Basics of Mechanical Engineering-2

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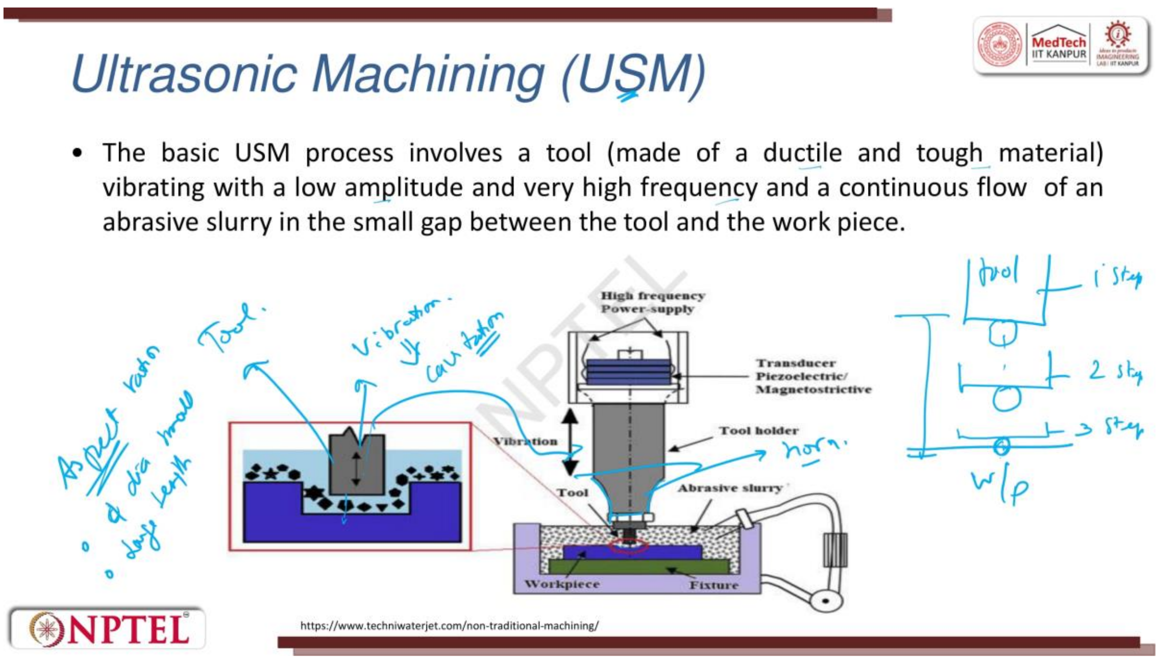
Week 11

Lecture 44

Non-Conventional Machining (Part 2 of 3)

Welcome to the continuing lecture on non-conventional machining processes.



So, the next process is going to be the ultrasonic machining process. The basics of the ultrasonic machining process involve a tool made out of ductile and tough material vibrating at a very low amplitude. It has a very high frequency and a continuous flow of abrasive slurry. In a small gap between the tool and the workpiece, machining occurs.

So, if you look at it, this is the vibration that is given, which is attached to a tool here. So, this is called a sonicator. That sonicator creates piezoelectric sonicators, which are available. You create the vibration, and this vibration, whatever you create, is amplified by this portion called the horn. So, this horn multiplies the amplitude.

The vibration will be 21 kilohertz. There is no change. But it will be a very small amplitude. Piezo crystals, when stacked together, give only 1 micron or 2 micron displacement. So, now you have to increase the displacement to 5 microns, 8 microns, 10 microns, or 15 microns.

So, what we do is we attach the transducer to a horn. The function of this horn is to multiply and enhance the amplitude. Then, this amplitude is connected to a tool. So, this is what the tool looks like. This is the tool.

This is a tool, right? The tool vibrates, and when it vibrates, it moves up and down. So, here you have the abrasives which flow in the media kept there. So, the abrasive, when it moves here along with the water media, forms a slurry. So, the slurry is filled on top, or the slurry can be pushed from one side and sucked on the other side.

You can fill it up, and then it can do. Now, what happens when the vibration is given, right? When the vibration is given, the tool comes in contact with the abrasive. Assume that you have a bat—a tennis bat, table tennis bat, or ping pong bat. You have a ball.

The ball bounces. So now when the ball is bouncing, you are trying and you have a hard surface, the table. So now you try to move down the ping pong bat. So the ball will try to hit. When you go down and down and down, the impact can be large.

The ping-pong ball will go vibrating faster and faster and faster. After some point of time, the amplitude dies. That is a long-term story. But if you move from here to here to here, you can see the frequency increases, the impact increases. And then it can try to make some indent on the table.

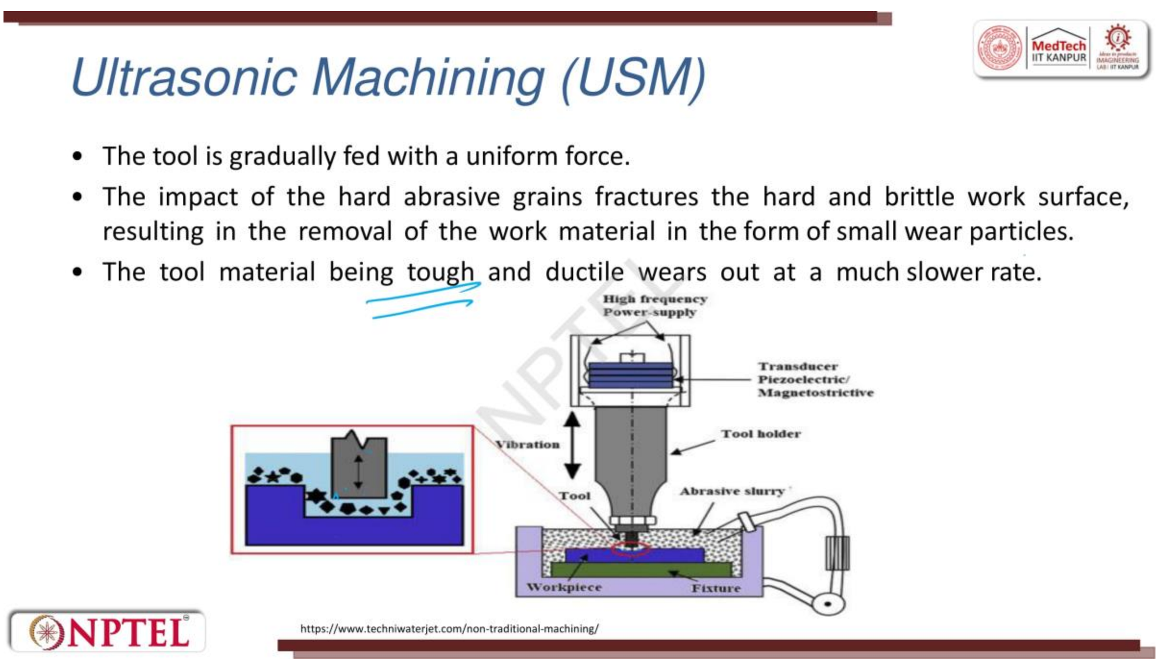
So, in the same way here, it is not one ping pong ball. There are several ping pong balls. These are abrasives. These abrasives are loose and they can move easily in the media. And now you start vibrating.

When you start vibrating, the abrasive hits the tool and then tries to come and hit the workpiece. So, here there are three steps involved. So, here the abrasive is present. This is the workpiece. This is the tool.

As the abrasive moves down, the tool moves down. So the tool comes here; this is step 1, this is step 2, where the tool is at a very large distance from the workpiece. Next, the tool moves down, so it is step 2. Now, in step 3, what happens? The tool comes here, the abrasive comes here; this is the third step.

So, when this happens, it is almost similar to abrasive jet machining. There is chipping happening from the workpiece, which can be used for removing and taking away material. So, here what happens? The chip gets moved away along with the abrasive and slurry. It moves away.

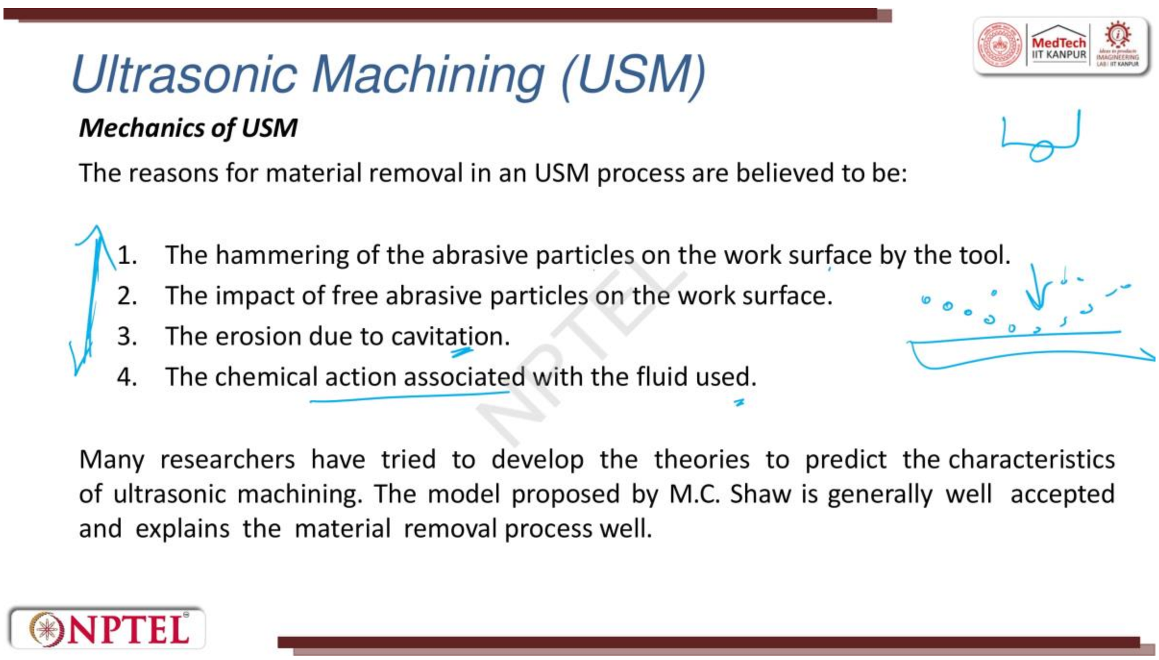
So, whenever it is vibrating at 21 kilohertz, it tries to create a cavitation effect. This cavitation effect also tries to remove the loose particles that are sticking onto the workpiece. And then, whatever feature is to be generated, it gets generated very nicely. So, ultrasonic machining is very effective when we use brittle materials. It can perform very high aspect ratio machining. That means very small diameters, small diameters, and very large lengths can be achieved. These high aspect ratio holes are made using ultrasonic machining.



So, the tool is gradually fed with uniform force. The impact of the hard abrasive grain fractures the hard and brittle workpiece surface, resulting in the removal of material in the form of small wear particles. The tool material is always tough.

Why? Because if the tool material is also hard, then there will be chipping off of the tool material as well as the workpiece material. Here, I do not want the chipping of the tool, so I try to use a tough material. So, this tough material will give some leeway for indentation inside the tool, but it will not have tool wear. So, that is why we always choose the tool material to be tough, and this tool is braced.

You remember we studied bracing and welding is braced to the horn and this horn can be screwed or it can be again joint to the piezo actuators right. So the slurry can be recirculated put a filter and then it can be recirculated.



So the mechanisms can be hammering of the abrasive particle on top of the work piece impact of free. So this is whatever i said tool moving down so the other way round is there are free abrasives which keep coming hitting the surface and going. So the load need not be happening here

Because there are random in nature when the tool moves up still the abrasive slurry can be flowing down. So the impact of free abrasives on the workpiece can lead to a removal of material. Cavitation as I told you when the ultrasonic creates up and down motion it can create bubbles.

These bubbles have very high local pressure when it explodes it tries to remove material. There can be a small chemical action with the fluid which is almost negligible. So, these three are very important material removal mechanisms as far as ultrasonic machining is concerned.

Ultrasonic Machining (USM)

M.C. Shaw's Model of USM Mechanics

In this model the direct impact of the tool on the grains in contact with the work piece is taken into consideration. Also, the assumptions made are:

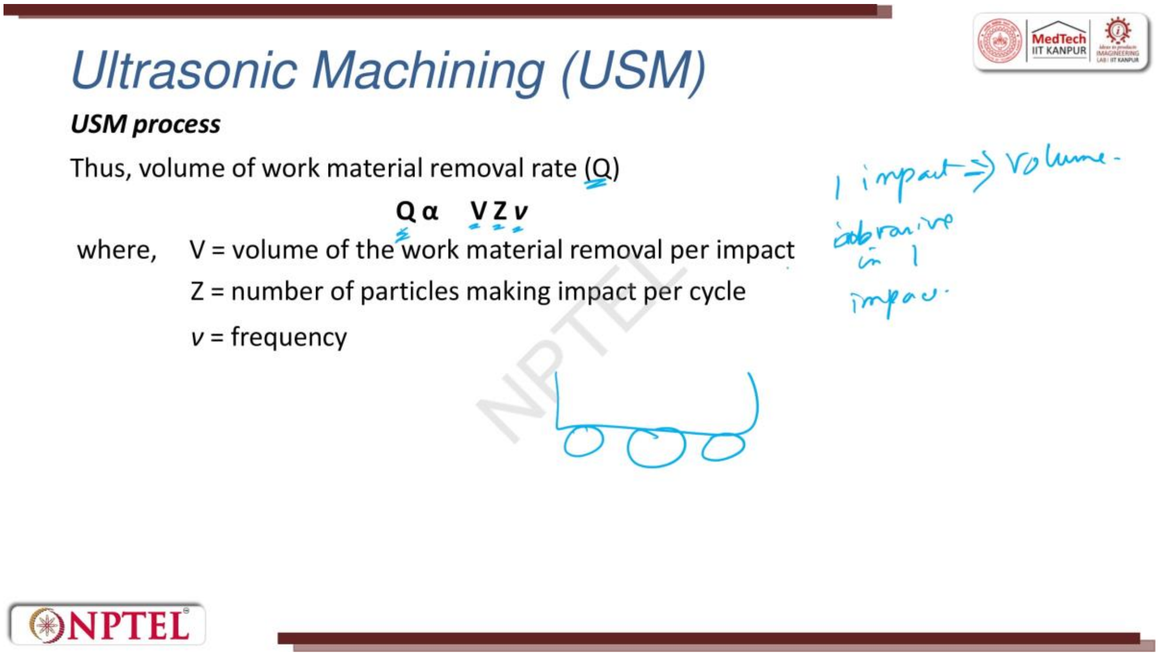
1. The rate of work material removal is proportional to the volume of the work material per impact.
2. The rate of work material removal is proportional to the no. of particles making impact per cycle.
3. The rate of work material removal is proportional to the frequency (no. of cycles per unit time).
4. All impacts are identical.
5. All abrasive grains are identical and spherical in shape.

MC Shaw made a model. So, I am just presenting you this model to understand what will be the material removal rate. And who are all the key players in the material removal rate as far as ultrasonic machining is concerned. So, there are assumption made while making the model by M.C Shaw.

The rate of material removal is proportional to the volume of the material per impact. So, what he says is, he says the rate of material removal, MRR, is proportional to the volume of material per impact. So, you know, one abrasive impact. So, when I know in one slurry how many abrasives are there, I multiply it and then I say it.

The rate of workpiece material removal is proportional to the number of particles making impact in a cycle. So, this is what I said here. The rate of material removal is proportional to the frequency. How many times I hit? All impacts are identical. All abrasives are identical.

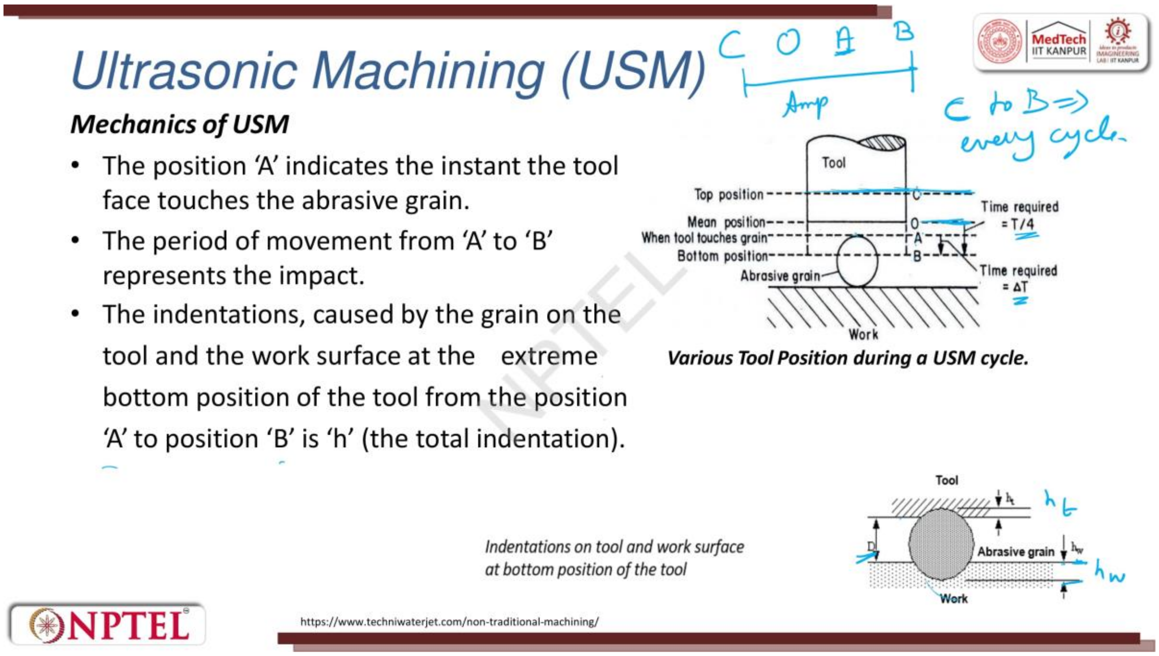
So, because the abrasives are random in nature, I cannot do it. So, what I do is I make every abrasive spherical. And all the impact that happens on one abrasive also tries to happen on the other abrasive, the same impact.



So, by making all these assumptions, I am able to calculate the volume of material removal rate, Q. Q is nothing but is directly proportional to the volume of material removal per impact, right.

V, and Z is the number of particles present there, and nu is the frequency. By multiplying this, right, so I know per impact what is the amount of volume removed, Then I know how many abrasives are there in one impact. Abrasives in one impact. So what does it mean is you have an abrasive.

We are now currently taking one. There can be five abrasives. So, number of abrasives per impact per cycle, then the frequencies, how many times I do. So, through multiplying all these things, I can try to find out the volume of material removal. The proportionality can be removed by a constant K. That constant K is a workpiece tool material and abrasive material interaction.



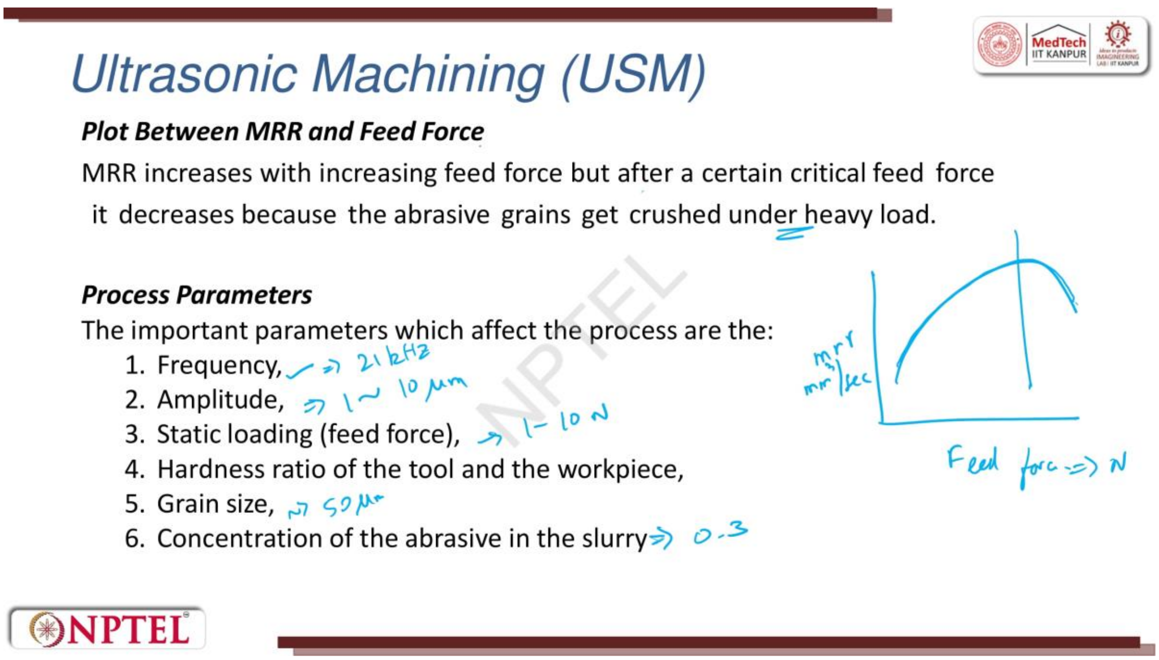
So, as I said earlier, the mechanism of material removal, you can try to have a position A. Which is the mean position, indicates the instant the tool face touches the abrasive. So, the tool moves from C position to B position. The tool moves from C to B, that is every cycle.

It moves from C to B. So, when it comes to a mean position, the mean position is between C and B, halfway is O. At position A, the abrasive comes in contact with the tool. So, now you can clearly say C, O, A, and B. This is the amplitude, this is the mean, and this is the point when there is contact coming in with the workpiece, right? So, from here, from the mean position to the O position, see, the total time T is nothing but C to B and back to C is T.

Now, when I move from O to B, it is T by 4, that is what is told, T by 4. Now, I do not know the exact position where A will come in contact and what the abrasive size is. We are assuming it to be the same, but in reality, there can be a change. So, the time taken to move from A to B is delta T. So, the period of movement from A to B represents the impact.

So, the impact time is delta T. The indentation caused by the grain on the tool and the workpiece at the extreme position of the tool from position A to B is H. So, what is H? So, the depth in which the abrasive tries to indent into the workpiece is H. And when it tries to indent, it is also possible that it will try to indent the workpiece.

So, there is going to be an H which happens here, HW, then this is HT, a small indentation, right. So, this is what we are trying to say. So, now we can try to go further and understand. So, D is the distance, or we can say the distance between the tool and the workpiece is D, okay. So, now what we can do is we can start calculating the material removal rate, which is a little advanced for this course. But I just wanted to introduce all these things to you.



So, the plot between MRR and the feed force shows that the MRR increases with the feed force. So, this is MRR, and this is the feed force. So, it goes like this: the units will be millimeters cubed per second or something, and the feed force will be in Newtons. So, as the force keeps on increasing—what is the force?

The critical feed force is this force. When we apply a load on top of it, that is the feed force. But after a certain feed force, there will be a decrease. So, this is the maximum, and after hitting the maximum, it reduces. Why does it reduce?

The abrasives gets crushed. So, what are all the process parameters which are very important in ultrasonic? The frequency which is almost constant 21 kilohertz, the amplitude which can vary from 1 to 10 microns. The static load which can vary from 1 to

10 Newton, the hardness to tool ratio this is very important. At the grain size is many a times which is less than 50 microns which is always less than 50 microns.

The concentration we will always go 0.3 (30 percent to 40 percent) is the concentration limit. So, these are the process parameters and these are the values which generally we use for ultrasonic machining.

Ultrasonic Machining (USM)

Relative material removal rates
(frequency = 16.3 kHz, amplitude = 12.5 um, grain size = 100 mesh)

Work material	Relative MRR
Glass	100.0
Brass	6.6
Tungsten	4.8
Titanium	4.0
Steel	3.9
Chrome steel	1.4

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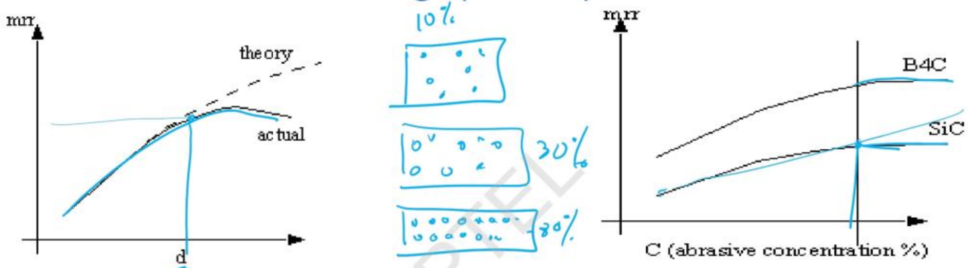
So, when we try to have a relative hardness glass if you try to take it as 100. Brass it is 6.6 is the material removal rate, tungsten it is 4.8, titanium it is 4, steel it is 3.9 and chrome steel it is 1.1. So, you see we are comparing to glass what will be the material removal rate.

Ultrasonic Machining (USM)



- MRR should also rise proportionately with the mean grain diameter 'd'. When 'd' becomes too large, the crushing tendency increases.
- Concentration of the abrasives directly controls the number of grains producing impact per cycle.
  - MRR is proportional to $C^{1/4}$ so after C rises to 30% MRR increase is not very fast.

So, when we plot with respect to grain size, so this is the graph which talks about it. So, the material removal rate also increases with the mean grain diameter D, but after a certain point it will crush. So, the material removal rate is reduced. Theoretically speaking, it will try to continue a straight line, but practically it will start crushing. So, we have to choose at this point the material removal rate.

The concentration of the abrasive is also the same. If you have more and more and more concentration, it is truly speaking it has to remove lot of material. But moment the concentrations are very high, then majority of the energy is spent between striking and striking of abrasives. See, when you try to take 10 percent, you will try to have these are the abrasives. When you have 30%, it is something like this.

When you have 80%, it will be like this. So, in 80%, what happens? Rather than the abrasive tool, abrasive hitting at the workpiece, it will be more of abrasive-abrasive hitting. When abrasive-abrasive hitting, it does not come in contact with the workpiece, the abrasive gets damaged. So, there also you have a maximum saturation point, afterwards it is almost constant or it decreases.

So, the concentration of the abrasive directly controls the number of grains producing impact. The MRR is proportioned to C 1 by 4. So, after C rises to 30 percent, the MRR is not very fast.

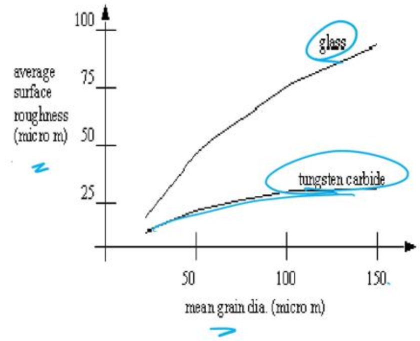
Ultrasonic Machining (USM)

Apart from the process parameters some physical properties (e.g. viscosity) of the fluid used for the slurry also affects the MRR. Experiments show that MRR drops as viscosity increases.

Although the MRR is a very important consideration for judging the USM but so is the surface finish.

Dependence of Surface Finish on Grain Size

- Surface finish is more sensitive to grain size in softer materials like glass.
- Harder materials, such as tungsten carbide, show less dependence on grain size.
- In brittle fracture, fragment size in harder materials is less affected by impacting particle size.



So, if you see the roughness which is getting generated with respect to mean size, moment the size of the abrasive goes large. The chip what is getting extracted is also large, the cavity which is formed is large.

So, roughness is high. So, as the abrasive size increases, the roughness also increases, right? So, there is a difference between tungsten carbide as an abrasive and glass as an abrasive. So, if you see glass as an abrasive, when it tries to hit the workpiece, it also shatters. So, because of that, the glass creates a lot of scratches, and the average roughness is very high when we use glass.

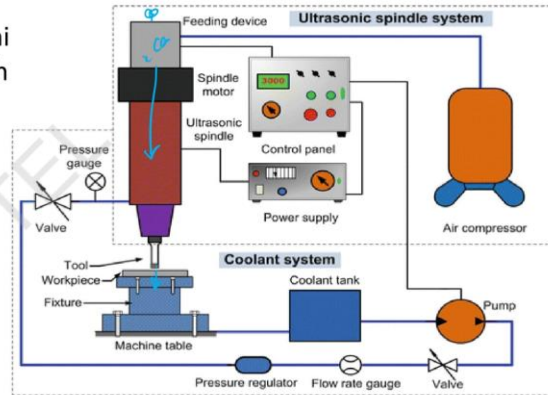
So, depending on the surface finish and grain size, the surface finish is more sensitive to grain size in softer materials like glass. Harder materials like tungsten carbide have much less impact. The brittle fracture and fragment size in harder materials are less affected by the impact of particle size.

Ultrasonic Machining (USM)

Ultrasonic Machining Unit

The main units of an Ultrasonic Machining uni are shown in the figure below. It consists of th following machine components:

1. The acoustic head.
2. The feeding unit.
3. The tool.
4. The abrasive slurry and pump unit.
5. The body with work table.



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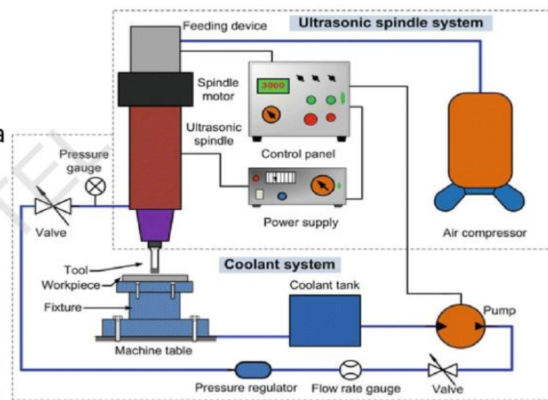
Ultrasonic Machining (USM)

Acoustic Head

1. The Acoustic head's function is to produce a vibration in the tool.
2. It consists of a generator for supplying a high frequency electric current, a transducer to convert this into a mechanical motion (in form of a high frequency vibration).
3. A holder to hold the head.
4. A concentrator to mechanically amplify the vibration while transmitting it to the tool.



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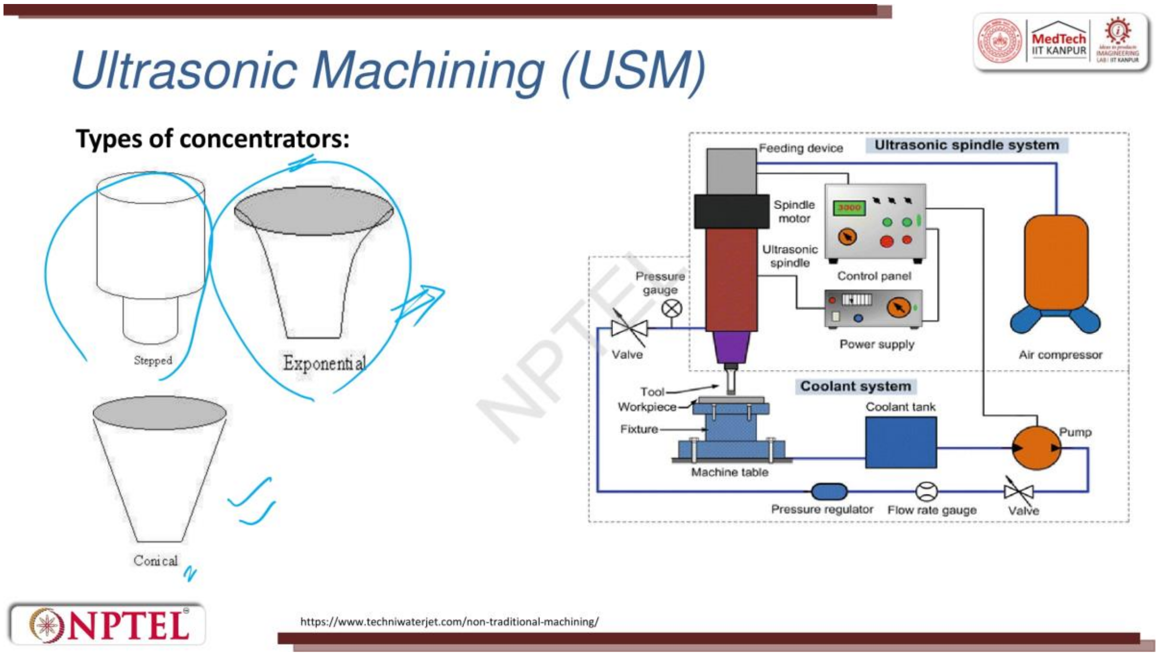

So, this is the schematic diagram, as I have already explained. This is the acoustic head. So, here it is all called a sonicator. This is the horn. This is the tool. The tool is in turn attached to a small profile, whatever you want. So, there is a feeding unit because when you are trying to drill a hole, there has to be feed which is given.

It can be based on gravity. You can put a weight here, or there can be a solenoid which comes and does it. So, there is a feed unit, there is a tool which is there. Abrasive slurry concentration we have already seen. The body with the table is also seen. So, we can use an air compressor to pressurize the feed, or we use a solenoid, or we use gravity. So, the acoustic head is to produce the vibration. It has a generator, a holder to hold the head, and a concentrator to mechanically amplify this.

So, we are talking about the horn. So, there are various types of concentrators. I called it a horn. You can also call it a concentrator. There are stepped concentrators, there are exponential concentrators, there are conical concentrators.

The exponential concentrator is the best, but manufacturing difficulty is there. That is why we always go for a tapered one. So, the horn which is used is always tapered. So, the horn is used for multiplying or amplifying the amplitude.

Ultrasonic Machining (USM)

Abrasive Slurry

- The most common abrasives are Boron Carbide (B_4C), Silicon Carbide (SiC), Corrundum (Al_2O_3), Diamond and Boron silicarbide.
- B_4C is the best and most efficient among the rest but it is expensive.
- SiC is used on glass, germanium and most ceramics.
- Cutting time with SiC is about 20-40% more than that with B_4C.
- Diamond dust is used only for cutting daimond and rubies.
- Water is the most commonly used fluid although other liquids such as benzene, glycerol and oils are also used.

Slurry concentration, we have seen boron carbide, silicon carbide. Then you have corundum, alumina, diamond, boron silicon carbide; all these things can be used. The best one we use is always B4C, which has a very high hardness. And here, since the temperatures are not very high, the boron carbide does not dissociate. So, we use boron carbide as the material here. Silicon is also used on glass. The cutting time with silicon is about 20 to 40 percent more than that of B4C. Diamond dust particles can also be used. The water is used for slurry making.

Ultrasonic Machining (USM)

Advantages of USM:

- No thermal damage.
- Suitable for fragile materials(brittle materials like glass, ceramics, and semiconductors.

Disadvantages of USM:

- Slow material removal rate.
- Limited to small-sized workpieces.

Applications of USM:

- Precision machining of brittle materials like glass, ceramics, and semiconductors.
- Used in medical applications and optical industries.for delicate machining.
- Suitable for making micro-sized features.

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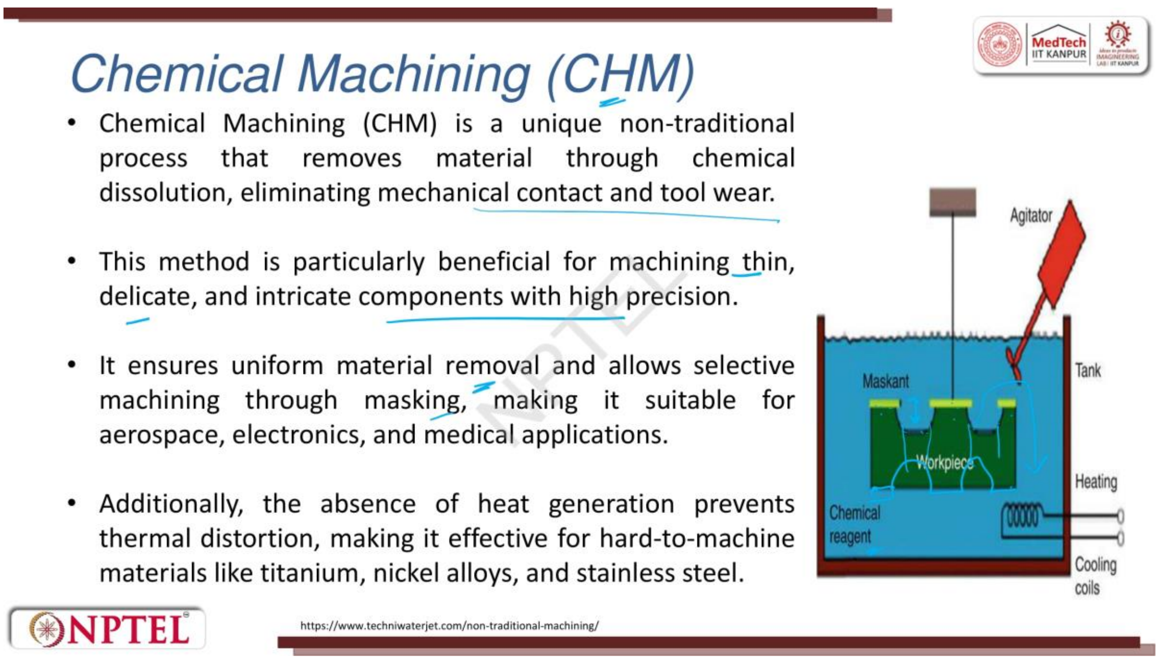
Then the advantages: very high aspect ratio holes can be made, and a very large array of holes can be made. Basically, you move the table, and the ultrasonic can be done. It is very slow compared to drilling. Fragile materials can be used for machining. So, there is no thermal damage at all. What is the limitation? It is a slow process, and it is used only for small-size workpieces.

Large workpieces, holding, deflection—all these things come into play. They find a lot of applications in ultrasonic machining, medical applications, and also in micro-sized features.



The next process of interest is going to be the chemical machining process. In the chemical machining process, as I told you, we will try to use a chemical as an etchant, which is always acidic. So, this etchant is mixed and diluted with water, and it is filled inside a tank.

That is called a chemical reagent. Now, you try to keep the workpiece, and on top of the workpiece, you apply a maskant—that means you apply a mask. This mask tries to protect the material where it does not need to be etched. To ensure continuous etching and prevent the slurry from depositing in the machined area, we always use an agitator to create a vortex.

This vortex disturbs the slurry material and removes it from the space where it is being machined to the bottom. We can also use a heating element. This heating accelerates the etching process. Chemical machining is a unique non-traditional machining process that removes material through chemical dissolution, eliminating mechanical contact and tool wear. Here, there is no cutting force.

So, very fragile sheets can be made. If you see Lord Krishna's photo, they etch it. Or Jesus' photo, they etch it. And if you want to write some Quranic words, they etch it. They are all done with very thin sheets.

They are all done by chemical etching. So, the method is particularly beneficial for machining thin, delicate, and intricate components. It ensures uniform material removal and selective machining through a mask. So, if you do not put the mask, what will happen? Uniform thinning will happen.

You have an object, you put it into an etchant, and you start rotating the cylinder. You will have uniform etching happening all around the cylinder. And see, there are multiple things. You have to rotate it. You have to reciprocate it.

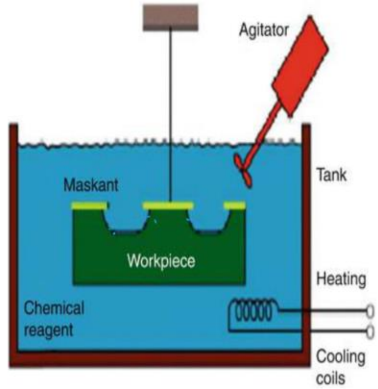
So when you reciprocate and rotate, you will have a thing. Suppose if you do not reciprocate and only rotate, you will get a taper. So you can play with the shapes that you want. So if you are trying to use a solid, then you try to remove material. If you want to do it selectively, you try to put a mask.

You can also create a very high aspect ratio hole. So, both sides can also be done. So, you can generate a profile like this so that you can create a hole if possible. Additionally, the absence of heat here means there is no thermal damage to the workpiece made.

Chemical Machining (CHM)

Process of Chemical Machining :

- The Chemical Machining (CHM) process begins with **cleaning**, where the workpiece is thoroughly cleaned to remove any contaminants that could affect the machining process.
- Next, **masking** is performed by applying a chemically resistant maskant to protect areas that should not be etched.
- During the **etching** stage, a chemical etchant dissolves the exposed material, shaping the desired features.
- After machining, the **maskant removal** step ensures the protected areas are exposed. Finally, **finishing** involves cleaning and polishing the part for a refined surface.



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So, what is the process? The chemical machining process begins with a cleaning step where the workpiece is thoroughly cleaned, then a mask is applied. If you want to do it selectively, a mask is applied, then there is an etching stage. Then finally, when the etching is over, the mask is removed and the workpiece is cleaned. And we remove all the traces of the etchant which is there so that corrosion cannot happen.

Chemical Machining (CHM)

Advantages of **Chemical Machining:**

- No mechanical stresses – avoids tool wear and residual stresses.
- Can machine complex and intricate shapes with high precision.
- Works on hard, brittle, and thin materials without distortion.
- Suitable for batch production with minimal setup costs.

Disadvantages of Chemical Machining:

- Chemical handling and disposal require special precautions.
- Slow material removal rate compared to other machining methods.
- Limited to thin materials – not suitable for thick workpieces.
- Not ideal for mass production due to process time and cost.

Applications of Chemical Machining:

- Aerospace (turbine blades, lightweight structures), electronics (circuit boards, micro-components), automotive (engraving, precision machining), medical.

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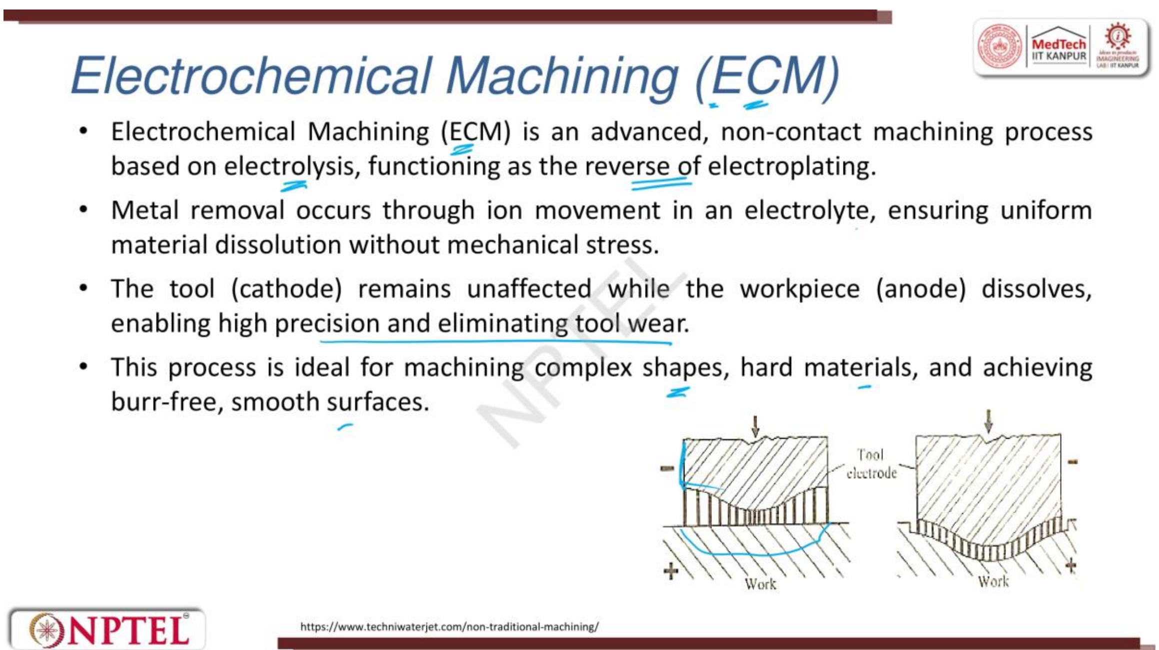
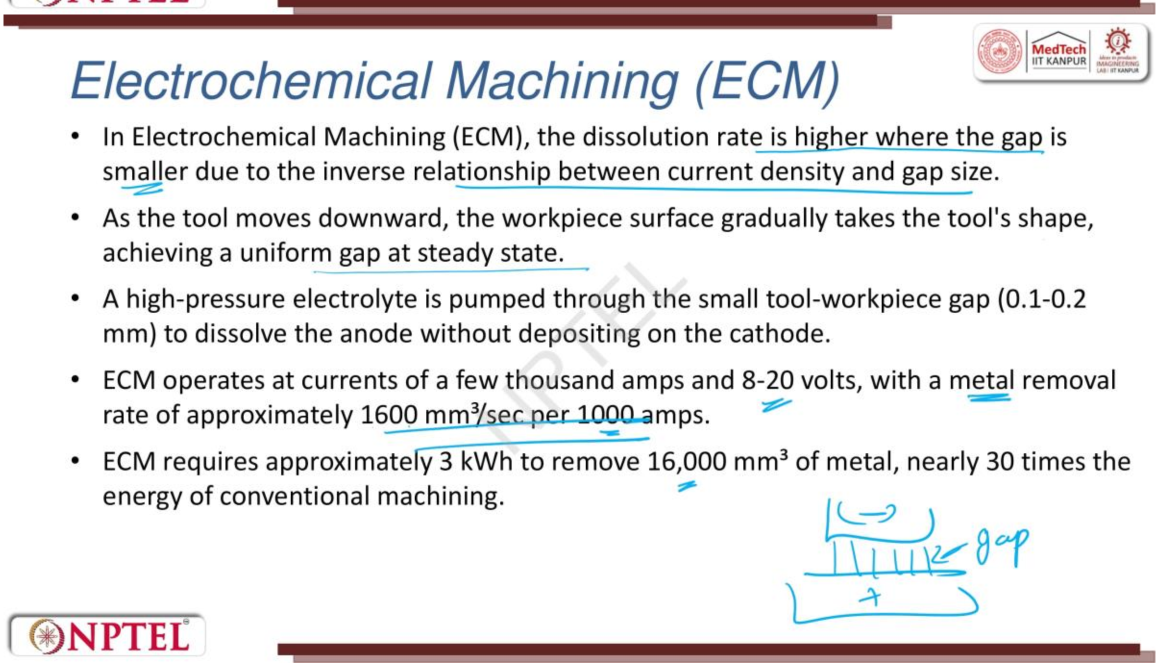
So, the advantages are no mechanical stress, no machining, and the ability to machine complex and intricate shapes. So, it can do full machining or it can do engraving on top, or it can also do a taper if possible. So, work on hard, brittle, and thin material can be done; it is suitable for batch production.

Chemical handling is always a challenge; the material removal rate is low, limited to thin machining, and it is not ideal for mass production. So, aerospace components, many of the transformer components, and very thin laminates are made out of chemical etching.





So, electrochemical machining is the next process, which is an advancement of chemical machining. I wanted to accelerate the machining process. So, here, what I do is attach it with electricity. So, the electrochemical machining process is an advanced non-contact machining process based on electrolysis. It functions the same way as the reverse of electroplating. There, it was only etching.

So, here, electrolysis happens. In plating, what happens is you have an anode from an anode. You try to remove material and deposit it on a cathode. While depositing, I do not allow this to deposit. I remove the material. So, from the anode, material is getting removed.

It is not getting deposited on the cathode. I move the electrolyte out. So, that is electrochemical machining. So, the material removal through ion movement in an electrolyte ensures uniform material dissolution without mechanical stress in electrochemical machining. So here, you use a tool called a cathode, then you attach the workpiece to the anode.

So, you give a tool profile whatever you want. Based upon the tool profile and the distance you maintain, the current density is what is there. The amount of electrolysis that happens, the amount of material dissolution that happens, changes. So, based upon the tool profile, you can create the workpiece profile you want. Here, there is no tool wear, no heat-affected zone, and no heat generated.

So, it is a very wonderful process. The tool remains unaffected while the workpiece dissolves, enabling high precision and elimination of tool wear. The process is ideal for making complex shapes, hard materials, and smooth surfaces. Very high aspect ratio holes can be made. Very large complex curvatures, if you want, can be made.

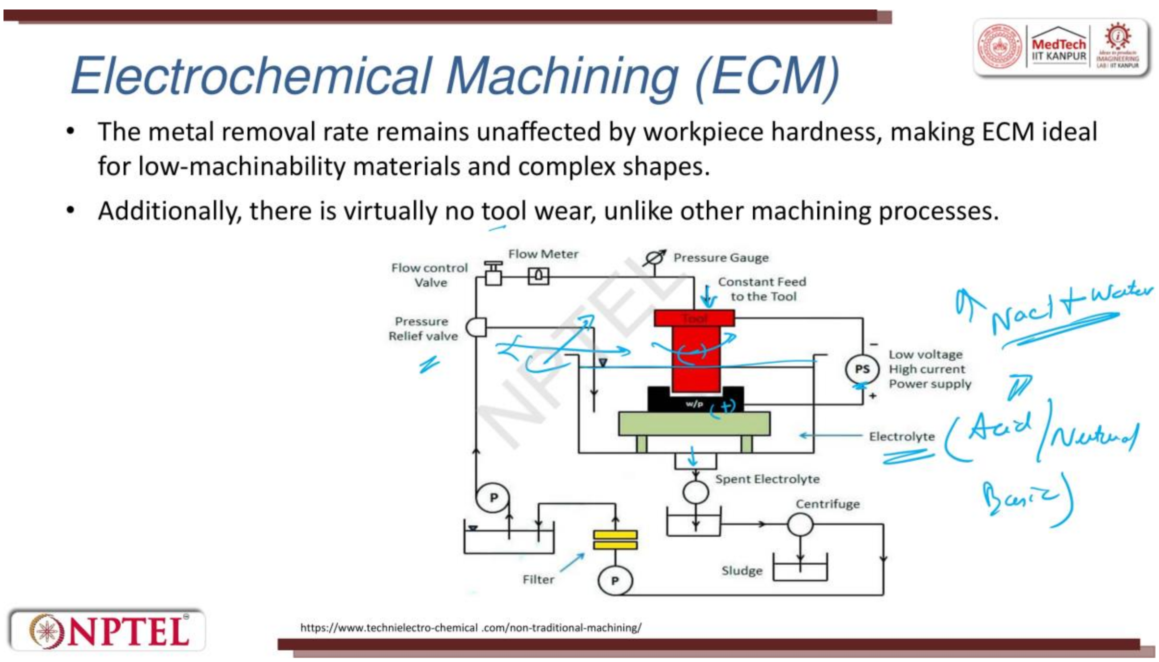
You can use it like sinking. You can also use it like milling. That means, like in a milling operation, I used to have a tool. I rotate the tool and move the workpiece in the XY plane. You can try to make a pocket.

So, in this process, the advantage is there is no heat, and the surface finish is extremely well. So, in electrochemical machining, the dissolution rate is higher when the gap is smaller. So, basically, it depends on the current density. So, there is an inverse relationship between the current density and the gap. So, this is negative, this is positive, and what we are trying to talk about is the gap.

Depending upon the current density, the material removal rate will be as such. And when the tool moves down. So, if you keep it at one point and do it, the etching will happen and then stop. So, now I have to keep moving the tool. So, there is a feed rate given as the tool moves downward; the workpiece surface gradually takes the tool shape, achieving a uniform gap at steady state.

High-pressure electrolyte is used such that very small gaps can be maintained, and material removal can also happen. Very large currents will be used. Current densities will be phenomenally high. The voltages will be small. The current densities will be very high.

So, you can see here the material removal rate is 1600 mm^3/1000 amps. So, it can remove 16000 mm^3 of material, nearly 30 times faster than the conventional method. But the energy consumption is very high for the electrochemical machining process.



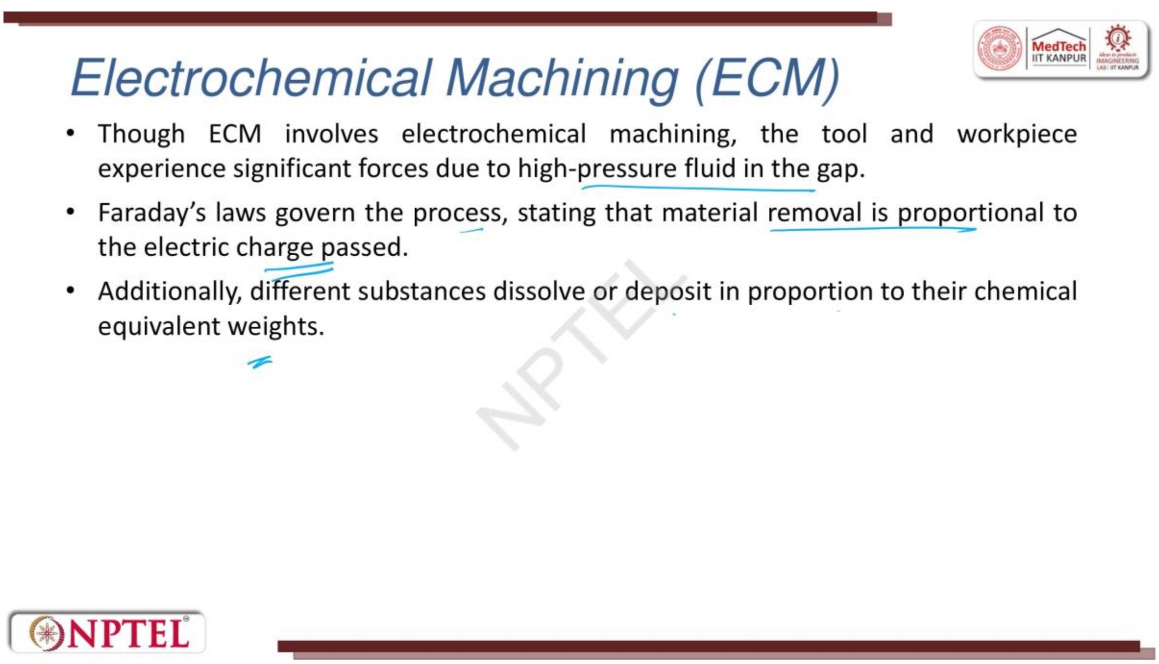
So, this is how the process looks. So, I give a constant feed from the top. This is the tool. The tool does not come in contact with the workpiece. There is no mask in use. The tool has to be a conducting material. Whatever is the profile on the tool will be replicated on the workpiece.

So, the tool is given the negative potential. The workpiece is given the positive potential. The tool can rotate and move in the XY plane. And so now what is happening in the entire thing, the tool, the workpiece, the stand, everything is sunk inside a electrolyte. This electrolyte can be acidic, can be neutral, can be basic.

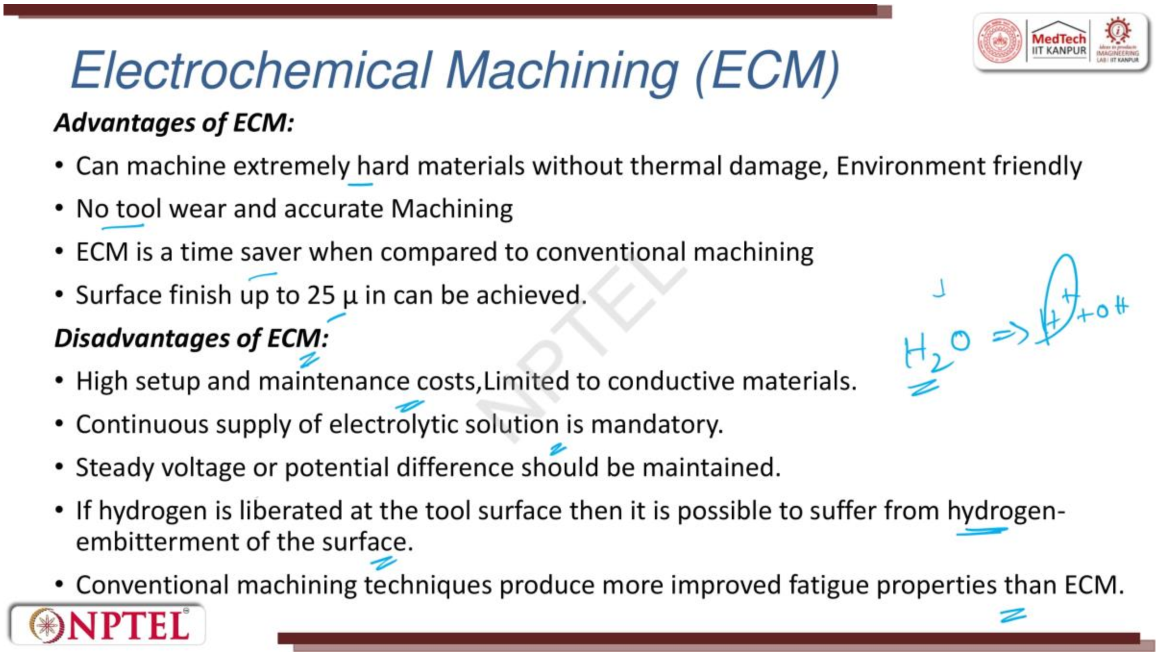
So what do I do? I try to have NaCl plus I try to mix it up with water, maintain some mole percentage and then I try to fill up the electrolyte. I can also take HCl. I can also take HNO3. Depending upon the workpiece tool combination, you can try to choose it.

So now in the presence of the electrolyte. And Faraday's principle coming into existence, there will be a material removal rate which is happening. So, the feed is given from the top. So, the electrolyte whatever is there is pumped inside, this is the power supply. The electrolyte is pumped inside and then the electrolyte is also removed from here.

So, we maintain a constant level and the Whichever gets removed here passes through multiple filters. They remove the sludge and then it gets recirculated. The electrolyte can be pressurized or it can be free-flowing. The material removal rate remains unaffected by workpiece hardness, making ECM ideal for machining low-machinability materials and complex shapes. Additionally, there is no tool wear, which makes this process more versatile than any other non-conventional machining process.



Although ECM involves electrochemical machining, the tool and the workpiece experience significant force due to high-pressure fluid in the gap. Faraday's law governs the process, stating that the material removal rate is proportional to the electric charge passing through. Additionally, different substances dissolve or deposit in proportion to their chemical equivalent weight.



So, these are the advantages: extremely hard materials can be machined, no tool wear, and it is faster than conventional machining processes. You can achieve up to 25 microns accuracy. The disadvantages are that since it involves reactions and dissolution, the equipment maintenance is very difficult. The electrolyte solution must be constantly maintained, and you should also understand what happens when the current passes. When current passes through a liquid, hydrolysis occurs. So, the water will evaporate.

Then, once the water is evaporated, the concentration level goes high. In order to maintain it, we always keep adding water. A steady voltage potential is required. If hydrogen is applied, because when you apply hydrogen, water forms. And when you apply an electrolyte there, it is going to make H+ and OH-, right?

So, this H+ is hydrogen. So, if hydrogen is liberated at the tool surface, then it is possible to suffer from hydrogen embrittlement of the surface. So, the hydrogen—because water dissociates—produces hydrogen. This hydrogen can enter into cracks, and these cracks, while in service, can lead to damage. So, this is a disadvantage that happens in this process. So, here, because of that, the fatigue property is always a little compromised when we use the electrochemical machining process.

Electrochemical Machining (ECM)

Applications of ECM

ECM is mainly used in the areas where conventional machining techniques are not feasible.

One of the main applications of ECM is found in the *aerospace industries* where accuracy is very important when complex shaped difficult to machine materials are needed to be machined.

- Different Industrial techniques have been developed on the basis of Electrochemical Machining Such as
  - a. Electrochemical Cutting
  - b. Electrochemical broaching
  - c. Electrochemical drilling
  - d. Electrochemical deburring

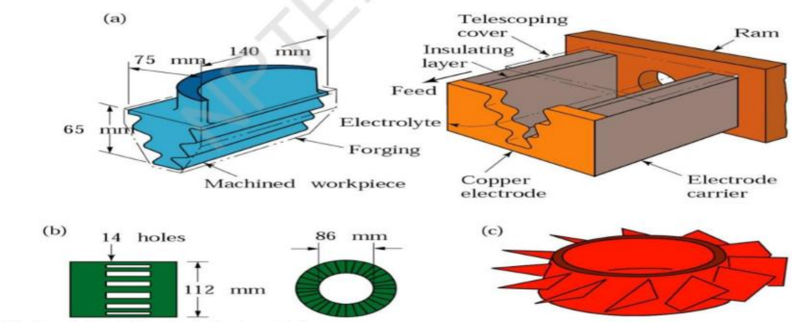
Electrochemical Machining (ECM)

Different parts made by electrochemical machining:

(a) Turbine blade material : nickel alloy

(b) Thin slots on a 4340-steel roller-bearing cage.

(c) Integral air foils on a compressor disk.



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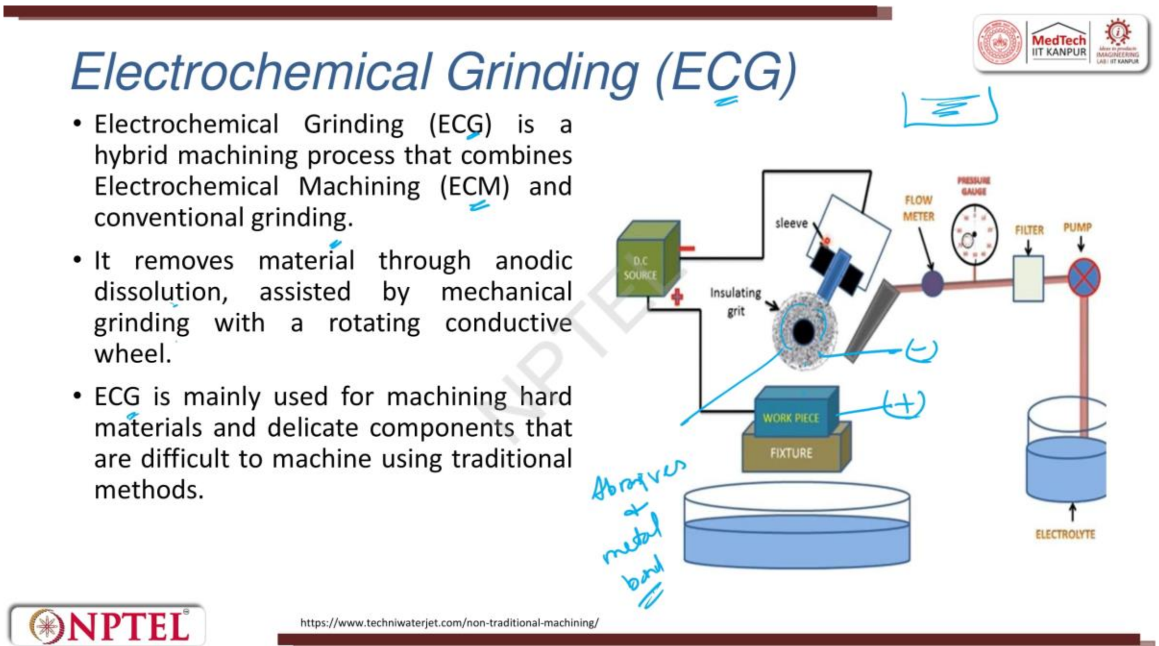
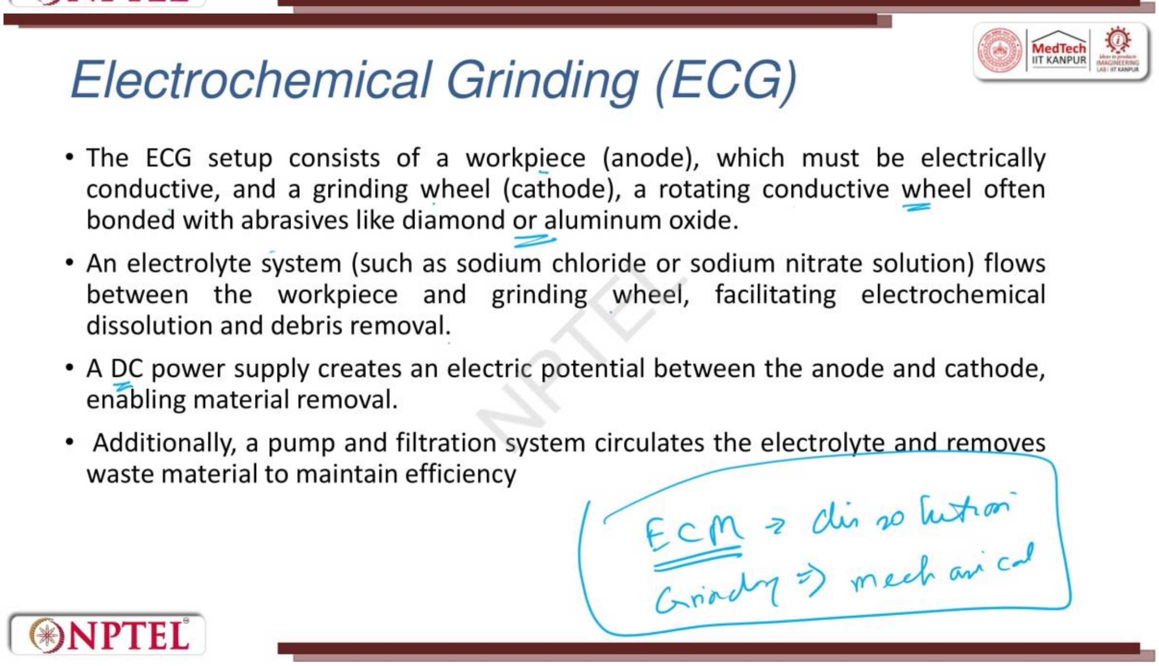
So, the same electrochemical machining process can be used for electrochemical cutting. It can be used for electrochemical broaching, drilling, and deburring. So, you can see here such parts when they are machined by the electrochemical machining process. Turbine blades can be made; thin slots have been made for roller bearings, and the airfoil compressor discs are also made using this process.

So, the electrochemical machining process is a very versatile process. So, as I told you here, you can see that electrochemical machining can be applied to cutting, broaching, drilling, and deburring.





We will try to show an example of electrochemical grinding. So, every other process is the same as grinding, but here what we do is we try to use abrasives that are metal-bonded. So, the negative terminal can be given here, and the positive terminal is given to the workpiece.

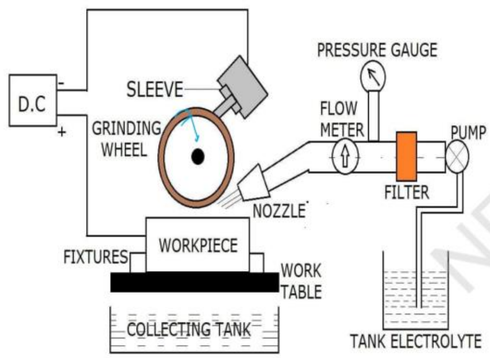
The flood coolant we use in grinding is replaced here by an electrolyte. The rest is the same; the workpiece is given. So, you can see here the metal-bonded wheel is given the negative potential, and the positive potential is given. There is an electrolyte that is flowing, which tries to create electrolysis and dissolution. So, the advantage is that wear is reduced to a large extent, and the material removal rate is phenomenally high.

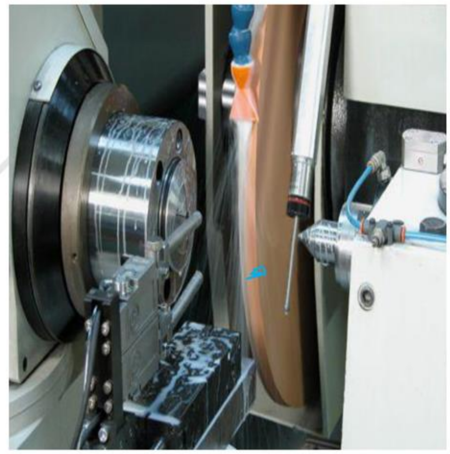
The heat generation at the workpiece is drastically reduced. Electrochemical grinding is a hybrid process wherein it is a combination of electrochemical machining and conventional grinding. The material is removed through anodic dissolution assisted by mechanical grinding. So, first dissolution happens, and then the mechanical grinding removes the material. So, ECG is mainly used for hard materials, and delicate components are made using the electrochemical grinding process.

The setup consists of a workpiece, which must be electrically conductive, and a grinding wheel, which is also a conducting grinding wheel. So, a metal bond is used, and the abrasives can be diamond. So, here ECM is used by a dissolution process, and we try to remove material. And then we try to perform the grinding process. Wherein the mechanical action removes a little bit of abrasives, the material, whatever is there.

So, grinding is mechanical. So, we use both in combination. So, that makes the process very efficient. The electrolyte system flows between the workpiece and the grinding wheel, facilitating electrochemical dissolution and debris removal. A DC power supply of low voltage and very high power is used. A pump is used for maintaining and filtering the electrolytic system.

Electrochemical Grinding (ECG)





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Electrochemical Grinding (ECG)

Advantages of Electrochemical Grinding:

- *No heat-affected zone* – prevents thermal damage and residual stresses.
- *Can machine hard and tough materials* like superalloys and stainless steel.
- *No tool wear – the* grinding wheel lasts longer.
- *Burr-free and precise machining* – suitable for medical and aerospace applications.

Disadvantages of Electrochemical Grinding:

- High initial setup and maintenance cost.
- Limited to conductive materials only.
- Slow material removal rate.
- Electrolyte disposal challenges – requires proper handling.

So, this is how it looks in reality. So, this is the wheel, then you remove it. So, here is the wheel. The abrasives are not 100 percent; if you see here, they are bonded to a disc.

So, here the abrasives are bonded in metal bonding. No heat is generated, as I told you. Hard and tough materials can be processed with no tool wear and are free from burst. The disadvantages are: the initial cost is very high, and only conductive materials can be processed. It can be slow in terms of material removal rate compared to grinding, but many times it is also faster. So, this point has to be considered. It can also be higher on a need basis. Electrolytic dissolution—so we have to be careful in handling it.

Thank you very much.