Basics of Mechanical Engineering-2

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Week 11

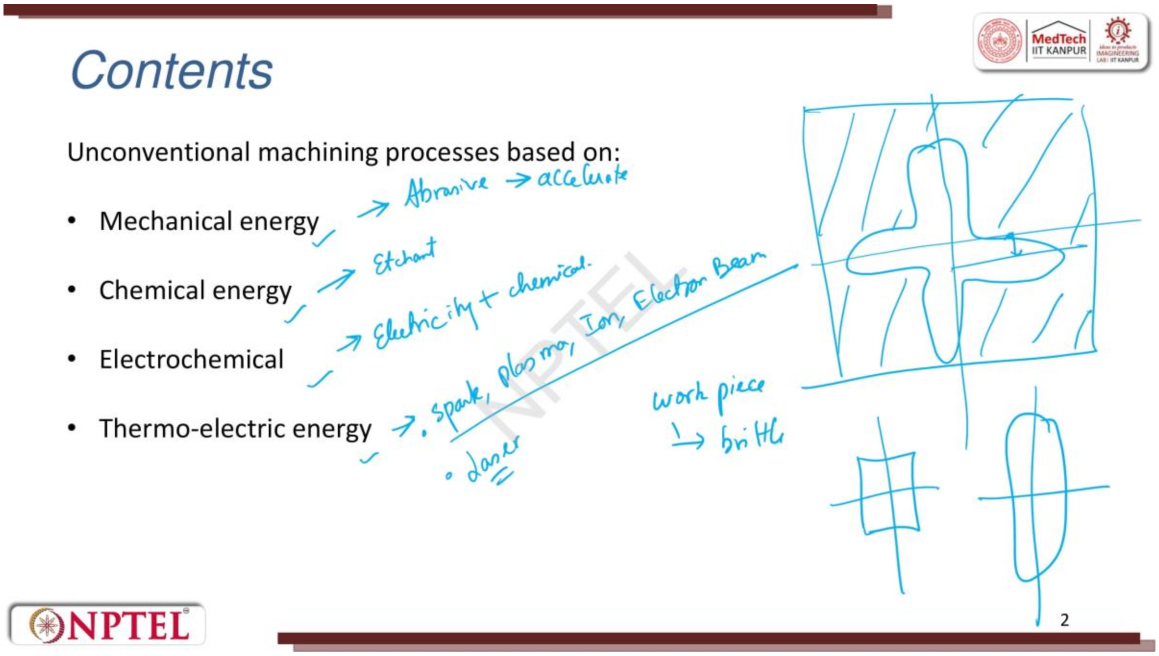
Lecture 43

Non-Conventional Machining (Part 1 of 3)

Welcome to the next topic which is on non-conventional machining processes. Friends, we saw constant volume process, we saw subtractive process. In subtractive process we saw drilling, turning, milling, grinding, etc. So, in all these processes, there was a direct contact of the tool with the workpiece, that is one. Second thing is, the tool geometry predominantly could be dictated such that you can find the output.

For example, in terms of roughness, you can try to dictate. So, this was there, but not in every condition that this techniques can be used. So, here we are trying to look at those processes where in which the tool need not be harder than the workpiece, the tool has a geometry. The third thing is where we can try to make complex shapes. These are the situations wherein which we always prefer to go for non-conventional machining process.

The tool which is softer than the workpiece. Here we can use light or heat as a source. We can use spark as a source. So wherein which it is softer than the workpiece but it has a temperature component very high.



So, in the content, we would first try to see non-conventional machining processes. Wherein it can be mechanical energy-based, chemical, electrochemical, or thermoelectric energy-based processes. Mechanical, of course, is the same thing wherein we try to use an abrasive. We accelerate it at a very high speed, which tries to hit the workpiece and remove material. Chemical is where we try to use an etchant to remove material. Thin foils can be processed this way.

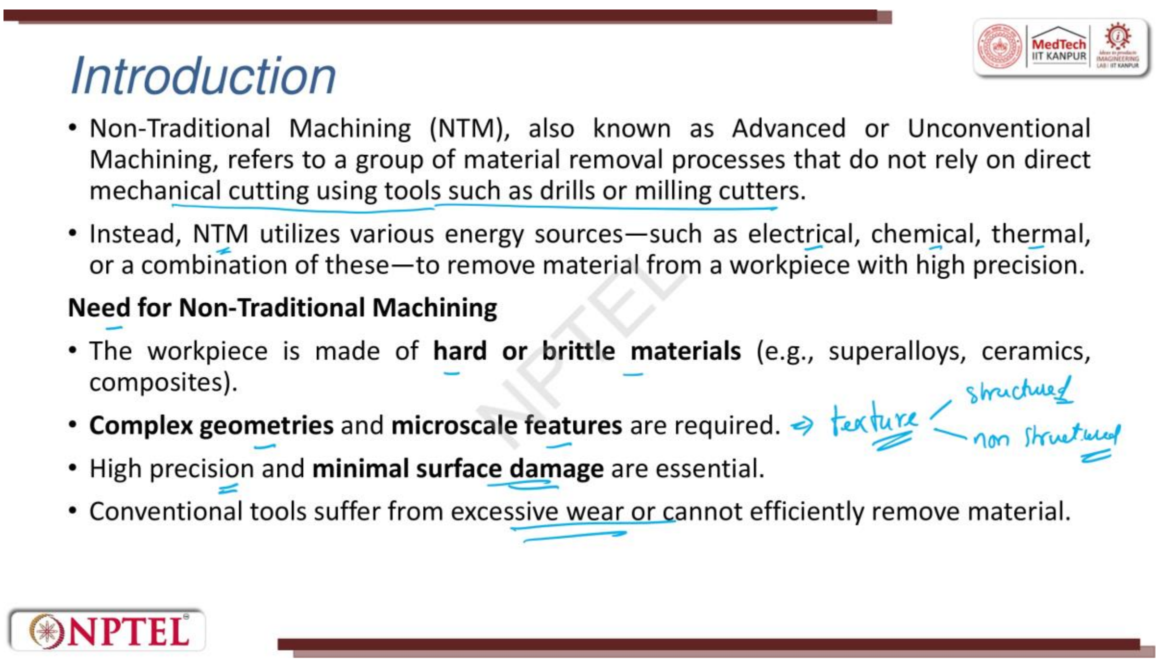
Engraving on boards is done by chemical machining. If the workpiece is slightly thicker and you want to achieve depth faster, we combine electricity and chemical processes, which is electrochemical. And here, when we talk about thermoelectric, it includes spark, plasma, ion beam, and electron beam, which can be used where electricity-based thermal processes are applied. Alternatively, we can use a laser, which is optics-based heat, to remove material. So, these are the various sources used in non-conventional machining processes.

As I told you, if you want to make a complex geometry like this, wherein this has to be machined onto the workpiece. So, you can see this geometry here. It is not axis-symmetric. So, it is offset by a certain distance, and the geometry is also not the same. So, here, making a tool and machining is very difficult.

We use non-conventional machining processes. If you want to make a square hole, it is very difficult to make it in a conventional machining process, like an oblong hole. It is very difficult to make through conventional machining processes. This is where we move towards non-conventional machining processes. The other scenario is if the workpiece is brittle, like diamond or glass.

So, here you cannot use the conventional way of doing it. We use the non-conventional way of removing material, especially for complex shapes and brittle materials. Various sources of energy are used to remove material, which falls under unconventional machining processes. Naturally, you should understand that since it uses abrasives, etchants, electric plus chemical, spark, or plasma ions, The material removal rate will be considerably lower than in conventional machining processes.

In conventional machining processes, there is a tool that comes in contact with the workpiece. So, the amount of chip removed is larger in conventional machining processes.



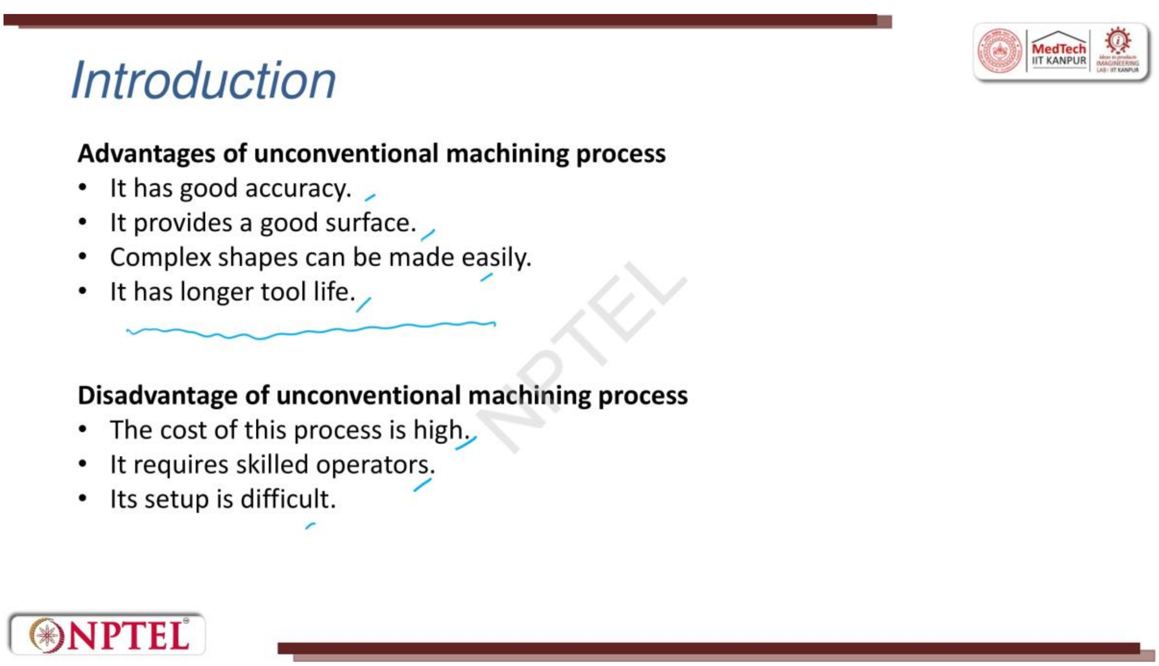
Non-traditional machining, also known as advanced or unconventional machining, refers to a group of material removal processes That do not rely on direct mechanical cutting using tools such as drills or milling. Instead, in NTM, we use electric, chemical, thermal, or a combination to remove material.

So, where is the need? When the workpiece is very hard or brittle, we always use non-conventional machining processes. And if the workpiece is very fragile in terms of thickness—for example, 0.1 millimeter, 0.2 millimeter, 0.3 millimeter. For all those sheets, if you want to machine them, doing so by conventional machining processes is next to impossible. Complex geometries and microscale features.

A very small amount of material has to be removed. As I told you, the material removal rate is very low in non-conventional machining processes. Now, can we use it as an advantage? So, you know the material removal is very small. So, can I use this as an advantage and make very small features?

Why are these very small features required? These features, when they are done on a surface, are called textures. They can be structured or non-structured. That means the geometry you try to generate can be random in nature or exactly placed in locations. When we try to go in a lift, on the lift panel, you will see that a lot of textures are done.

So, that is all texturing. So, micro-scale features are done. So, there we use non-conventional machining processes, and wherever you have very high precision and minimal surface damage. We will always go for non-traditional machining processes, and the tool here does not suffer any tool wear because they are not in contact. So, since they are not in contact, there is no tool wear. So, to a large extent, you can try to dictate and get the output you want.



So, it can give you good accuracy, good surface finish, and complex features can be made. It has a longer tool life. The disadvantage is the cost is very high. Sometimes it needs a skilled operator. The setup sometimes can put a little constraint on you.

Introduction

Feature	Conventional Machining	Unconventional Machining
Definition	Uses physical cutting tools to remove material.	Uses thermal, chemical, or electrical energy to remove material.
Material Removal Mechanism	Mechanical cutting through shear deformation.	Non-contact methods like electrical discharge, chemical dissolution, or laser ablation.
Tool Contact	Direct tool-workpiece contact.	No direct contact in most cases.
Material Suitability	Works well for softer and medium-hard materials.	Suitable for hard, brittle, and complex materials.
Accuracy & Surface Finish	Moderate accuracy and surface finish.	High accuracy and superior surface finish.

NPTEL

Introduction

Feature	Conventional Machining	Unconventional Machining
Tool Wear	High due to direct contact.	Low or negligible as tools may not touch the workpiece.
Complex Shapes	Difficult to machine complex shapes.	Easily produces intricate and micro-sized shapes.
Production Speed	Generally slower for intricate parts.	Faster for complex shapes and hard materials.
Energy Consumption	Lower energy consumption.	High energy consumption due to advanced processes.
Cost	Lower initial and operational cost.	Higher cost due to expensive equipment.
Examples	Turning, Milling, Drilling, Grinding.	EDM, ECM, Laser Cutting, Ultrasonic Machining.

NPTEL

So, when we look at the definition between conventional and non-conventional, it is almost like a recap. The definition is using a physical cutting tool to remove material. Here, thermal, chemical, or electrical energy is used to remove material. The material removal mechanism is mechanical cutting through shear action.

So that is why we were always talking about the shear plane and shear deformation. Here, it is non-contact. So, when we are trying to use electric and heat, it will be melt vaporization. Then, chemical dissolution can be one, and when we use a laser, it is ablation. When we try to use abrasives, it almost follows the same shear deformation.

Tool contact—direct tool contact—is not there. So, it is there in conventional; here, it is not there. So, material suitability—it is always suited for materials that are softer than the tool material. We always go for conventional. Here, hard, brittle, and complex materials can be considered.

Accuracies and surface finish—moderate accuracy and surface finish can be achieved by conventional methods. In unconventional methods, you can dictate and achieve a very high surface finish. Tool wear is very high here, and here, it is considerably low. It is very difficult. You have to modify the tool to create a replica.

For example, we saw form tools. So, based upon the geometry, you try to give the profile. So, it is very difficult to make such things. But in unconventional, it is easy to make. Production speed, they are slow to, generally slower for intricate shapes.

Faster and complex shapes can be on hard materials, it can be made through unconventional way. Energy consumption, it is low here. Here, it is very high here. So, this is one disadvantage which is there in unconventional. The other big disadvantage is since it is all dictated by melt, vaporization, abrasive heating at a very high velocity.

The final dictating of dimensional accuracies are slightly lower when talk about conventional machining. Higher cost due to expensive equipments, low initial costs. Examples for unconventional are turning, milling, drilling, grinding. So, here you will see processes like EDM, ECM, laser cutting, ultrasonic, etc.

Need

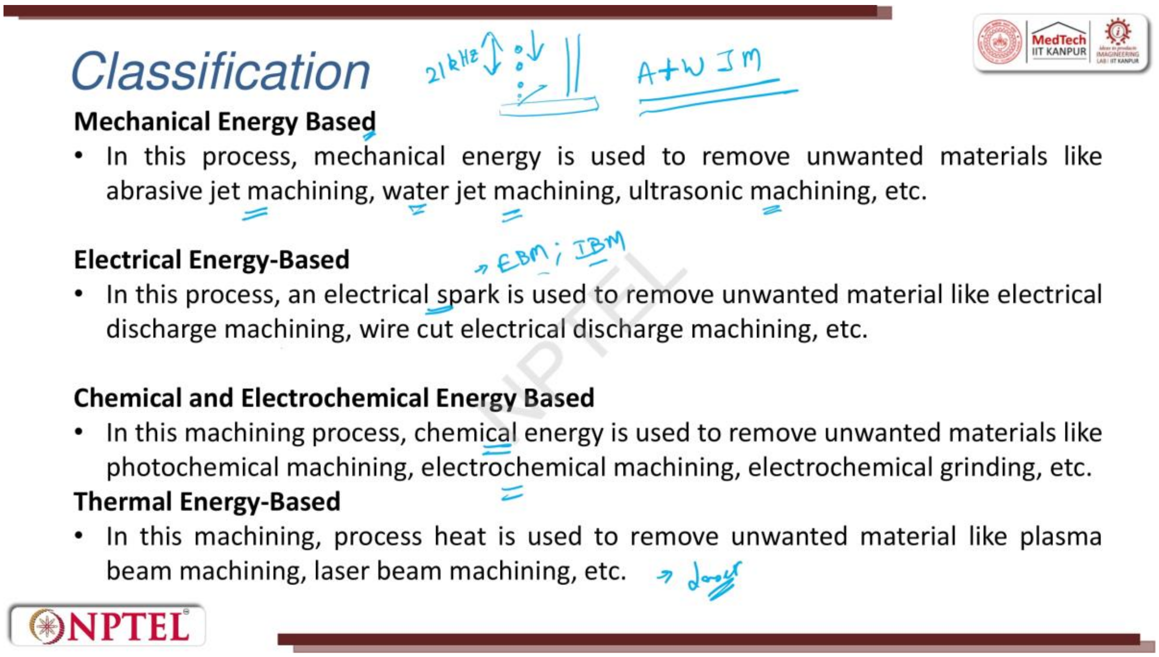
- Greatly improved thermal, mechanical and chemical properties of modern materials – Not able to machine thru conventional methods. (Why???)
- Ceramics & Composites – high cost of machining and damage caused during machining – big hurdles to use these materials.
- In addition to advanced materials, more complex shapes, low rigidity structures and micro-machined components with tight tolerances and fine surface finish are often needed.
- To meet these demands, new processes are developed.
- The shape of the part is complex, such as internal and external profiles, or small diameter holes.

So, the need we have already seen. So, if you have a ceramic or a composite material, or a very complex shape. If your demands are not very high, and new processes are to be developed for machining. Then unconventional methods will be tried, and complex shapes can be made.

Classification

- Different types of energy are used in this machining process to remove metal.
- Because of which on the basis of energy use the unconventional machining process can be classified into four categories:
  - Mechanical Energy Based
  - Electrical Energy-Based
  - Chemical and Electrochemical Energy Based
  - Thermal Energy-Based

So, we have seen this classification. They are classified as mechanical energy-based, electrical energy-based, chemical and electrochemical-based, and thermal energy-based. So, these are the four classifications of non-conventional machining processes.



When we talk about mechanical energy-based, here, the unwanted material is removed by using abrasive jet machining, water jet machining, or ultrasonic machining. We will see that in detail later. When we say abrasive jet, abrasives are small hard particles that can be either hard or soft. These hard particles, when they hit a surface, will try to remove the material. So, how can it remove material?

I can accelerate the speed and allow a jet of abrasives to hit the workpiece. So, here, there is a shear strain hardening phenomenon happening, and then the material is removed. So, I can replace this abrasive with a jet of water. That is what is called water jet machining. So, I use a jet of very high velocity, which comes and hits the workpiece, and it can remove material.

Then I can try to have a combination of abrasive plus water jet machining process. So, this process is a combination of abrasive and water jet and when it tries to hit at the workpiece, it can try to remove material. The next one is ultrasonic. Same abrasives come in contact, but I try to vibrate it at ultrasonic frequency, 21 KHz. I try to vibrate and with a very small amplitude.

So, it is a quick impact load which keeps on coming and hitting the surface through which also I can try to remove. The electrical energy based, I try to create a spark, I try to create a plasma. And this plasma tries to hit at the workpiece and try removing material. So, electric spark can be done, electron beam can be done, ion beam can be done. So, electric spark can also be used.

So, when I say electron beam, ion beam, spark, here what happens is these electrons. These ions and the spark which is getting generated, they all travel at very high speeds and hit at the workpiece. So, they try to heat the workpiece and remove material. So, the unwanted material is getting removed by a discharge which is there to remove. Chemical and electrochemical, the chemical energy is used.

So, it basically reacts. This reaction can be accelerated by applying potential. So, electrochemical reactions are possible. You try to put a mask on top and remove the material wherever you want. This is typically what we do for many of the artifacts.

We try to take a copper sheet and then stick a sticker onto the copper sheet. And then what we do is, wherever the sticker is not there, the direct copper is exposed. We immerse it inside a chemical and then start removing it. Thermal-based is basically where we try to use a laser for removing material.

Classification

1.Mechanical energy based unconventional machining processes:

- I. Abrasive jet machining (AJM)
- II. Water jet machining (WJM)
- III. Ultrasonic machining (USM)

2.Chemical energy based unconventional machining

- I. Chemical machining (CHM)

3.The electrochemical-based unconventional machining processes:

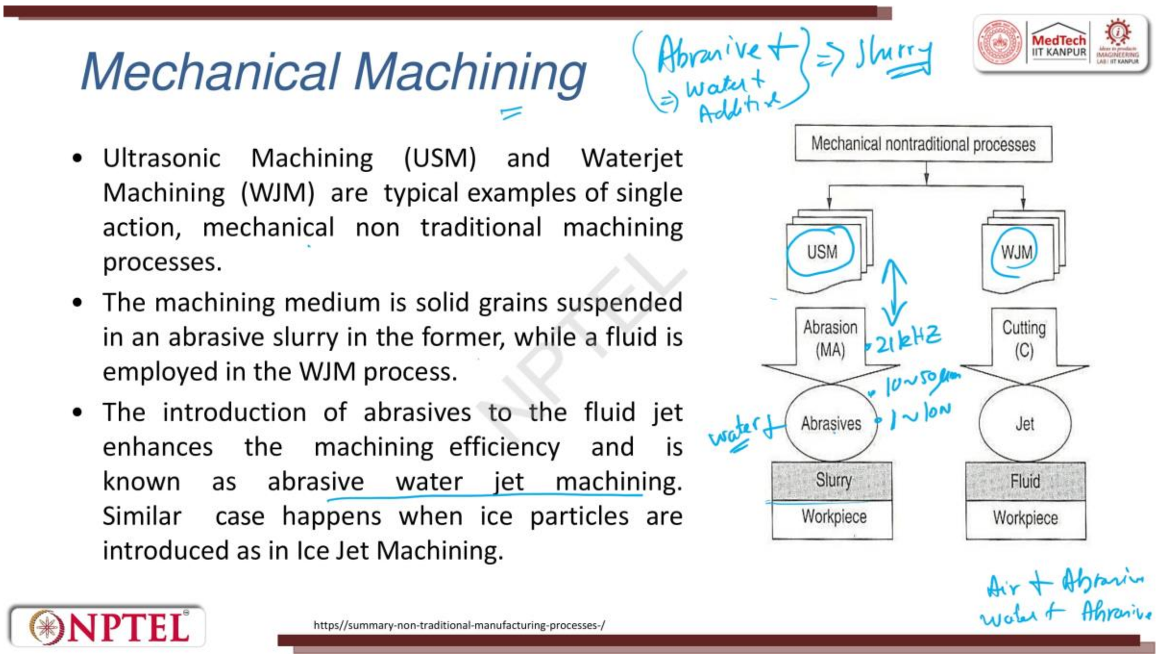
- I. Electro-chemical machining (ECM)
- II. Electrochemical grinding (ECG)

Classification

4. Thermo-electric energy based unconventional machining processes:

- I. Plasma Arc machining (PAM)
- II. Electron-Beam machining (EBM)
- III. Laser-Beam machining (LBM)
- IV. Ion-Beam machining (IBM)

Under mechanical, we have abrasive, water jet, and ultrasonic machining. Under chemical, we have chemical machining. Under electrochemical, you have electrochemical machining, and a variant of electrochemical machining is electrochemical grinding. So, this tries to open up your thought process about the hybrid. The conventional process can also be blended with the non-conventional to create hybrid processes. Then, under heat, we have plasma, electron beam, laser beam, and ion beam.



So, now first let us look at mechanical energy ultrasonic machining. So, ultrasonic machining. So, here you have abrasives. These abrasives are free abrasives. So, they can freely fly in air, but I want them to be cohesively held, so the abrasive is mixed with water.

Water of a small content, right? So, it's only to make sure it is almost like a paste, so it flows on top. This abrasive gets mixed with water and forms a slurry. So now, this slurry is placed on top of the workpiece. Now, the ultrasonic vibrates at 21 kilohertz with a 10 to 50 micron amplitude continuously, with a load also present. There is a load which you can try to have, 1 Newton, 10 Newton, or something—1 to 10 Newton—you can apply a load.

So, this load will be applied on the ultrasonic head, so that the slurry is at the bottom, then you have the workpiece. Now, the ultrasonic will move like a CNC machine and it will try to create the feature, whatever you want. When we go to water jet, now this ultrasonic is replaced by a jet. So, wherein we talk about 100 bar pressure of water, then 100 bar, 300 bar—very high water jets are available—50 bar, 30 bar. What is used in academic purposes are 30 bar to 50 bar.

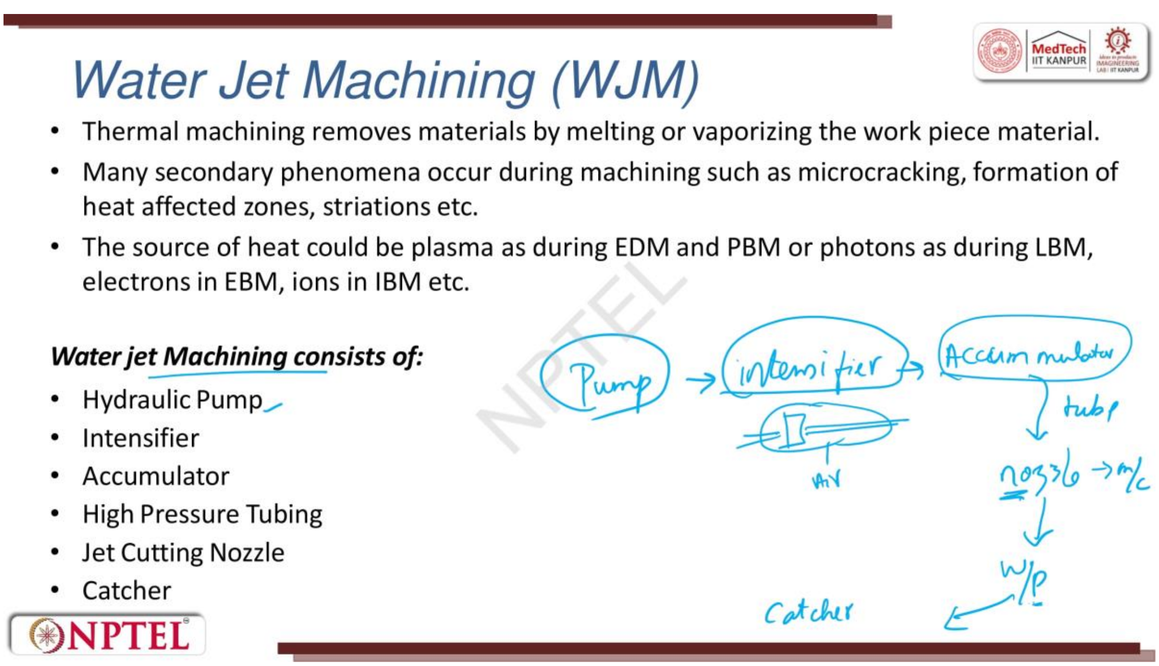
So the water is pressurized at such a high velocity, and it just goes around the workpiece to cut the profile. When we try to clean a car or a floor, we increase the water pressure to do it. Why do we do it? The water pressure is slightly higher, so it hits the dust particles and moves them out. The same principle is used here.

So, the ultrasonic and water jet machines are typical examples of single-action mechanical non-traditional machining processes. The machining media is a solid grain suspended in abrasive slurry. This is what I said. So, you have abrasive. Plus water—this can be water, ethanol, or glycerol, whatever it is.

So, you can find this put together with other additives to make the slurry. Now, the viscosity of the slurry is dictated by the volume fraction of the water. It can flow easily or very tough. So, the slurry is made while a fluid is employed in water jet. We are just comparing it.

So, the introduction of abrasive to the fluid jet enhances the machining efficiency. And it is known as water abrasive jet machining. So, here also, we are not only talking about water; you can also use only abrasive. Wherein the abrasive is hit at the workpiece by using air or water. So, it will be air or water.

Plus abrasive, or it will be water plus abrasive. It tries to hit the workpiece and starts removing material. So, these two processes fall under mechanical machining processes.



So, what all is there in a jet machining process? You will have a hydraulic pump. This hydraulic pump will be attached to a pump. This pump will be attached to an intensifier because this intensifier has to multiply and increase the pressure. So, increase the pressure. So, this intensifier will be like a piston moving from left to right and other things. So, this will try to intensify the air or the water that is there.

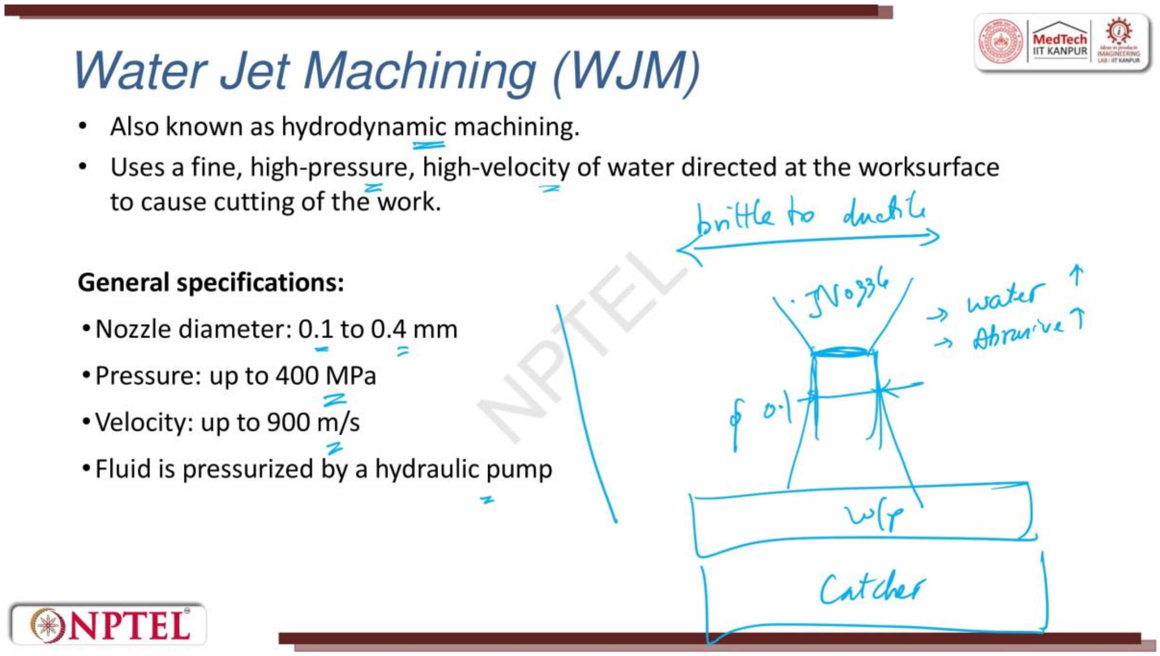
Then, we will try to have an accumulator. Why do we have an accumulator? Because when we try to use an intensifier left to right, it will stop there, and right to left, it stops there. So, it will have a bang-bang effect and a stop. So, in order to have a smooth, continuous effect,

we have an accumulation of either water or abrasive and air, or water and abrasive, or only abrasive. So, we have an accumulator. This accumulator then pushes the media through a tube. This comes in contact with a nozzle. Now, this nozzle is controlled.

This is a machine, and this controls and falls on the workpiece. So, the structure goes like this. And after it hits the workpiece, the pressures are very high. So, since the pressures are very high and it gets exposed to the atmosphere, what we do is we have catchers. So, these catchers can reduce the pressure after cutting.

So, these are all the main parts of a water jet cutting machine. You will have a pump. And then you will have an intensifier. This intensifier is a piston. Then you will have an accumulator.

Through a tube, it goes to a nozzle. This nozzle is attached to a machine which can move in the x, y, and z directions, whatever it is. And then it hits the workpiece. The moment it hits the workpiece, the pressures are high. In order to reduce the pressure, it has a catcher.



So, if you look into it, it is also known as hydrodynamic machining. Here, very high pressure and very high velocities are directed on top of a workpiece. So, from brittle material to ductile material, you can have a huge spectrum of material workpieces in which you can create geometry. When we try to have ductile materials, the pressures are phenomenally high. So, the strain hardening behavior reaches the ultimate tensile.

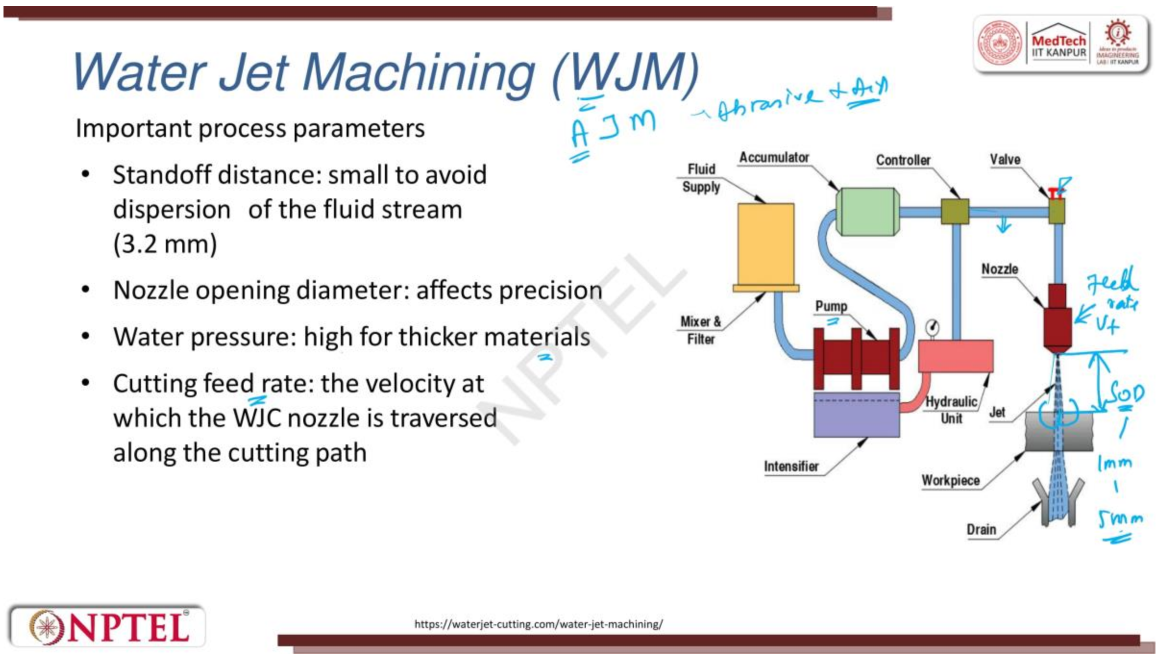
Strength will quickly decrease from the elastic limit or the start of the yield point to the fracture point. So, you should also try to do this with ductile materials. So, brittle to ductile materials can be considered. The nozzle diameter is 0.1 to 0.4 mm. Why is that important?

Because if you have a nozzle with a diameter of 0.1 mm. This is the nozzle diameter, and this is how the water is gushing. So, when the water is gushing, it will not form a cylinder. It will slowly try to flare up a little bit. This is the workpiece.

This is the nozzle or the jet that comes out. So, this is the diameter 0.1 mm. So, the feature size it cuts can also be very precise. And you should understand there is always going to be wear and tear on this nozzle. Because the water is at very high pressure, and you will also have abrasives coming out at very high pressure.

There can be wear and tear at the nozzle. This is the only tool where we generally have abrasive cutting. So, the pressures, as I told you, are 400 MPa; the velocities can go up to 900 m/s, and the fluid is pressurized. So, the fluid—whatever we say—can be water, it can be water plus a little bit of polymer, or it can be water mixed with abrasive. So, these are the general specifications.

The pressure with which it comes out is 400 bar; while cutting and coming out, it will be at least 200 bar or 100 bar. It will not be immediately zero. So, everything has to be considered. So, you will have a catcher at the bottom of the workpiece.



So, this is how a typical schematic looks for water jet cutting. If I change this water jet to abrasive jet machining, the only difference will be adding abrasive plus air. The fluid media, which was water, will be replaced by air. Can I use only air for cutting? You will not get enough kinetic energy to cut the material. So, we always mix it with abrasive and then try to heat it.

The latest is mixed water, air, and abrasive, which is also possible. So, here if you see, there is something called a standoff distance, or SOD. There has to be a small standoff distance maintained. Otherwise, the nozzle will directly hit the workpiece, and the water will gush out. It will try to gush out from the spot.

This will, in turn, hamper the flow or damage the nozzle. To avoid this, we always try to maintain a standard SOD, or standoff distance. This can range from 1 mm to 5 mm, depending on your requirements. So, here the standoff distance is small to avoid dispersion of the fluid stream. If the standoff distance is very large, the flaring of the jet will be large.

So, there is a trade-off. You cannot keep it too close, nor can you keep it too far. You should keep it at a distance where flaring is minimal, yet high pressure for cutting is maintained. The nozzle opening directly affects precision. So, here in the nozzle, what we provide will be attached to a machine.

So, feed rates you can give, feed rates where in which it can move. That is one and then the other thing is the abrasive volume flow rate you can try to dictate. So, movement of the machine and the abrasive flow rate. So, that is possible. So, water pressure the high for thicker materials we use.

So, the velocity with which the water jet cutting nozzle transverse is called as a feed rate. Like what you gave in the tool moving against the workpiece feed rate. So, here also you will have a feed rate. Whatever else we have already discussed. So here you will have a fluid supply, then this fluid supply is attached to a pump, this pump is attached to an accumulator.

Then this accumulator is in turn attached to a controller, right. So, here you can try to have abrasive which is coming. So, here you will try to have an intensity which comes and mix. So, basically we will try to mix water plus abrasive if you want to have or if you want to have water abrasive and air you can mix it. So, this is sent to through a pipe which is of very high pressure tube pipes which is all made out of stainless steel and they are all seamless weld.

So, that means they are extruded. So, then that is attached to a valve. So, through this valve, you try to control all the ratios you want, then send it to a nozzle for machining.

Abrasive Jet Machining (AJM)

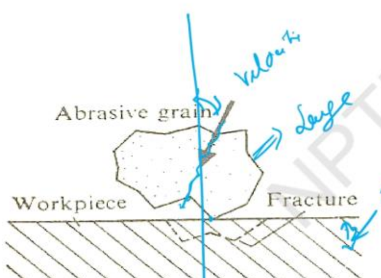
- In AJM, the material removal takes place due to impingement of the fine abrasive particles.
- The abrasive particles are typically of 0.025 mm diameter and the air discharges at a pressure of several atmosphere.

So, in abrasive water jet, So, here it is a water jet. So, I replace this water with abrasive. So, in abrasive water jet, the material removal takes place due to the impingement of fine abrasive particles. It will be like a bullet—very fine, 400 bar, like a bullet.

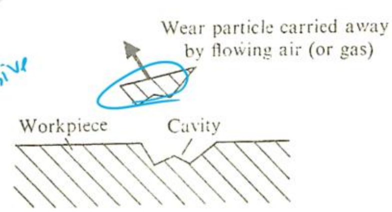
So, the abrasive particles are of very small diameter; it will not be one abrasive, but a jet of abrasives. So, this jet of abrasives will try to hit. What is the advantage over a water jet? The flaring can be controlled, the kinetic energy can be improved, and the material removal rate will be faster.

Abrasive Jet Machining (AJM)

Abrasive particle impinges on the work surface at a high velocity and this impact causes a tiny brittle fracture and the following air or gas carries away the dislodged small work piece particle.



Fracture of work surface



Formation of cavity

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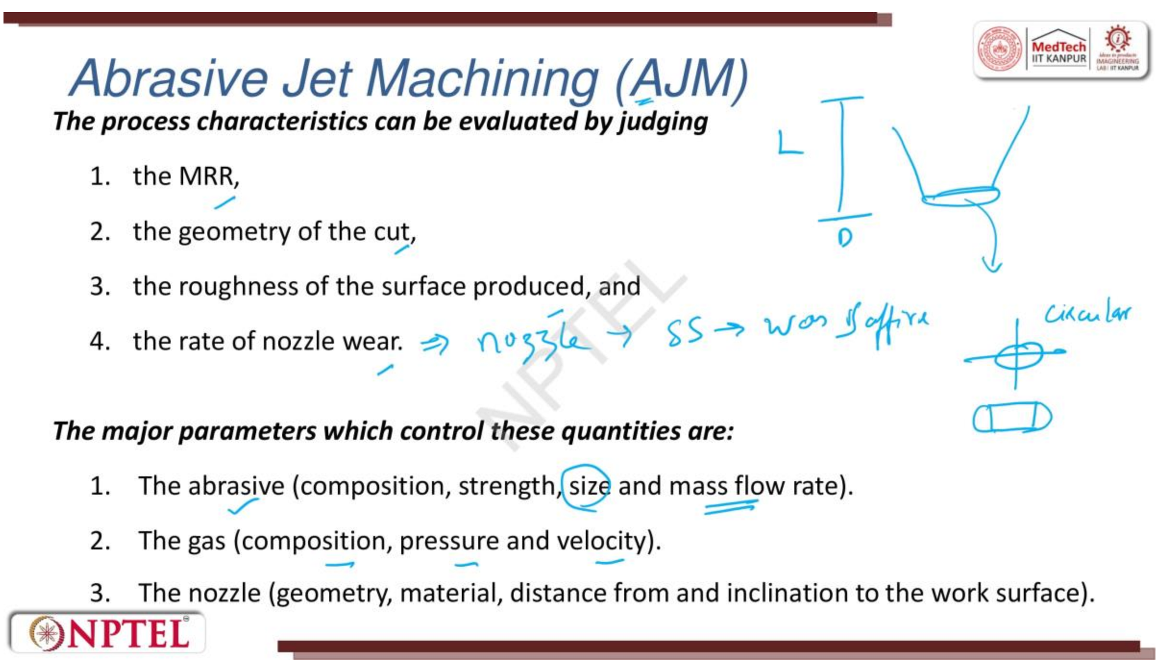
So, in the abrasive jet process, when the abrasive tries to hit the workpiece, it has the same phenomena as grinding. So, when the velocities are very high, if the particle size is large and the velocity is high, what happens?

The abrasive particle itself, when it hits the workpiece, can shatter. So, when it shatters, it creates new cutting edges. That is one possibility when the abrasive size is too small. Then, exactly when it hits, there is also an angle with which the jet comes—it can be 90 degrees. It can be 80 degrees, or depending upon the requirement, it can be 75 degrees.

It can be 40 degrees, so depending upon the impingement, the amount of material removal also plays a role. So, when you try to go at 45 degrees, the abrasive will start hitting and glazing. So here, what happens is we do not do cutting, but we try to improve the compressive stress. So, why is it important? The moment the compressive stress improves, the material can withstand a longer time when you put it in the service condition.

So, that process is called shot peening, wherein it is done using a continuous jet—that is also possible. So, the abrasive particles impinge on the work surface at a very high velocity, and the impacts cause a tiny brittle fracture. So, when the workpiece—this is the tiny brittle fracture which happens—and this gets away from the portion. When the water moves or when the air moves. So, the cavity is a very small depth which is done.

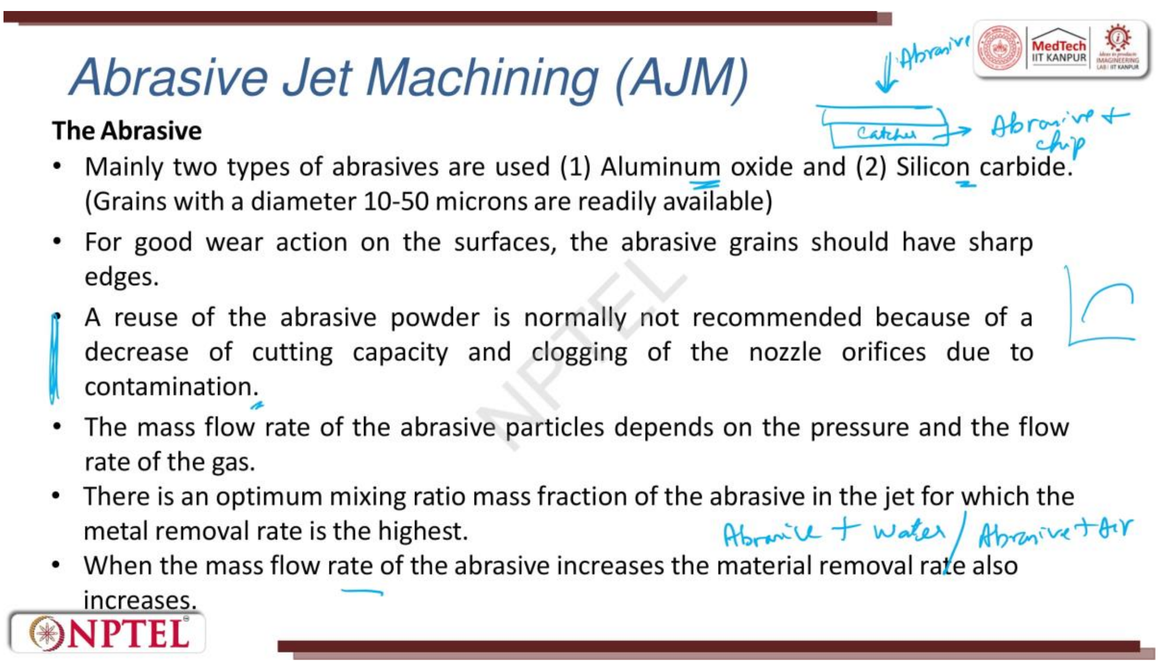


What is the advantage of the abrasive jet process over the water jet? The material removal rate is high. The geometry of the cut can be controlled. The surface finish is better when we use abrasives. The rate of nozzle wear is, to some extent, better than in water jet cutting.

Generally, the nozzles are not made out of stainless steel. They are made out of tungsten or sapphire. So, the major parameters are going to be the abrasive. In abrasives, we will try to see the size of the abrasive and the mass flow rate. This is very important.

When we look at the gas, it is the composition, pressure, and velocity. The nozzle geometry can be circular or oblong. This is a cross-section. It can be circular. I am talking about the jet geometry.

So, this is a jet. So, the jet outlet geometry is what we are talking about. So, the nozzle geometry, the outlet geometry. The other thing is nozzle geometry also depends on the length-to-diameter ratio. Material, distance from where it is done, then inclination of the workpiece. So, these are the parameters which play a very important role when we try to do either water jet cutting or abrasive jet cutting.



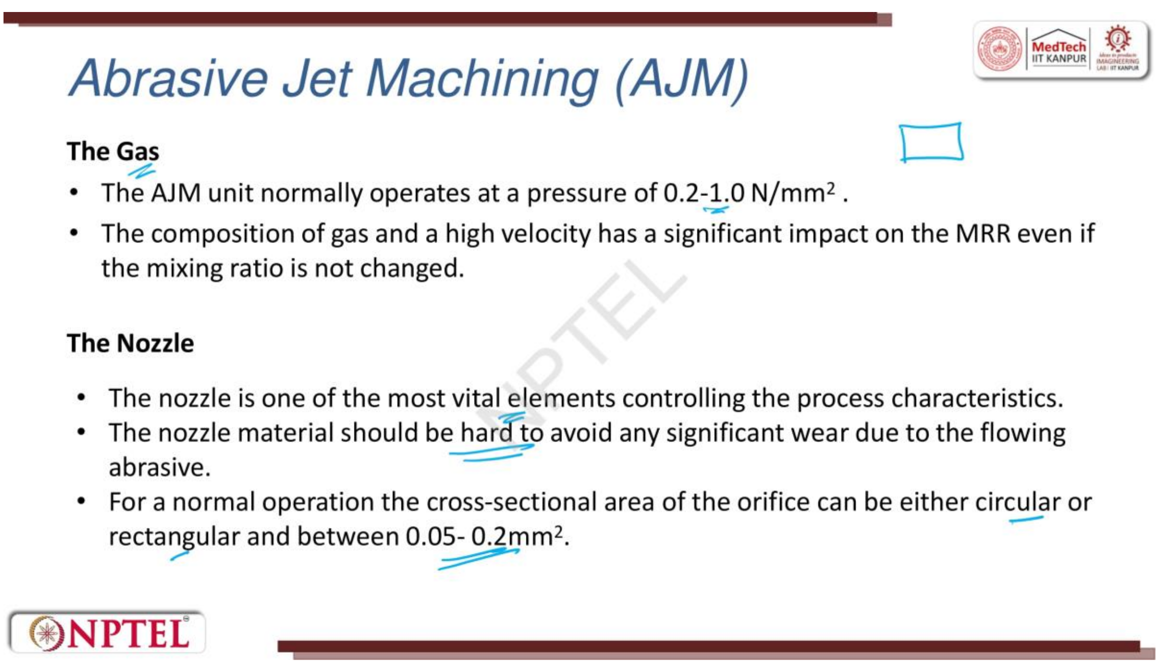
So, we can use aluminium oxide or silicon carbide, depending upon your requirement. The jet nozzle abrasives which flow out, When it tries to hit the workpiece and I try to collect it in the catcher, I get back these abrasives. But this abrasive will also have chips.

If I can figure out ways and means to remove the chips, I can reuse the abrasives. Reuse of abrasive powder is normally not recommended. Because of the decrease in cutting capacity and clogging of the nozzle due to contamination. So, somehow if I can remove the chips and sieve them, I can reuse the abrasive. So, what happens is the abrasive size gets reduced.

If the size is not reduced much, you can reuse it. If the size is reduced, it can always lead to clogging. So, this is a caution that you have to take. The mass flow rate of the abrasive depends on the pressure and the flow rate. There is an optimum mixing ratio.

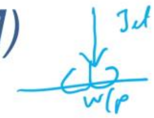
What is the mixing ratio? Abrasive plus water or abrasive plus air. So, we have a mixing ratio. You cannot do 100 percent abrasives or 100 percent water. So, we try to have a mixing ratio and then proceed.

When the mass flow rate of the abrasive increases, the material flow increases, but it cannot keep going to 100 percent. So, you will have a response something like this.



The gas, normally the pressures are 1 N/mm^2. Composition is also very important. The nozzle is the vital element in the entire process. It has to be hard to avoid wear and tear. The cross section area is very important. It can be circular, it can be oblong or it can be rectangle. Rectangle generation of the nozzle is very important. The generation of the orifice rectangle is very very important and which is very difficult. Here we do not use conventional machining we use always non-conventional machining process right.

Abrasive Jet Machining (AJM)



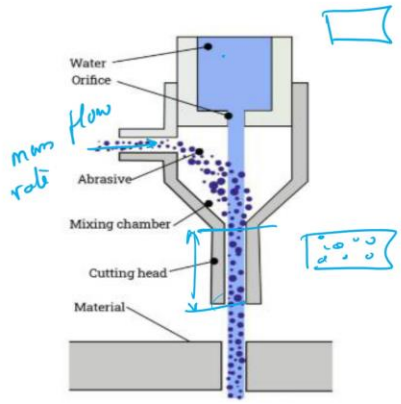
Nozzle to Tip Distance (Stand off distance)

- The nozzle tip distance (NTD) or the stand off distance is a critical parameter in AJM.
- The NTD not only affects the MRR from the work surface but also the shape and size of the cavity produced.
- As shown in the figure below, when the NTD increases, the velocity of the abrasive particles impinging on the work surface increases due to their acceleration after they leave the nozzle. This increases the MRR.
- With a further increase in the NTD, the velocity reduces due to the drag of the atmosphere which initially checks the increase in MRR and then decreases it.

This is the standoff distance we have seen and understood what is the need for the standoff distance is the major thing is jet hitting the workpiece. So, there is a return flow of the jet when it hits the surface because water hits remove material and it comes up. So, when it comes up it should not hamper the further jet coming that is the only thing. So, that is why we try to maintain the standoff distance.

Abrasive Jet Machining (AJM)

- The gas propulsion system supplies clean and dry gas (air, nitrogen, or CO_2) to propel the abrasive particles.
- The gas may be supplied either by a cylinder or a compressor.
- In case of a compressor a filter or a dryer may be used to avoid water or oil contamination to the abrasive powder.
- The gas should be non toxic, cheap and easily available and should not excessively spread when discharged from nozzle into atmosphere.



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So, if you see a nozzle, it is pretty interesting. So, you will see water coming and then in the side, you see there is abrasives coming. So, here the mass flow rate is very important because when the abrasives are coming inside and there is a jet of water. Now here the abrasives has to mix with the water. Here you will have only water.

Here you will have water plus abrasives. These abrasives have to be uniformly mixed. So what we do is we always have a mixing tube. In the nozzle, which is also part of it. So, that will try to give you.

So, here there are a lot of designs. So, the abrasives will go in a spiral, and then the water will be in between. So, as it goes, the spiral tapers. The taper will also be there, almost close to the exit. There will be mixing, and then that will try to hit the surface.

The propulsion system supplies the dry gas, which can be air, nitrogen, or CO2. The gas can be supplied through a cylinder or through a compressor. The gas is non-toxic. Generally, it is a nascent material or a non-reactive material.

Abrasive Jet Machining (AJM)

S.No.	Characters	Details
1	Work Material	Hard and brittle materials like glass, quartz, ceramics, mica
2	Abrasive	Aluminum oxide, Silicon Carbide, Glass powder, Dolomite
3	Size of Abrasive	Around 25µm
4	Flow Rate	2-20 g/min
5	Medium	Nitrogen, Carbon dioxide or Air
6	Velocity	125-300 m/s
7	Pressure	2 to 10 Kg/cm2
8	Nozzle Material	Tungsten Carbide, Synthetic Sapphire
9	Life of Nozzle	Tungsten Carbide – 12- 20 hours Synthetic Sapphire – 300 hours
10	Nozzle tip clearance	0.25 to 15 mm
11	Tolerance	± 0.05 mm
12	Machining Operation	Drilling, cutting, deburring, cleaning

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So, when we talk about abrasive water jets, the workpiece—what it can do. The abrasives that we can think of, we can also use dolomite glass powder. The abrasive size is 25 microns; flow rates, pressures, and velocity are very important. The life of the nozzle is only 10 to 12 hours. The nozzle dictates the price because it has wear and tear. The other thing is when we talk about high pressure, the sealant between the accumulator. The piston is also very expensive.

Thank you very much.