Basics of Mechanical Engineering-2

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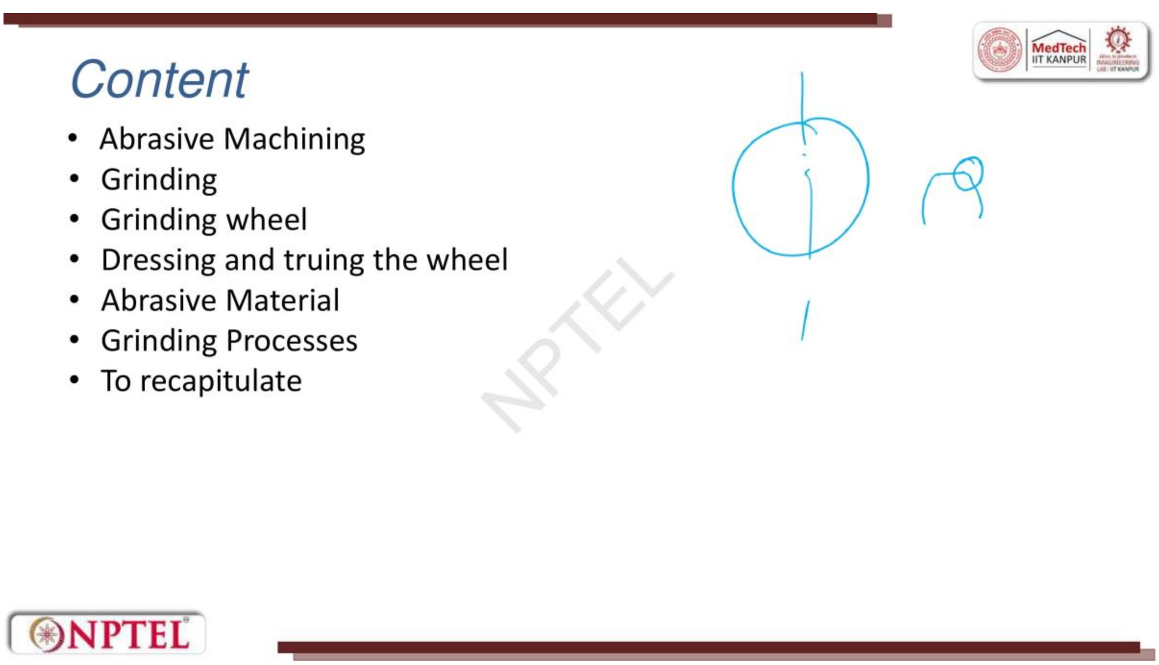
Week 10

Lecture 38

Basics of Machining (Part 6 of 7)

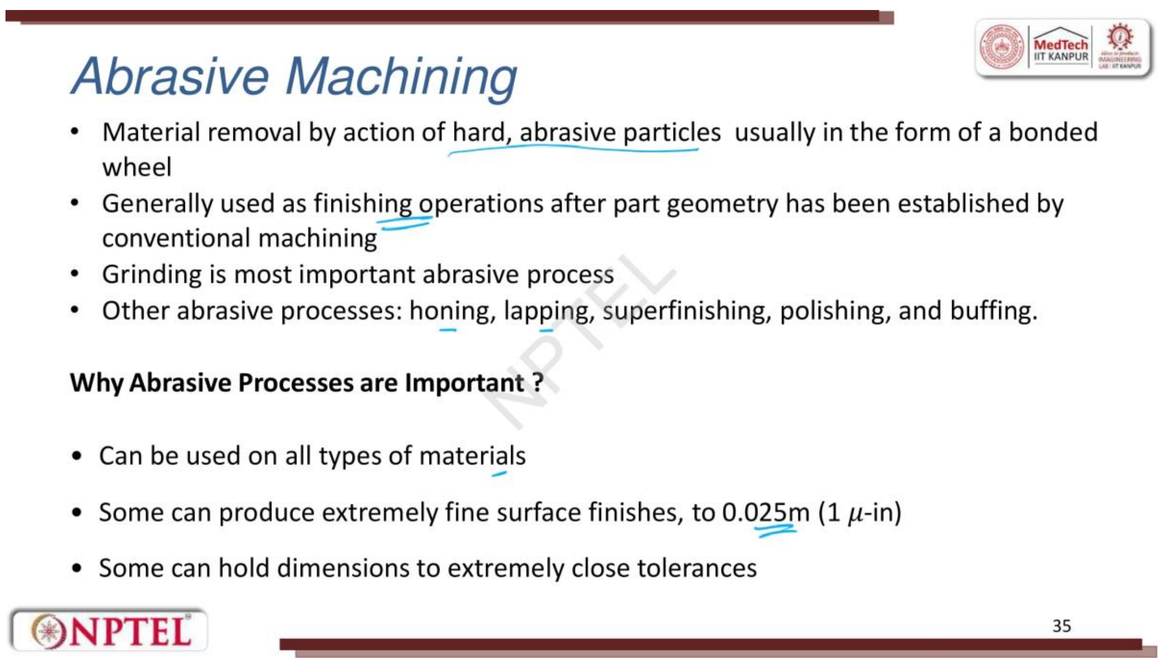
Welcome, friends, to the last segment of this machining lecture. In this lecture, we will primarily focus only on grinding operations. In the two lectures, whatever we saw—a single-point cutting tool, a multiple-point cutting tool. So here, now the cutting tool is reduced to a powder. Now, once it is reduced to a powder, what happens to the geometry?

How do you decide the geometry? So, that is what we are going to see in this lecture. And there was a question asked by some of the students: 'Sir, what happens to the geometry in milling compared to that in turning?' In turning, you said you have six angles in a solid tool—six angles and one nose radius. Almost all the things are there in milling also.



When we have a cutter and take a cross-section of it, you will see a tooth. You will see a tooth. In that tooth, if you further take a cross-section and observe, you will see clearance angle, relief angle, flank—everything there. So, that is why I did not go deeper into it. But friends, you should keep this in mind.

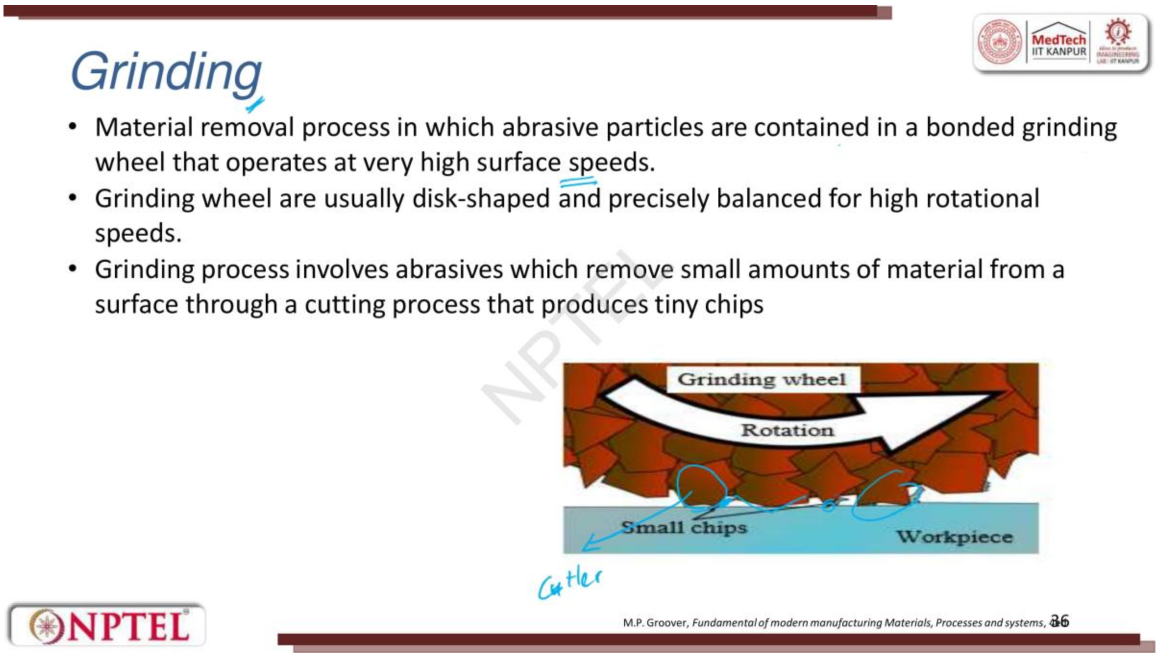
Here, you also have positive rake, negative rake, everything. Now, getting into this lecture, we will try to see abrasive machining, then we will try to see grinding, grinding wheel, dressing, and then we will try to see some of the abrasive materials and grinding processes. Finally, we will try to have a recap.



Abrasive machining: here, the material is removed by the action of hard abrasive particles. Usually, these abrasive particles are bonded into a wheel.

So, since they are small cutting tools and they are all bonded, The amount of material which is removed is going to be very small. So, if it is going to be very small, generally we use these operations for finishing, where major chips are removed and small asperities on the surface are removed by grinding. Grinding is a very important process, and like grinding, we also have other processes such as honing, lapping, super finishing, polishing, and buffing. All these things are almost the same.

The only difference can be whether the abrasives are loosely held or rigidly held. Why are abrasive processes very important? Because they can be used to remove all types of materials. You can remove ceramics, you can remove metals, and to some extent, you can also remove polymers. So, the finish you get can go up to 1 microinch, or about 25 microns.



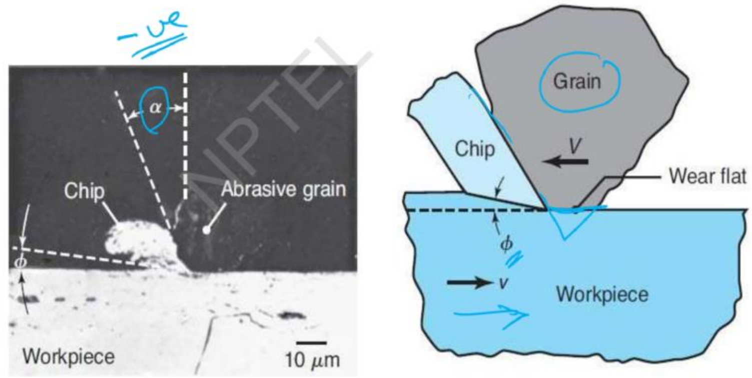
So, here if you see, this is a cutter, an abrasive, this is like a cutter. And between cutting edges, you see a small chip getting formed. It is very similar to that of milling. The only difference is the cutter size is small and then the cutter size is random. You can see here there is a star, there is a single point cutting tool, then there is a flat portion, then you have another thing.

So this is the difference. Irregular tool geometry and the tool cutter is very small. They are all held together by a paste. They form a wheel. So that process is called as grinding.

So material removal process in which abrasive particles are contained in a bonded grinding wheel that operates at a very high cutting speed. Why very high cutting speed? Because the chip size is very small. So, the tool contact is going to be very small. So, if it is very small and if you go very slow, it will take long time to finish and there will be lot of rubbing action. So, we try to move it at very high speed so that it can be removed, and here the chip size is very small.

Grinding

Grinding is a chip-removal process that uses an individual abrasive grain as the cutting tool.



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So, if you look into abrasive grinding or an abrasive, this is the grain size. When it tries to come in contact, it will try to remove material in the form of a chip. So, the sharp portion gets broken, and then you get a wear flat. The same phenomenon is there.

When the chip is formed, you have a shear angle, and this is the cutting velocity. The workpiece can move, or the grinding wheel can move. The grinding wheel can also go at very high speeds, right.

So, if you look into it, most of the time from the force plot and other things, we find that the rake angle will always be negative in grinding or with respect to abrasives. So, if it is negative, then the forces are very high. Once the forces are very high, the power is very high. So, the energy used for grinding will always be very high.

Grinding

Grinding applications include:

1. Finishing of ceramics and glasses
2. Cutting off lengths of bars, structural shapes, masonry and concrete
3. Removing unwanted weld beads and spatter
4. Cleaning surfaces with jets of air or water containing abrasive particles.

So, they are used for finishing ceramics and glass. They are used for finishing metal, structural shapes, masonry, and concrete. They are also used to remove unwanted weld beads and spatter. They are used for clearing the jet of air or the water containing the abrasives.

Grinding Wheel

Consists of abrasive particles and bonding material

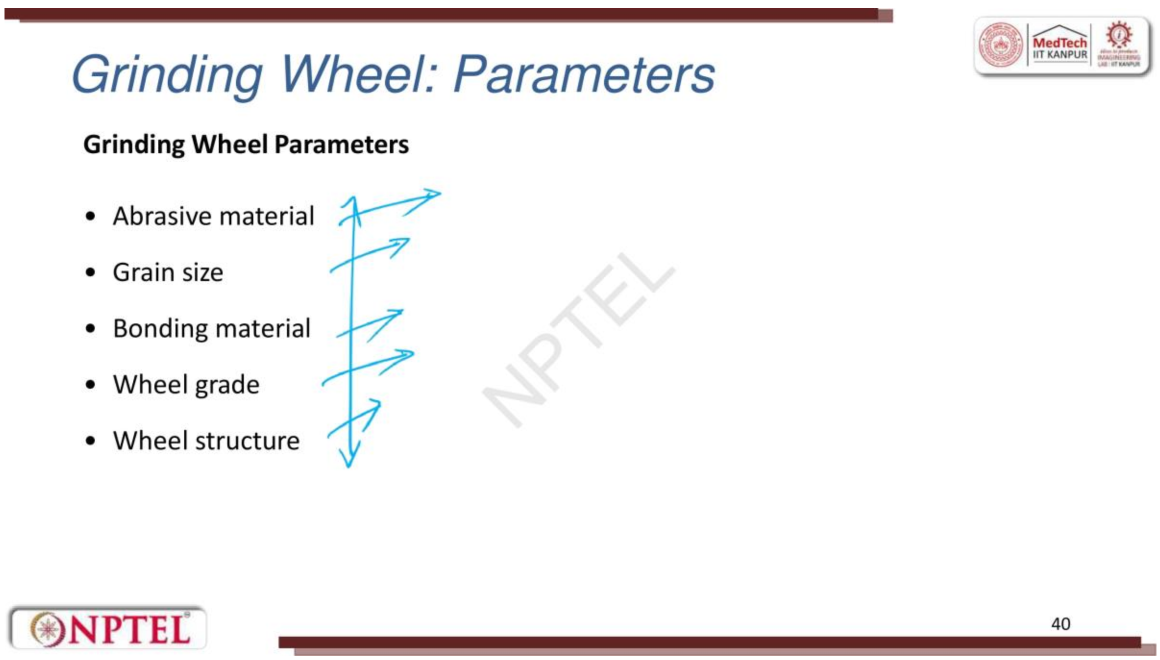
- Abrasive particles accomplish cutting
- Bonding material holds particles in place and establishes shape and structure of wheel

https://www.lemo-machining.com/info/grinding-processing-during-precision-machining-22449139.html

https://www.mmsonline.com/articles/7-key-factors-in-choosing-a-grinding-wheel

So, this is how a typical grinding wheel looks. This grinding wheel is mounted onto a grinding machine. And the grinding machine is horizontal. It is almost like your horizontal milling machine.

So, here the thickness is not very large. So, we do not have an overarm to support generally. You have it short and slender. So, it is mounted directly to a spindle. So, now the question is: how do you specify the grinding wheel?

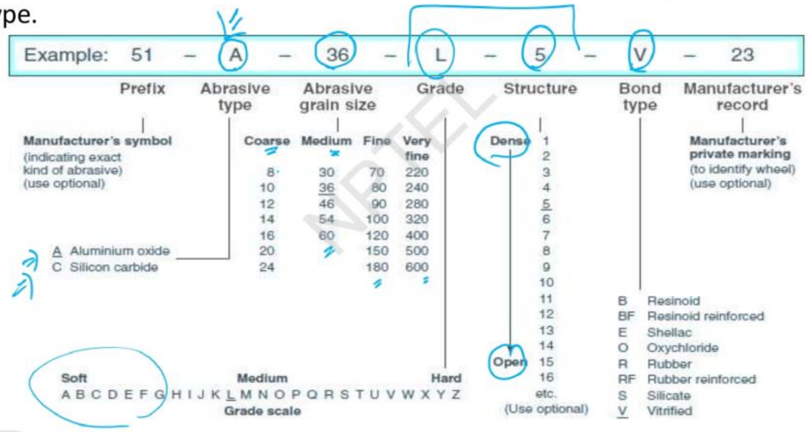


So, we specify the grinding wheel with the following parameters. What is the type of abrasive material used in grinding? What is its size? What is the bonding material used? What is the wheel grade?

Wheel grade refers to whether the abrasives are tightly packed or loosely packed. Then, we will try to look into the wheel structure. So, there are several different types of abrasives. The grain size is something we always observe and analyze. Bonding refers to the material used to bind.

Grinding Wheel: Parameters

- Due to their high cost, only a small volume wheels consists of abrasives
- Grinding wheels are indicated by the type of abrasive, grain size, grade, structure, and bond type.



So, this is how a typical grinding wheel specification looks. This section discusses the abrasive. If it begins with the letter A, it represents alumina. If it begins with the letter C, it represents silicon carbide. The number 36 refers to the abrasive grain size.

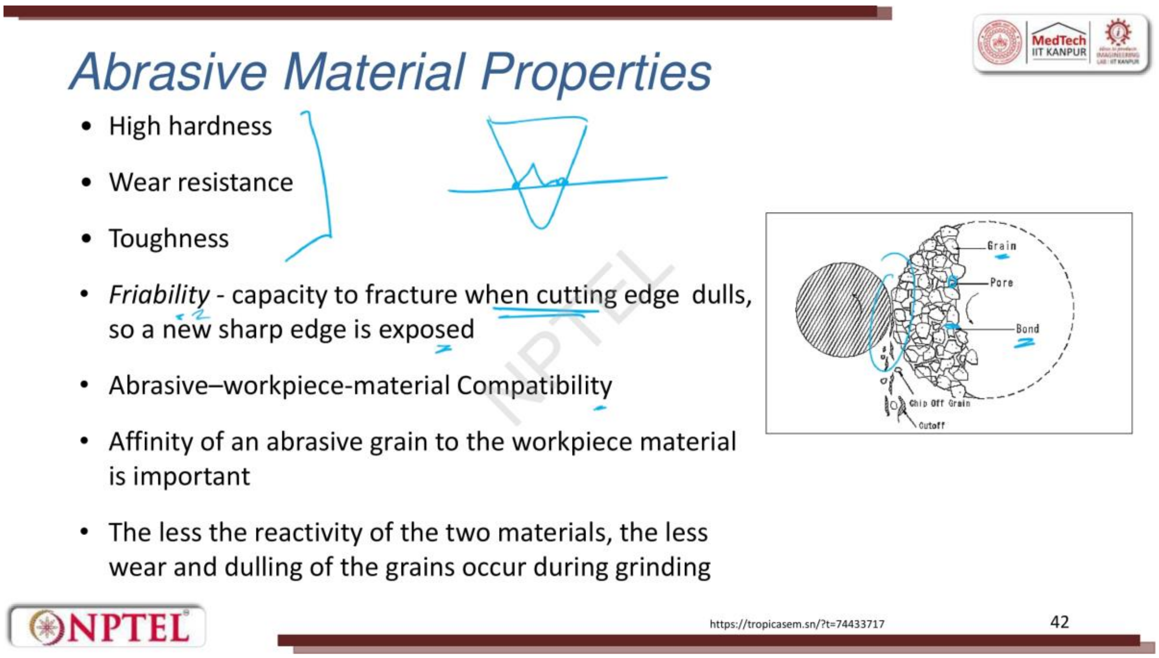
If it is coarse, it is 8, 10, or 12. If it is medium, it goes up to 60. Anything above 60 is considered fine. Very fine is also an option. What happens when the grain size is very small?

The chip size is very small. So the amount of material removed is very small. But you can precisely remove material. What is the grade? The grade is whether the material, the wheel is made out of metal which is soft, medium and hard.

If it is soft, what happens? As and when there is maximum load while cutting is given by the abrasive, the abrasive tries to resist the material. the workpiece material to form a chip. Suppose if the force is too high, then immediately what happens, the abrasive breaks or the abrasive falls out of the binding. If it does not do that, it is going to create a scratch.

So only for that what we do is we try to choose binding material which is soft or hard, whatever it is. So the grade talks about how is the binding there so that it can be eased out. The structure is it talks about whether it is closely packed or loosely packed or far away packed. So, densely packed and it is open packed. So, open packed means it can accommodate more chip.

Then V tries to talk about the bonding material. So, here friends understand these two are very important properties. Type of abrasive grain size and bond clearly understood. The grade whether the wheel is soft. For glass machining, it can be hard. For normal steel machining, it can be soft or medium. The structure is the openness between the abrasive, what is the size.



So, here also we talk about the three important properties, hot hardness, then wear resistance and toughness. So, this is the grain, this is the pore, this is the bonding material. The pore will lead to structure.

So friability, the capacity to fracture when cutting edge dulls, so a sharp cutting edge comes into action. So a sharp edge will try to fracture. So now what happens, you have two cutting edges. It randomly breaks. So, you will have many cutting edges.

Friability is the place when it is fracturing. Then abrasive workpiece material is compact. Abrasive workpiece material compatibility is also very important. The affinity of the abrasive grain to the workpiece is important. So, it should not diffuse any material from the abrasive gets into it.

So, for example, the abrasive should not dig and go stay there. So, hardness combination is also very important. It should be less reactive because here is going to be a very high temperature. The bond material should not get diffused into the workpiece.

Traditional Abrasive Materials

- Aluminum oxide (Al_2O_3) - most common abrasive
  - Used to grind steel and other ferrous high-strength alloys
- Silicon carbide (SiC) - harder than Al_2O_3 but not as tough
  - Used on aluminum, brass, stainless steel, some cast irons and certain ceramics

Newer Abrasive Materials

- Cubic boron nitride (CBN) – very hard, very expensive
  - Suitable for steels
  - Used for hard materials such as hardened tool steels and aerospace alloys (e.g., Ni-based alloys)
- Diamond – Even harder, very expensive
  - Occur naturally and also made synthetically
  - Not suitable for grinding steels
  - Used on hard, abrasive materials such as ceramics, cemented carbides, and glass

So, typically alumina is used, SiC is used. CBN can also be used, diamond can also be used. You should go back and correlate this with respect to different cutting tool materials we saw. HSS tungsten carbide coated carbide CBN artificial that is diamond, artificial diamond also we saw. So, here also we have alumina, silicon carbide, cubic boron nitride, etcetera.

Newer Abrasive Materials

Hardness of Abrasive Materials	Knoop hardness
Aluminum oxide	2100
Silicon carbide	2500
Cubic boron nitride	5000
Diamond (synthetic)	7000

So, the hardness is given very clearly diamond has the highest hardness as compared to that of abrasives.

Grain Size

- Small grit sizes produce better finishes
- Larger grit sizes permit larger material removal rates
- Harder work materials require smaller grain sizes to cut effectively
- Softer materials require larger grit sizes

Grain Size

- Abrasives are very small when compared to the size of cutting tools and inserts
- Abrasives have sharp edges and allow removal of small quantities of material
- Very fine surface finish and dimensional accuracy can be obtained using abrasives as tools
- Size of an abrasive grain is identified by a grit number
- Smaller the grain size, larger the grit number

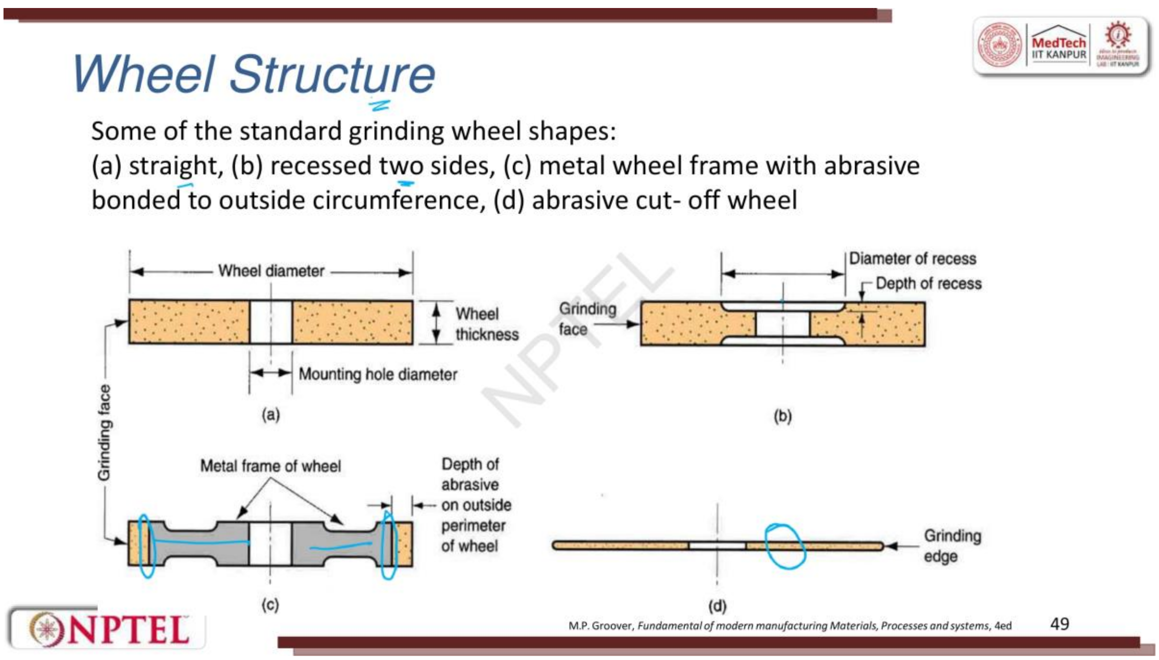
So, grain size I have already discussed. Smaller grit size produces better surface finish. Larger grit size the amount of material removal is there. So, larger grit size it can shear, create new cutting edges while machining. In small it is not possible. Soft materials require larger grit size. The grain size we have already discussed. So I am just going through it.

Common types of Bonds

1. **Vitrified:**
    - Consist of feldspar and clays
    - Strong, stiff, porous, and resistant to oils acids, and water
2. **Resinoid:**
    - Bonding materials are thermosetting resins
    - Resinoid wheels are more flexible than vitrified wheels
3. **Reinforced Wheels:**
    - Consist of layers of fiberglass mats of various mesh sizes
4. **Thermoplastic:**
    - Used in grinding wheels ,With sol-gel abrasives bonded with thermoplastics
5. **Rubber:**
    - Using powder-metallurgy techniques
    - Lower in cost and are used for small production quantities

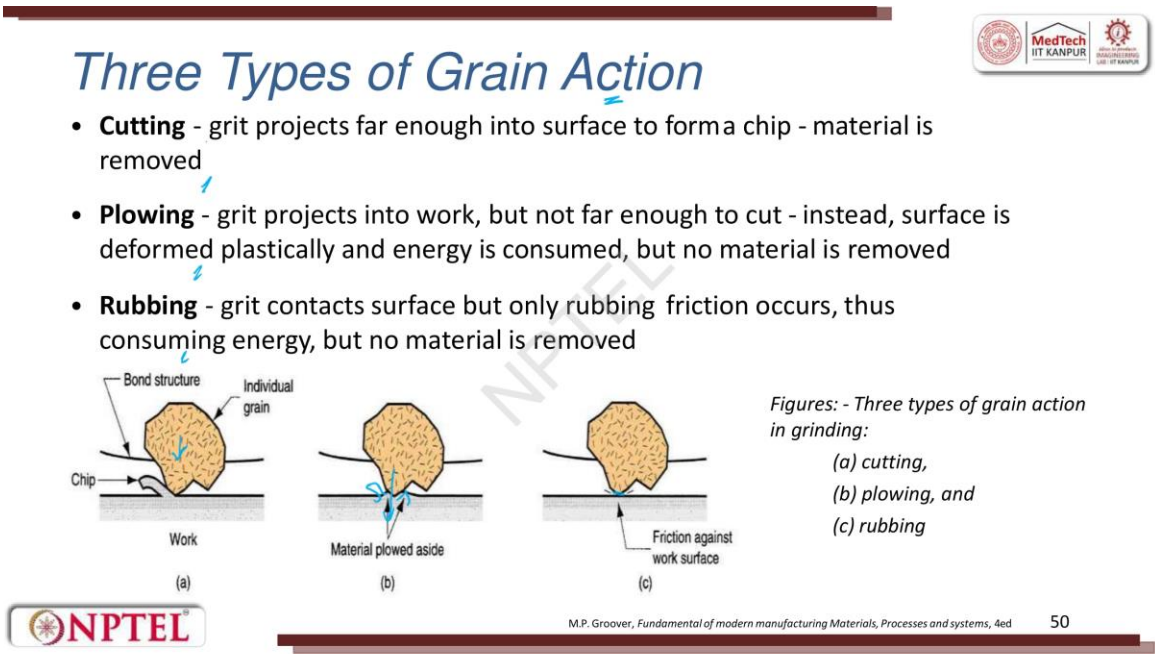
So, vitrified bond, resinoid bond, reinforced wheel bond, thermoplastic, rubber all are used. So, consists of feed spare and clay is vetrified bond. Resinoid bond is bond material with thermoset resin. You also have rubber like because these cutters are soft and they can try to take little bit of flexibility.

Thermoplastic is also used as a binder which we generate sol-gel abrasive bonding with thermoplast is also used. Reinforcement, the layer of glass fiber mat of various mesh size are used for reinforcement. So, all these things play an important role for holding the workpiece.



So, the wheel structure I have already discussed. Some of the standard grinding wheel shapes: straight; it can be there, then you can have two sided recess. These are two sided recess, then metal wheel frame with abrasives these.

So, here like in insert the other portion can be made out of metal and then we apply a bond here we have like an abrasive stick which is stuck on both sides. That is also possible. You can have a thin disc-like sawing operation. You can also have abrasive cutters or a slitting operation.



So, the general mechanism in grinding is going to be three. One is the cutting mechanism, the plowing mechanism, and then the rubbing mechanism. In the cutting mechanism, the abrasive comes in contact with the workpiece and removes a chip. So, that is called cutting. In the plowing operation, there is force, assuming the workpiece is soft. So, now the abrasive digs inside, and the material is plowed. It is not removed.

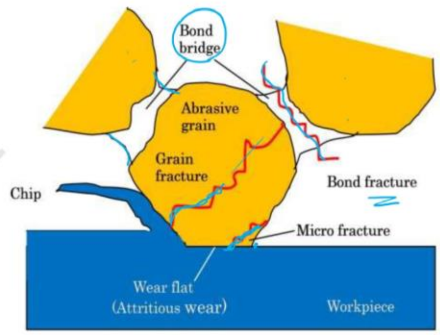
It is only displaced. It is not removed. In the rubbing action, there is no cutting. The edge of the abrasive is blunt. It does not cut. It just scrapes through, it rubs. So, this rubbing action is giving you lot of heat.

So, this heat will try to distort the workpiece properties. So, these are the three typical mechanisms. Cutting mechanism, plowing mechanism and rubbing mechanism. In plowing and rubbing the material is not removed, it is only displaced. In rubbing nothing happens.

Causes of Wheel Wear

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

- Edges of the fractured area become new cutting edges
- Tendency to fracture is called friability



So, the grain fracture as I told you, if you see one abrasive, the other abrasive, they are bonded together by the bonding bridge. This bonding bridge is the material what we discussed here, okay? And depending upon the force what is there while cutting so what happens is the abrasives can fracture so this fracturing only we learnt it as friability. Friability property with the capacity to fracture when the cutting edge dulls. So, this is what we are trying to see. And here, you can see while grinding operation happens, the abrasives can fracture half. It can fracture small, so that the fresh cutting edges come into action for removing material. So, there can be a small fracture of a grain, there can be half fracture of a grain, there can be a bond fracture alone.

The bond should also be in such a way such that if there is lot of resistance coming to the abrasive grain, then the easiest way should be the bond should fracture so that the fresh grain comes in contact, fresh abrasive comes in contact for machining. So, there can be a bond fracture, there can be a micro fracture, there can be a grain fracture.

Causes of Wheel Wear

Attritious wear - dulling of 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 force becomes excessive

So, the cause of the wheel wear like atrecious wear and bond fracture. Atrecious wear are dulling of individual grains resulting in a flat spot and rounded off edge analogous to tool wear whatever we have seen in the past. So, bond fracture also we have discussed.

Grinding Ratio

Indicates slope of the wheel wear curve

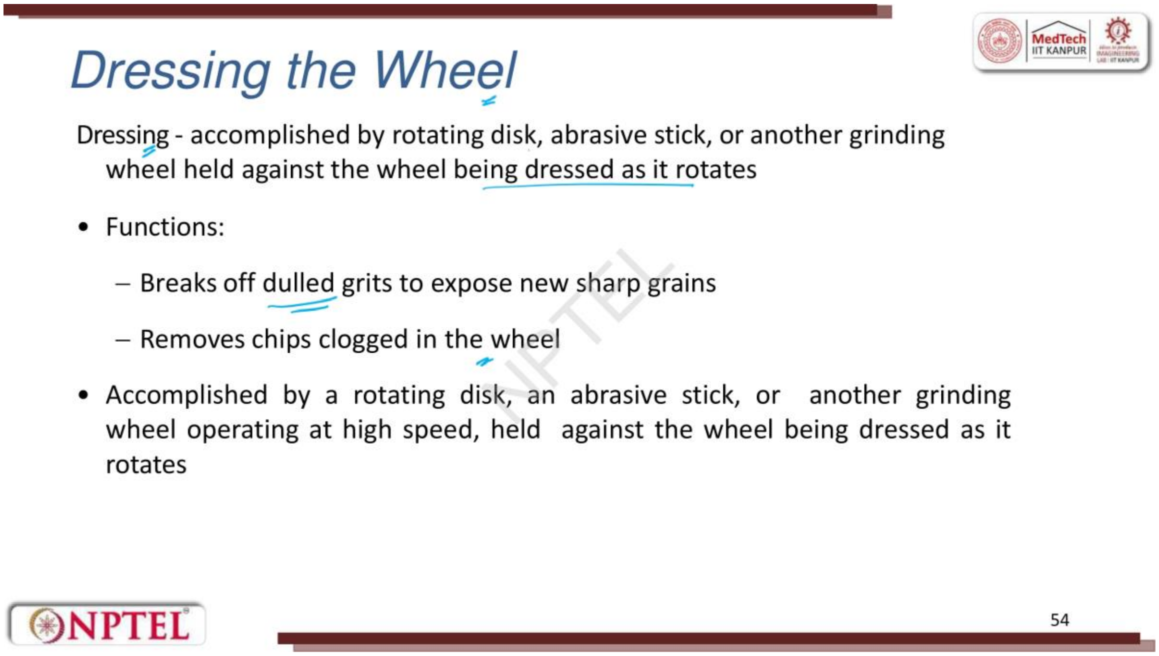
$$GR = \frac{V_w}{V_{gr}}$$

Where,
GR = grinding ratio;
V_w = volume of work material removed; and
V_{gr} = corresponding volume of grinding wheel worn

So, there is something like a cutting chip thickness ratio in grinding, and we have a grinding ratio. The grinding ratio is

$$GR = \frac{V_w}{V_{gr}}$$

So, that is called the GR (grinding ratio). Generally, we determine the grinding ratio to assess the compatibility between the workpiece and the cutter.



When the grinding wheel has many dull or flat abrasives, we must remove them. That operation is called dressing. Dressing is accomplished by rotating a disc, abrasive stick, or another grinding wheel held against the wheel being dressed as it rotates.

The function is to remove all the dull grains and also to eliminate chip clogging that occurs. After a few grinding strokes, we always perform dressing to expose fresh, sharp edges for contact.

Truing the Wheel

Truing - use of a diamond-pointed tool fed slowly and precisely across wheel as it rotates

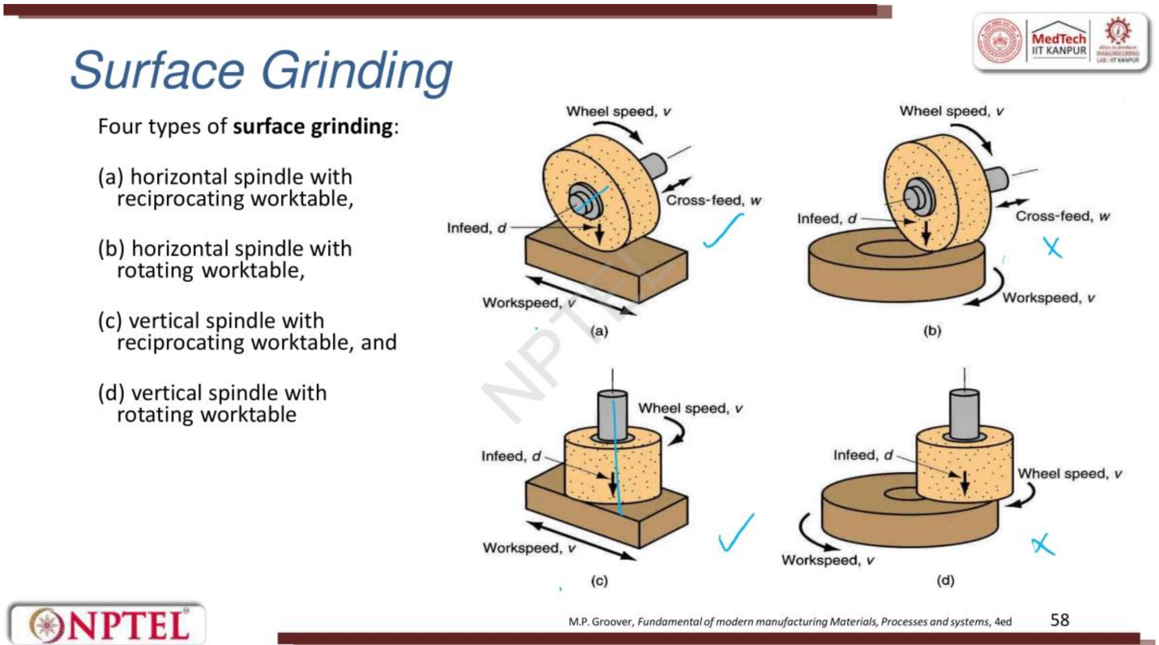
- Very light depth is taken (0.025 mm or less) against the wheel
- Not only sharpens wheel, but restores cylindrical shape and insures straightness across outside perimeter
  - Although dressing sharpens, it does not guarantee the shape of the wheel

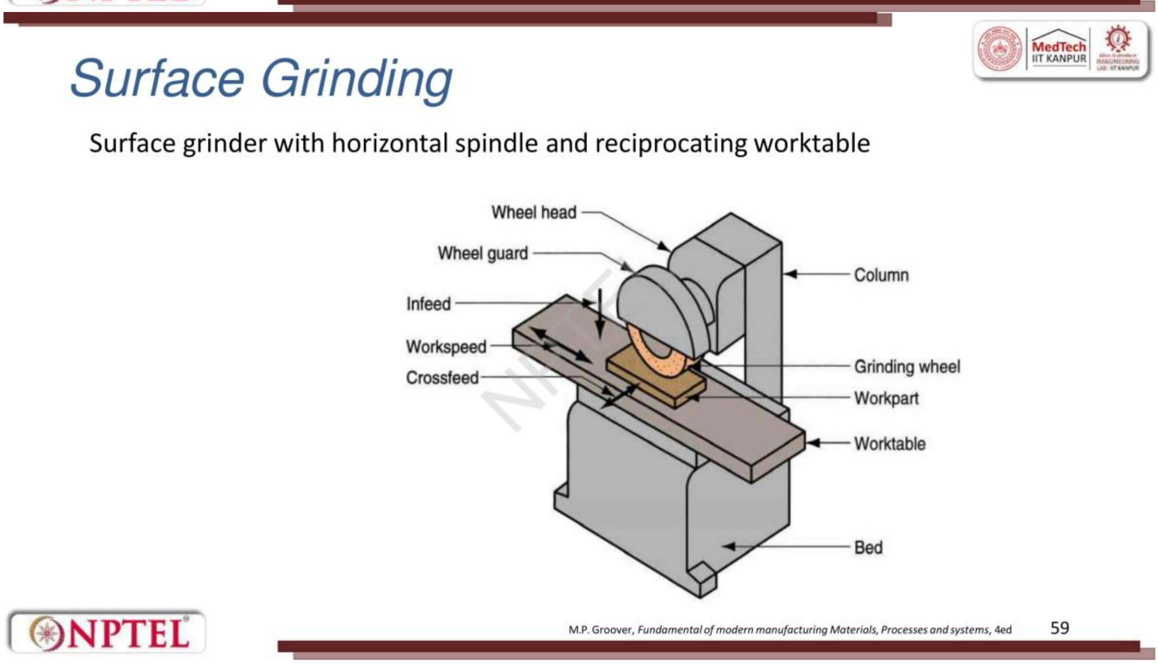
There is also another operation called truing. Truing involves shaping the grinding wheel to maintain its profiles. A diamond point tool is used, fed slowly and precisely across the wheel as it rotates. A very light depth is applied against the grinding wheel. This not only sharpens the wheel but also restores its cylindrical shape, ensuring straightness around the outer perimeter. So, that is truing.

Types of Grinding Operations

1) Surface Grinding
2) Cylindrical Grinding
3) Centreless Grinding
4) Creep Feed Grinding
5) Honing
6) Lapping
7) Superfinishing

There are different types of grinding, so we will see them like milling, where you had different types; turning, where you had different types; and in the same way, you have different types of grinding as well.





So, surface grinding is one of the types. You can have horizontal, vertical, or rotating the horizontal spindle where the table can be reciprocating or rotating. So, in both cases, these are reciprocating types; these two are reciprocating, and these two are rotating. You can have it horizontal, or you can have it vertical. So, this is surface grinding.

The surface of the grinding wheel is used to grind the workpiece. So, here the periphery is used; the difference is only rotation, reciprocation, rotation, face reciprocation, or rotation. This is surface grinding. So, this is mounted onto a machine tool, which is called a surface grinding machine. So, again, the same way as what you have in a milling machine, you also have it here.

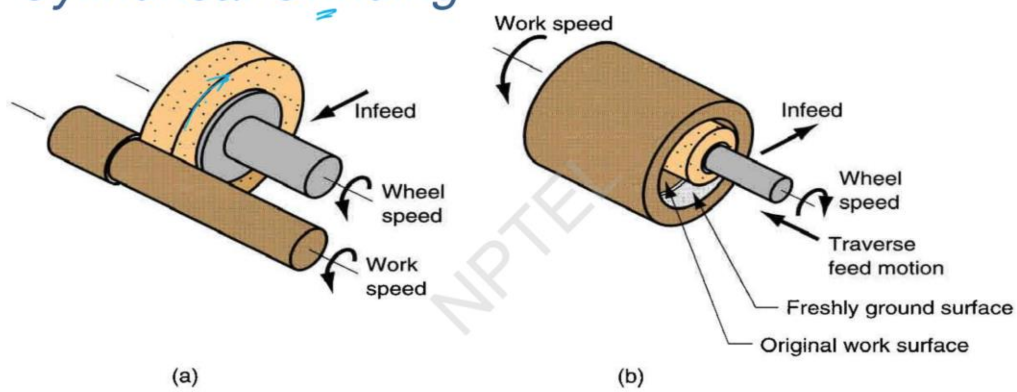
Cylindrical Grinding

Cylindrical grinding as its name suggests, is used for *rotational parts*. These grinding operations are divided into two basic types.

A. **External cylindrical grinding** which is similar to external turning. The grinding machine used for these operations closely resemble a lathe in which the tool post has been replaced by a high speed motor to rotate the grinding wheel.

B. **Internal cylindrical grinding** operates somewhat like a boring operation. The workpiece is usually held in a chuck and rotated to provide surface speed. The wheel is fed in either of two ways: (1) traverse feed or (2) plunge feed

Cylindrical Grinding



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

M.P. Groover, *Fundamental of modern manufacturing Materials, Processes and systems, 4ed*

You also have cylindrical grinding. Cylindrical grinding means where the part you produce can be externally cylindrical or internally cylindrical. Here, the spindle is mounted horizontally, and the grinding wheel is rotated against the workpiece. So, you can get a stepped shaft where you can grind. Internally, you can grind.

So, those things are called cylindrical grinding. So here, the first one was a flat surface, and here it is cylindrical.

Centreless Grinding

- Centreless grinding is an alternative process for grinding external and internal cylindrical surfaces.
- As its name suggests, the work piece is not held between centres. This results in a reduction in work handling time. Hence, centerless grinding is often used for high-production work.

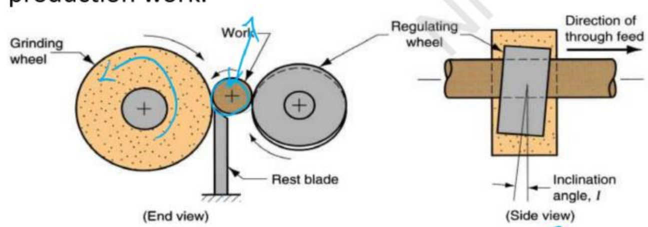


Figure - External centerless grinding

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The next one is centerless grinding. In centerless grinding, whenever you have a long, lengthy workpiece where the diameter is small and the length is long, you cannot hold it between the headstock and tailstock. So, here what we do is perform a centerless grinding operation.

So, here, like in cylindrical grinding, the grinding wheel rotates at an RPM, then you have the workpiece, which is supported through a regulating wheel. The regulating wheel will always be at an angle such that it tries to bite and pull the workpiece inside, grinds it, and then throws it out.

So, like a shaft, you can try to do small shafts. Shafts like these can be easily ground cylindrically using a centerless grinding machine. So, you will have a grinding wheel, a support that holds the workpiece, and a regulating wheel that regulates and pulls the workpiece. It is always made out of rubber; it only provides friction. The workpiece is supported on the rest blade.

Creep Feed Grinding

- Creep feed grinding is performed at very high depths of cut and very low feed rates; hence, the name creep feed.
- Depths of cut 1000 to 10,000 times greater than in conventional surface grinding
- Feed rates reduced by about the same proportion
- Material removal rate and productivity are increased in creep feed grinding because the wheel is continuously cutting
- In conventional surface grinding, wheel is engaged in cutting for only a portion of the stroke length

Creep Feed Grinding

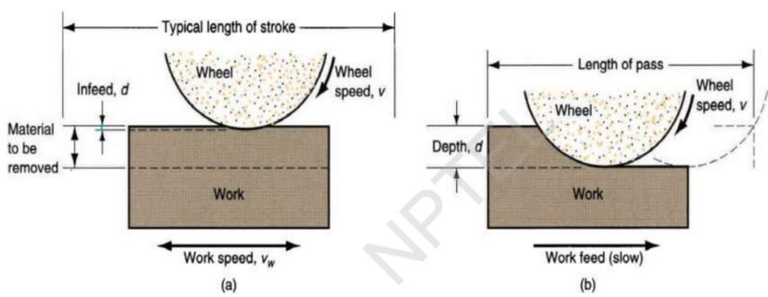


Figure - Comparison of (a) conventional surface grinding and (b) creep feed grinding

So, you also have creep feed grinding. Creep feed grinding has a very high depth of cut with very low feed rates. It is called creep feed grinding.

The depth can be 1,000 to 10,000 times greater than conventional machining. It is almost like a milling operation. Creep feed grinding. The feeds are very slow. The depths are very large.

So, this is how creep feed grinding is done. So, the infeed is this much. So, the material to be removed is this. So, here, this is the conventional way of doing it. In creep feed grinding, we do the depth in one shot.

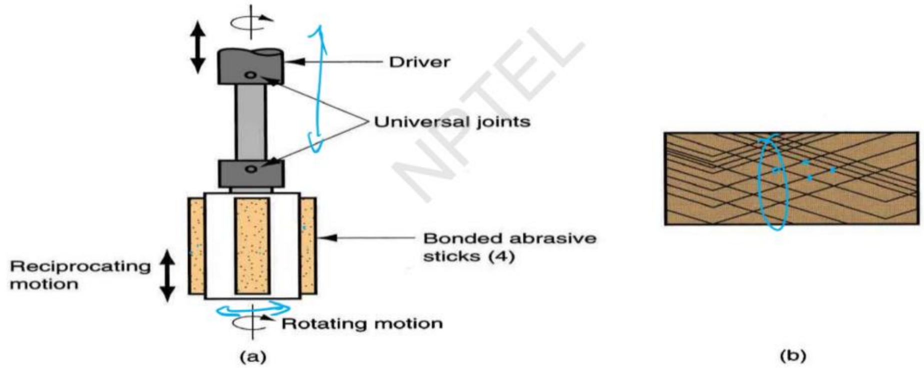
So, naturally, the grinding wheel should be harder, the abrasive should be better—all these comparisons are there. From grinding, there are some small extrapolations of grinding.

Honing

- Abrasive process performed by a set of bonded abrasive sticks using a combination of rotational and oscillatory motions
- Common application is to finish the bores of internal combustion engines
- Grit sizes range between 30 and 600
- Surface finishes of 0.12 μ m (5 μ -in) or better
- Creates a characteristic cross-hatched surface that retains lubrication

Honing

The honing process:
(a) the honing tool used for internal bore surface, and
(b) cross-hatched surface pattern created by the action of the honing tool



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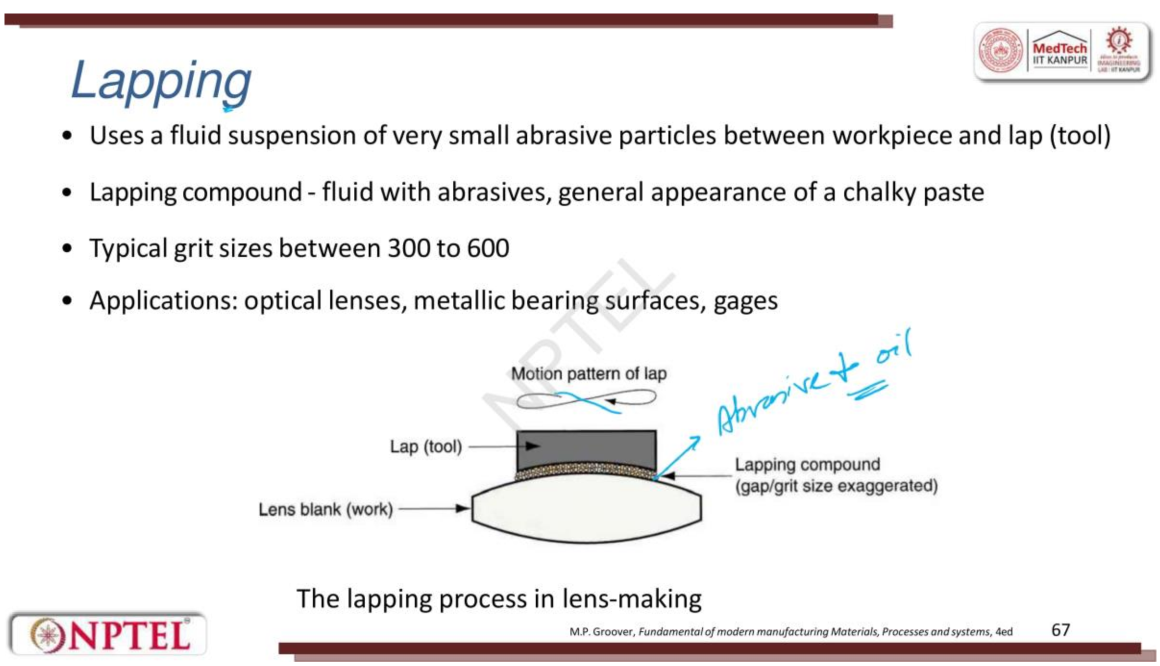
Honing is an operation wherein the grinding wheel—whatever I said—is converted into an abrasive stick. So, these abrasive sticks are placed peripherally on the tool. The tool rotates and reciprocates, and as it rotates and reciprocates, it also expands.

So, horning is an operation where you have a cylindrical hole, you want to expand like reaming you did. Here, you can expand the hole and inside the hole you can create crisscross hatch patterns. Why is this important? This is important because when you are trying to do a lubrication action between piston and the cylinder, these diamond like points, these are called as pinch points where the oil can be retained and it can help in lubrication. So, honing can be done internal, honing can be done external.

So, here it is a grinding wheel is cut into strips. These strips are located along the periphery of the tool. So, the tool reciprocates, rotates and also slightly expands.

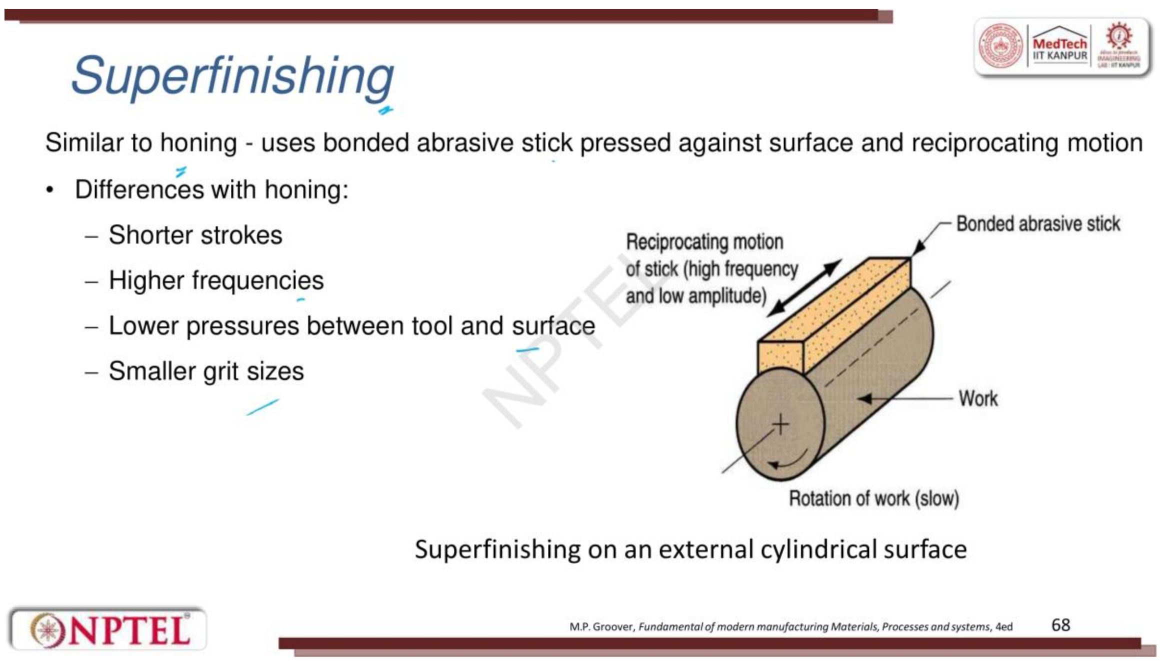


Lapping is another operation wherein which we completely use the abrasives as free. Abrasive plus you have oil or something to hold the abrasives together and now you have a lap which does not have any abrasive which is a tool which is on the top.

Then, you have something like mud like particles which are abrasive particles. So now, mud is there, then you have a lap and then this mud is held by some media, so it is all attached to each other. Now, you try to use the lap and then try to finish the surface. So, you can try to create figure of 8 pattern to generate a flat surface. It is almost like washing a vessel.

So, you have a vessel, which is a milk vessel, cylindrical, or a pressure cooker, which is cylindrical. Then, you have your hand, which is a lap. Then, between the cooker or the vessel and the lap, you have a brush. This brush has a soap particle. So, that is abrasive.

So, you can move up and down, up and down, up and down, and create—depending upon the abrasive size—a very smooth surface finish.



Super finishing is very similar to honing. We use an abrasive stick pressing against the surface and reciprocating the motion. It is the same as lapping, but the only difference between super finishing and lapping is that the abrasives are held, and then you can start moving them. So, by reciprocating at a very high frequency and very low amplitude, you try to perform a super finishing operation.

The strokes are very small; in lapping, they will be large. It has very high frequency, the pressures are low, and it has a very small grit size. Compared to honing, here, super finishing is done by a stick.

To recapitulate

- Explain Abrasive Machining
- Define Grinding
- What are types of Grinding wheel
- What is dressing and truing the wheel
- List various abrasive materials
- Grinding Processes

So, finally, to recap this lecture, we first saw what abrasive machining is, then we saw grinding. How do you specify a grinding wheel? Then, what is dressing and truing?

What are the different types of grinding operations? Then, we saw various advanced abrasive operations, which are used for generating very smooth surface finishes.

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Friends, we have used these references to prepare these slides, and thank you very much.