:
(i) Centre type cylindrical, (ii) Centreless cylindrical, (iii) Chucking type internal,
(iv) Planetary type internal, (v) Centreless internal, (vi) Surface grinder,
(vii) tool and cutter grinder (viii) special grinding machine (for machining crakshaft, cams, threads, gears etc.)

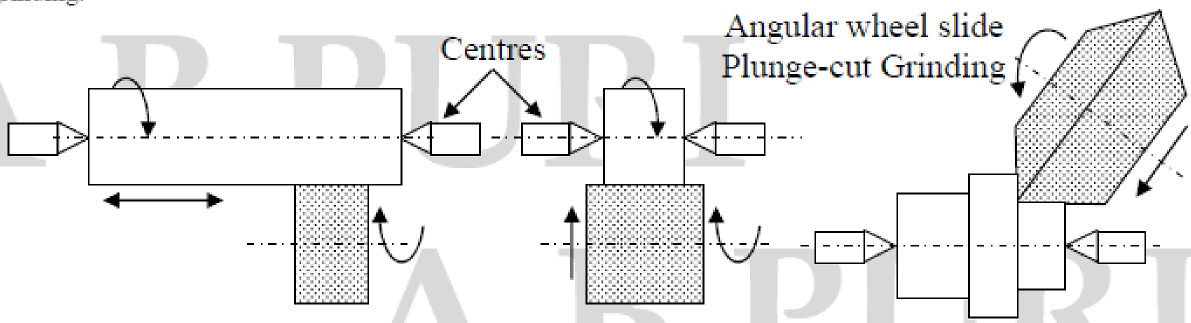
Surface grinder may be of two types (a) reciprocating type (b) rotating type
In **universal type of machines**, the table, headstock, spindle, wheelhead can be swivelled in horizontal/vertical planes. Also, they may have several attachments.

Based on operation, grinding may be of two types,
(i) **Surface grinding**, and (ii) **Cylindrical grinding**.



Traverse grinding: When the relative movement of the wheel is along the surface of the workpiece, it is called traverse grinding. The job is reciprocated while the wheel is fed (feeds in) in a direction parallel to the longitudinal axis of the workpiece. In case of cylindrical grinding, the job is larger than the width of grinding wheel.

Plunge grinding: The work rotates in a fixed position while the wheel is fed radially (i.e., in a direction normal to the longitudinal axis) to produce cylindrical job whose length is equal or shorter than the width of grinding wheel (GW). A profiled or formed GW is usually employed in plunge grinding. Generally, it is applicable for cylindrical grinding.



Traverse Grinding Plunge Grinding

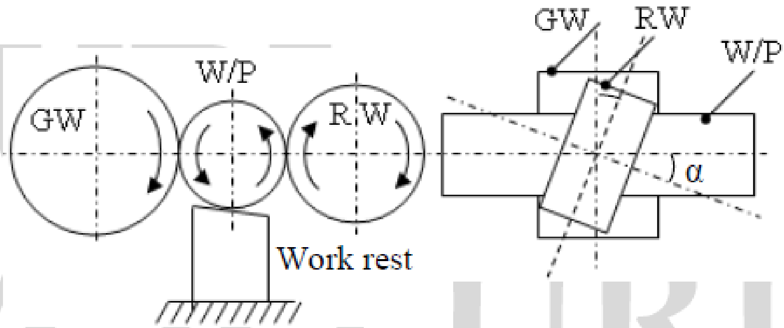
** **Creep-feed Grinding:** In creep-feed grinding, the wheel depth of cut (d) is kept very high (as high as 6 mm) mostly to obtain the finished job in a single pass. The workpiece speed is low and the MRR is very high. The wheels are mostly softer grade resin bonded with open structure to keep temperature low and improve surface finish. Grinders with capabilities for continuous dressing with a diamond roll are also available.

Centreless Grinding:

This type of grinding eliminates the need of centres, drivers and the other fixtures required to hold the job. Centreless grinding may be of three types, (a) **Through-feed**, (b) **In-feed** and (c) **End-feed.**

(a) Through-feed centreless grinding

The main elements are grinding wheel (GW), regulating wheel (RW, or back-up wheel/ pressure wheel) and a work-rest (WR) between the two wheels. The RW controls the speed of rotation of the workpiece and also the rate of feeding of the workpiece past the grinding wheel.



Centreless grinding (through-feed type)

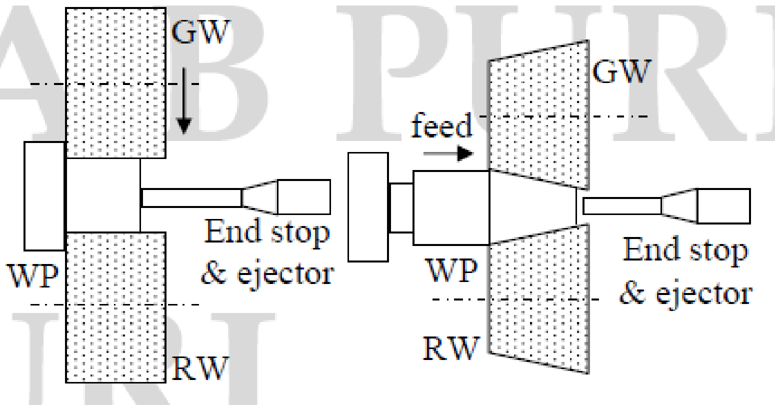
The top surface of the work-rest is inclined towards the RW. The RW is slightly tilted and runs at a very low speed (≈ 5% of GW) in such a way as to provide a lateral force component, feeding the workpiece between the two wheels ($s = \pi dn \sin\alpha$, d is the diameter of RW). An angular adjustment of 0°-10° is provided in the machine for this purpose. However, the angle of inclination may be as high as 30°, but smaller angles are used for large diameter work and to eliminate chatter while using wide wheels. The direction of rotation for GW and RW is same whereas for work, it will be automatically opposite. In through-feed centerless grinding, the workpiece is fed through the grinding wheel completely, entering on one side and exiting on the opposite. Thus, it can only be used for parts with a simple cylindrical shape. The above principle for centreless grinding can be applied for external, internal grinding.

(b) In-feed centreless grinding

It is similar to plunge grinding. The RW is given a tilt of 20' to 30' to assure that the resultant thrust holds the work against a shoulder of the workpiece. This is used for grinding parts which have shoulders or a particular profile.

(c)End-feed centreless grinding

End-feed grinding is best for tapered workpieces. In end-feed centerless grinding, the workpiece is fed axially into the machine on one side; grinding operation continues and comes to rest against an end stop. The advancement of the work is controlled by the movement of the rod (loader-pusher) acting along or in combination with the traversing action of the inclined RW.

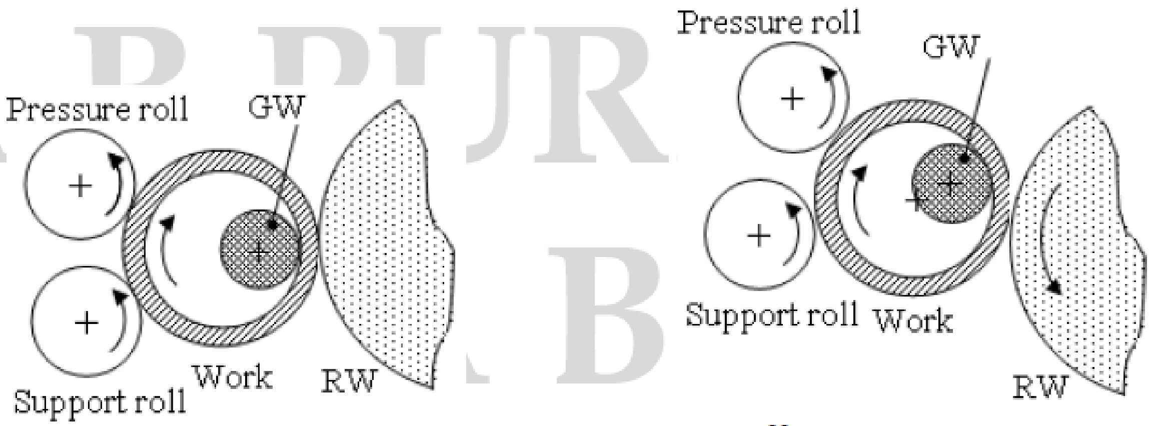


In-feed type End-feed type

Internal centreless grinding:

There may be two schemes: On centre type and Off-centre type.

In on-centre type, tubular workpiece is supported between RW (or control wheel), support roll and pressure roll, such that centres of RW, GW and workpiece lie on the same line. The wall thickness of the workpiece is accurately ground even for very thin tubes. In off-centre type, GW centre does not lie on the line joining the centres of RW and workpiece. They are prone to duplicate the errors of the outside periphery of job in the internal ground surface.



On centre type Off centre type

Truing and Dressing

A produced surface can not be more accurate (or true) than the grinding wheel producing it. **Truing** operation is done to make the periphery of the wheel concentric with its axis (i.e., to make the circumference a true circle, hence the word truing) by removal of abrasives from the cutting face and the sides of the wheel, restoring the original geometric shape. Also, the cutting capacity of a GW can not be fully utilised if its periphery has gone dull or clogged with foreign material. **Dressing** of the wheel is done to recover the proper cutting action of the wheel face by removing the layer of dulled grains or when the wheel becomes loaded. Loading occurs when the porosities on the grinding surface become filled or clogged with chips. Sometimes, dressing is done to generate a certain form or a profile on a GW as required by the job in form grinding. The clogging is known as **loading** of wheel and the dulling of grains is known as **glazing** of wheel (because of the shiny appearance of the wheel surface). However, loading occurs when (i) workpiece materials are soft, (ii) selection of GW is improper, e.g., wheel with low porosity and selection of process parameters are improper.

Balancing of Grinding wheel

Vibration in grinding operation is critical from the point of view of wheel life and surface finish of the job. Assuming that the machine is rigid and the bearings are in good condition, vibration is caused to a large extent due to 'out-of balance' and 'out-of-round' wheels. Since the wheel speeds are high ($\approx$ 3000 rpm), a slight out-of balance will result in a large force. This may result in excessive vibration, poor surface finish. So balancing is absolutely necessary.

Generally, 'balancing weights' are provided on the mounting flange of the grinding wheel. By mounting the wheel on a static balance stand equipped with two knife edges, wheel is brought to rest (or static balance) by moving the weights. Then, it is mounted on the grinding machine and dressed to concentricity.

Grinding wheel

While choosing a grinding wheel the following factors are considered:
1. Abrasives material and its types, 2. Grain size or grit size, 3. Grade or strength of bond, 4. Density or structure of the wheel, 5. type of bond, 6. Wheel shape (not used to specify a wheel)

1. Abrasives: It may be classified as: (a) natural and (b) artificial. However, hardness and toughness are the main criteria for selecting abrasives.

(a) Natural abrasives: Solid quartz or sandstone, corundum, emery and diamond. Corundum (55-65% Al_2O_3) and emery (75-95% Al_2O_3) are aluminium oxide with varying amount of impurities. They have better hardness and abrasive action than quartz. Diamond is the hardest substance. However, the cutting characteristics are not uniform with the wheel made of natural abrasives. So, artificial or synthetic abrasives are always preferred for their purity and better results. Moreover, their properties can be controlled.

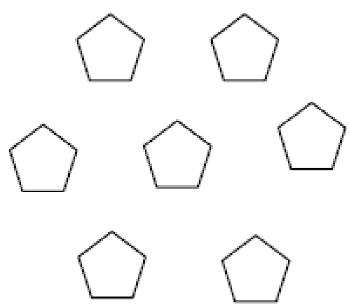
(b) Artificial or Synthetic abrasives:

Aluminium oxide: (a) It can withstand a temperature upto 2000°C. It produces sharp edges when fractured. Their hardness and toughness are quite high. It is designated as 'A'.
Use: High tensile strength steels, steels, ferrous alloys, other high tensile materials. It is mainly used in dry grinding of heat sensitive steels. Alumina (Al_2O_3) with slight impurities is used for general purpose grinding.
Silicon carbide: (a) Black ($\approx$ 95% SiC), (b) Green (98% SiC), superior quality. The raw material for SiC is mainly SiO_2 and petroleum coke or anthracite. They possess higher hardness but lesser toughness and hence brittle. Designated as "C".
Use: Non-ferrous metals, non-metallic elements, cast iron, cast aluminium, cemented carbide etc.
Cubic Boron Nitride (CBN): Second hardest material.
Use: For hardened and difficult-to-grind steels. It has a long life. As the temperature is very less, it produces better quality of surface.
Boron Carbide (B_4C): Its hardness approaches to that of diamond, but it is brittle.
Use: Lapping of cemented carbide tools, cutting precious stones and grinding tool materials of high hardness.
Diamond: It retains its strength at elevated temperature. It is inert to any sort of chemical attack. It possesses high hardness and toughness. With controlled crystal configurations, ductile materials can also be grinded.
Use: Ceramics, glass, stones, cemented carbides, electro-chemical grinding

2. Grain size (or grit size): It is denoted by a number indicating the number of meshes per linear inch of the screen through which they pass after crushing. So, MRR is proportional to the actual grain size and quality of finish is inversely proportional to the grain size.

Very coarse:	6, 8, 10, 12, 14	Very fine:	150, 180, 220, 240
Coarse:	16, 20, 24, 30	Super fine:	280, 320, 400, 500
Medium:	36, 46, 54, 60	Special:	1000 and above
Fine:	80, 90, 100, 120		

3. Grade: This refers to the 'strength of the bond' in a wheel or 'hardness of the wheel' i.e, the power of abrasive particle to hold together and resist disintegration under the cutting pressure. Thus, the grade of a wheel depends on both the 'type' and 'amount of bond material' in the wheel. A soft work needs lower cutting force, so the grains can retain their sharpness for a longer time. Hence, binder should be strong. For a hard work, cutting force being large, the wheel glazes very quickly rendering the wheel ineffective. So, to make the wheel self-sharpening by removal of blunt grits, binder should be weaker. The grades of wheel are designated by letters A to Z.



Very soft:	A to G	Medium:	L to O	Very hard:	T to Z
Soft:	H to K	Hard:	P to S		

4. Structure (or density of grain): This is a measure of porosity of the bonded abrasive grains. The abrasive grains and the bond material do not occupy the entire volume of the grinding wheel. There are pores among grains and binding agent. This spacing is called porosity. This is essential to provide clearance for the grinding chips, as otherwise they would interfere with the grinding operation. The small spaces cause wheel loading and ineffective cutting. Structure is represented by numbers from 0 to 15. '0 to 8' is dense structure and "9 to 15" is open structure. Open structure is preferred for soft, tough and ductile material and for high stock removal. Dense structure is used for hard and brittle materials and for finish cuts.

5. Type of bond:

(V) Vitrified bond (clay, feldspar, and other fluxes): They are strong, rigid and retain high strength at elevated temperature. They are not affected by water, acids and oil. MRR can be made high. They maintain smooth finishes. However, they are brittle and have poor shock resistance.
(B) Resinoid bond (from synthetic resin): The temperature produced during grinding is less. They are used for rough grinding, cutting-off operation, high speed grinding and for finishing operation. They are also called organic wheels as the bond is an organic compound.
(S) Silicate bond: It has silicate of soda as an important ingredient. It is affected by water and alkaline solutions and is less sensitive to shocks than vitrified bond wheels. It can not withstand a high temperature.
(R) Rubber bond: It is used for cutting off wheels, regulating wheels. They are affected by dampness and alkaline solution. It possesses high strength and elasticity.
(E) Shellac bond: The abrasive particles are mixed with shellac and moulded into a wheel shape. Wheels are strong, flexible and can be made thin. The cutting temperature is only 120 to 150°C, and they are comparatively easy to manufacture. They are used for grinding cutlery, ceramics, marbles, finishing of C.I rolls, grinding camshafts etc.
(O) Oxychloride bond: In this process, abrasive grains are mixed with oxides and chlorides of magnesium and are made in the same way as vitrified bond wheels. Since this bond ensures cool cutting, grinding is done dry. They are used in disc grinding.
**Metal bonded wheels are used in case of ECG. Abrasives are diamond, CBN and Al_2O_3 while the metals used as bonding materials are bronze, Ni, Al- alloys, Zinc etc.

Wheel specification: Manufacturer's additional symbol for the abrasive (optional) - type of abrasive - grain size - grade - structure - type of bond - manufacturer's own wheel identification mark. Example: **51 - A - 36 - L - 5 - V - 23.**

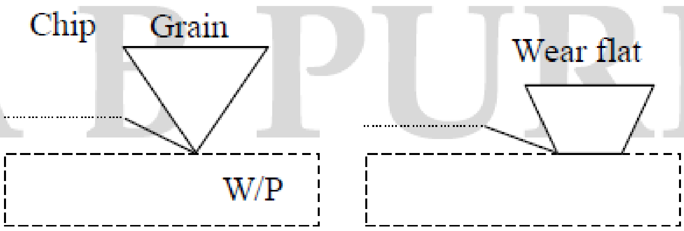
Wheel Shape: Self study

Grinding wheel wear: Grinding wheel wear is generally correlated with the amount of material ground by a parameter called the Wear Ratio or Grinding Ratio, defined as,

$$\text{Wear ratio, } G = \frac{\text{volume of material removed from the workpiece}}{\text{volume of material lost from the GW}}$$

However, grinding wheels wear by three different mechanisms as described below:

a) Attritious (also attricious) wear: The cutting edges of a sharp grain become dull by attrition, developing 'wear flat' similar to flank wear in cutting tools. Wear is caused by the interaction of the grain with the workpiece material, resulting in complex physical and chemical reactions involving diffusions, chemical degradations or decomposition of the grain.



b) Grain fracture: Grains fracture both at microscopic and macroscopic scale. Optimally, the grain should fracture at a moderate rate so that new sharp edges are produced continuously during grinding. This property is known as 'friability' of abrasives which gives them self-sharpening characteristics. However, this type wear refers the uncontrolled fracture of grains followed by disintegration from the wheel.
c) Bond fracture

Grinding Temperature: The surface temperature rise has been found to be a function of the ratio of the total energy input to the surface area ground.

Thus, $\Delta T \propto \dfrac{u(w \times l \times d)}{w \times l} \propto ud$, U = specific energy for grinding (W-s/ mm^3).

The peak temperature in chip generation can be as high as 1600 °C. However, the time involved in producing a chip is extremely short (in the order of μs), hence melting of the chip may or may not occur. The chips carry away much of the generated heat, only a small fraction is conducted to the workpiece. The sparks observed in grinding are actually glowing chips, because of the exothermal reaction of the hot chips with oxygen in the atmosphere. In an oxygen-free environment sparks are not observed.