

Introduction to Abrasive Machining and Finishing processes
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Lecture – 15
Advanced Abrasive Machining Process
(Abrasive Water Jet Machining Process)

Today we are going to study about, the Abrasive Water Jet Machining Process, which is one of the important processes in Advanced Abrasive Machining Processes.

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Overview of the lecture

- Introduction to Abrasive Water Jet Machining
- Various Elements of Abrasive Jet Machining Process
- Parametric Analysis of AWJM Process
- AWJM Process performance
- AWJM Process Capabilities
- AWJM Applications

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Till now we have seen in the previous class about Abrasive Jet Machining, where the air is a carrier medium, but here the water is the carrier medium. That is why it is named as Abrasive Water Jet Machining. Over view of the lecture, so introduction to Abrasive Water Jet Machining, then various elements of the abrasive machining jet machining process, parametric analysis of the, and performance of this process, capabilities, and applications of this abrasive water jet machining process we will see.

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AWJM: Introduction

- Abrasive water jet machining (AWJM) is a mechanical material removal process used to erode holes and cavities by the impact of abrasive particles of the slurry on hard and brittle materials.
- Since the process is non-thermal, non-chemical and non-electrical it creates no change in the metallurgical and physical properties of the work piece. ✓
- In principle, this process is similar to abrasive jet machining except that in this case water is used as a carrier fluid in place of gas.
- These processes offer advantage of cutting electrically non-conductive as well as difficult-to-machine materials comparatively more rapidly and efficiently than other processes

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So, this is an advanced version of abrasive jet machining; where, as I explained in the previous slide, the basic problem is the divergence will be very high because of the problem is kerf width whatever we want it may not achieve. So, you will achieve some stray width the some extra one that is called as stray cutting and other things will take place. To have a better cutting for that purpose we use a liquid that is called normally water so that will have a coherent type of jet ok. So, that we all see in this one introduction abrasive jet machining is a mechanical material removal process.

Because, the material removal is taken care by the abrasive action that these things. But aberration because of which it is used to call as a mechanical material removal process. And this erodes, basically abrasive particles erode the hole which is exposed and cavities by the impact of abrasive particles and the slurry on the hard and brittle materials. As I said in the abrasive jet machining also these particular processes are very good for brittle materials rather than ductile materials.

Because in the ductile material there may be a chance or in a soft material there will be always a chance that abrasive particles embed and it will create some problem ok. Since the process is non-thermal and non-chemical, because there is no temperature development as the water will play as a coolant and the chemical action is not there because water is not a reactive chemical. So, it is non-electrical, it creates changes to the metallurgical and physical properties.

That speak it will not create any metallurgical or physical properties of the workpiece; that means, that the customer is expecting a parent material to be there at the hole site or a cavity site, you are going to achieve that one. Because there is no thermal there is no chemical and other reactions are there the because of verge what you will going what the operator is going to get is no changes in metallurgical physical properties; that means, that the parent material properties will be there and the site of where the product is developed or where the hole or cavities developed ok.

In other terms what I mean to say is that if you are going to machine a hole with a laser beam machine or electric discharge machining. So, because of thermal effects what will happen, you will have a heat affected zone, recast layer, conversion layer, and so on. Where the microstructure is different metallurgical aspect is different. In abrasive water jet machining this thermal effects are not there because of which what will happen is that there is no metallurgical changes compared to that laser beam machining or electric discharge machining ok. That is how one can understand if I can compare the two processes, in principle this process is similar to abrasive jet machining process as I said except that in this case water is used as a career fluid in place of gas in abrasive jet machining process.

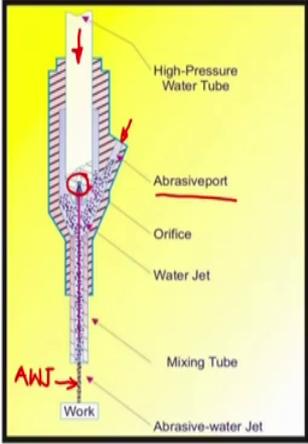
The process offer advantage of cutting electronically non conductive as well as difficult to machine material compared to rap pick and efficient comparatively rapidly and efficiently as with other process. That means, that if at all I want to cut a electrically in all conductive samples by EDM; it is not possible for that and if it is difficult to machine materials, then it is very hard or very brittle or something this type of materials it is very difficult to cut using the EDM process and other processes. But you can cut using abrasive water jet machining process.

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Working Principle

USED TO MACHINE :
✓ Non -metals : ceramics, composites, rocks, etc.
Metals : copper, aluminium, WC, lead, etc.

OPERATIONS :
Drilling, cutting, deburring, etc.
Can cut any kind of material, high edge quality, adaptable for remote control, recycling of abrasives



This is how the abrasive water jet machining we looks like, in the machining region there will be abrasive port that mean that abrasives are fed here. And high pressure water will be fed from this particular place and both will mix at the exit water is coming out and this is called orifice, from the orifice the high velocity jet of water is coming and abrasives are coming adjacent to it both are mixed in the mixing tube. And here abrasive water jet this is called abrasive water jet is going to impinge on the work piece ok.

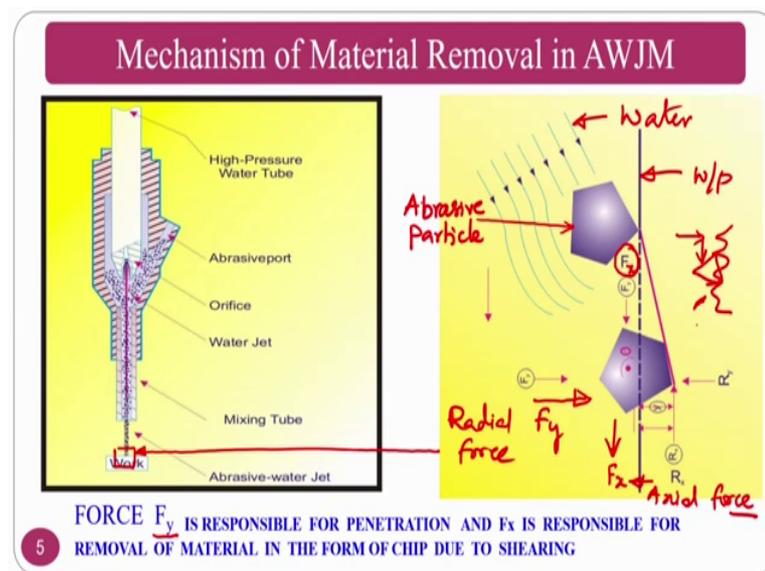
So, used to machine nonmetals basically so ceramic materials we can do composites rocks. Metal such as copper aluminum normally you do not prefer copper and aluminum and other things because these are the soft materials, but you can always use it. But preferably if since these are conductive materials if you go for electric discharge machining and other things you can do it, but there may be a chance of heat affected zone recast layer and other things ok. So, comparatively EDM is much better than abrasive water jet machining. If your requirement is partially metallurgical changes are there then you can go for that one otherwise you have to use this particular process.

However abrasive water jet machining you will have the problem of embedding of abrasive materials or abrasive particles on the surface of the soft materials. So, operations normally you can do drilling operation, cutting operation, deburring operation, all this things you can do. You can cut any kind of materials, high edge

quality, adaptable for remote control, recycling abrasives, also possible because in abrasive jet machining you do not have this flexibility of recycling of abrasives.

Because abrasives are getting fractured and this is same holds would for this particular process also at the same time there is a possibility of adherences of the work piece material to the abrasive particles which may make the abrasive particles dull. But here you have a carrier medium of water so the cooling ability is there and lubrication ability is there because of which the chances of the adherences of the work piece chips onto the abrasive particle is slightly less. But that is why you can recycle the abrasive particles in this abrasive water jet machining process.

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So, material removal mechanism if you see as you have seen the say if the similar figure in the previous one whenever the abrasive particles heat the workpiece ok. So, this is what is a machining region if you take the machining region here, what is going to happen here, is if you your jet is coming like this and this is your abrasive particle. This is abrasive particle and this is a carrier medium that is water ok.

So, you have many forces such as F_z which is moving in this direction, F_y which is makes the abrasive particle to move in this direction. So, because of this what will happen assume that this is my work piece surface; F_z is going to put. See if you can see here what is happening is force F_y is responsible for penetration, and F_x is responsible for removal of material. Here assume that normally the F_z you can assume that it is F_x

which is moving in this direction. F_y is indenting, and F_x is moving in the direction of the carrier medium. That means, that this is a radial force F_y is a radial force, and F_x is axial force ok.

That means that along the direction of the water impingement if it is moving that is called axial direction. That is why F_x is called as a axial force and radial direction if it is perpendicular to the axial direction that is nothing, but indenting direction so that is called radial direction. So, radial direction try to indenting to the surface and axial direction try to move forward along the direction of your carrier medium that is water. Because of which what will happen assume that this is my surface my abrasive particle is indenting on the surface. So, F_x will try to move and F_y try to move in this direction, because of which what will happen that chip will remove in the form of microchip the material will remove in the form of microchip because of this radial as well as axial forces.

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Visualization of Abrasive Water Jet Machining

- Visual examination using moving camera

By tilting the work piece or the nozzle , cutting would take Place at different angles of impact

Two modes of material removal take place

- Cutting mode in case of shallow angle of impact
- Deformation mode takes place at larger angle of impacts

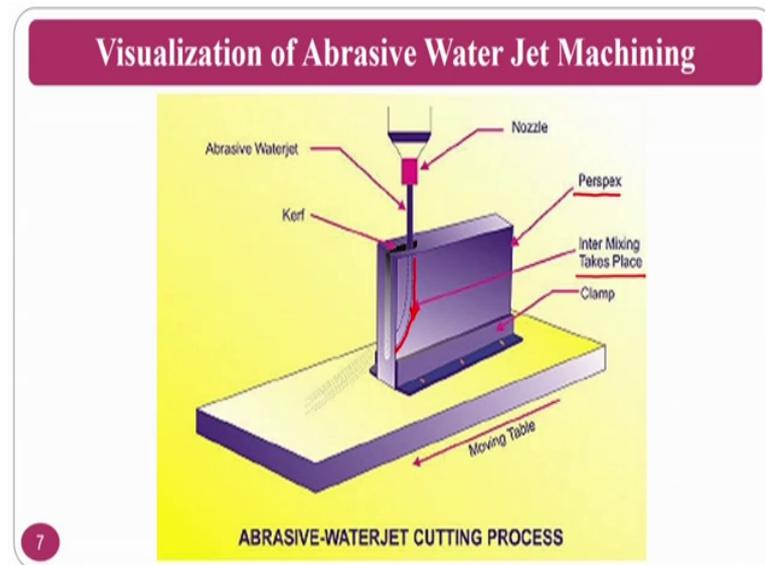
*Penetration rate and depth of cut → $f(\text{time keeping other parameters as constant})$

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So, for understanding abrasive water jet machining, there is a visual examination is conducted with the moving camera by tilting the work piece on the nozzle, cutting would take place at different. Two modes of material removal is observed; one is the cutting mode, another one is a deformation mode, ok. Normally the cutting mode will be done at the shallow angles of impingement, but the deformation normally takes at the large

angles of impact ok. Penetration rate and depth of cut is a function of time keeping other parameters as a constant ok.

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If you do like that if you do the visualization. So, basically the people have taken the Perspex. Perspex is a transparent polymer material. Just they have impinge with the abrasive jet and they observe it. Because as it penetrates it loses its energy and tries to go out because this is the path that it follows. So, in this is the intermixing takes place in this one because of the abrasives are heating one some of the abrasives are at kinetic energy at the same time some of the abrasives are low velocity because it is already stagnated there because of which what will happen this type of path it is observed ok.

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Mechanism of Material Removal in AWJM

Jet drag

- As the abrasive moves through the material, the lower portion of the jet legs behind the upper section as shown in figure.



Jet kerf

- Thickness of the cut made by the jet,
- This is negligible for harder and thinner material.

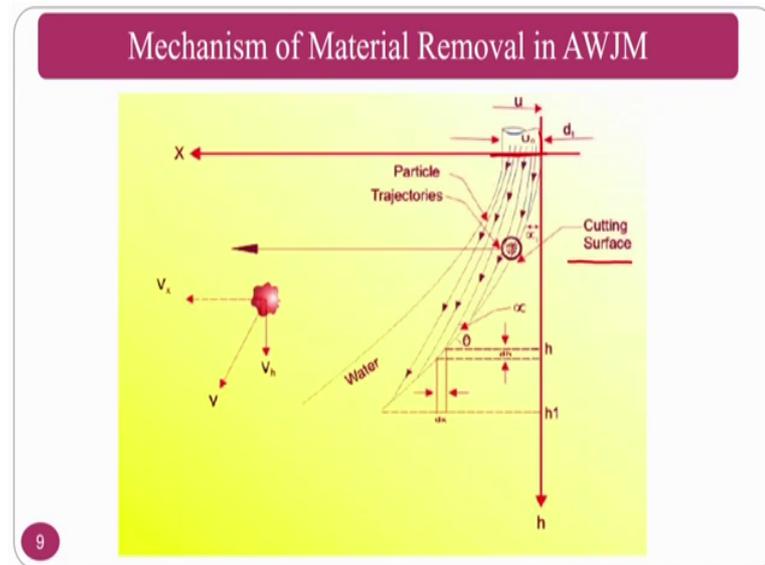


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The same thing if you can observe here because of the jet drag and jet kerf. As a abrasives moves through the material the lower portion of the jet legs behind the upper section as shown in the figure that is what this is the jet which is coming out. This is the upper portion and this is a lower portion another portion ok. So, as soon as jet kerf; kerf is nothing, but the width thickness of the cut made by normally assume that this is the work piece where in we are cutting a split off this thing.

So, this is the width is nothing, but the kerf ok. How much thickness of the split we are making or something is nothing, but are to simply to understand assume that I have a surface on which I want to make a channel ok. So, I want to make a channel on the surface. So, if I make a channel of this is my metal surface this is my metal surface and this is a micro channel this is nothing, but the kerf ok. Since these negligible for harder and thinner materials normally the kerf thickness is very fine in terms of harder and thinner materials.

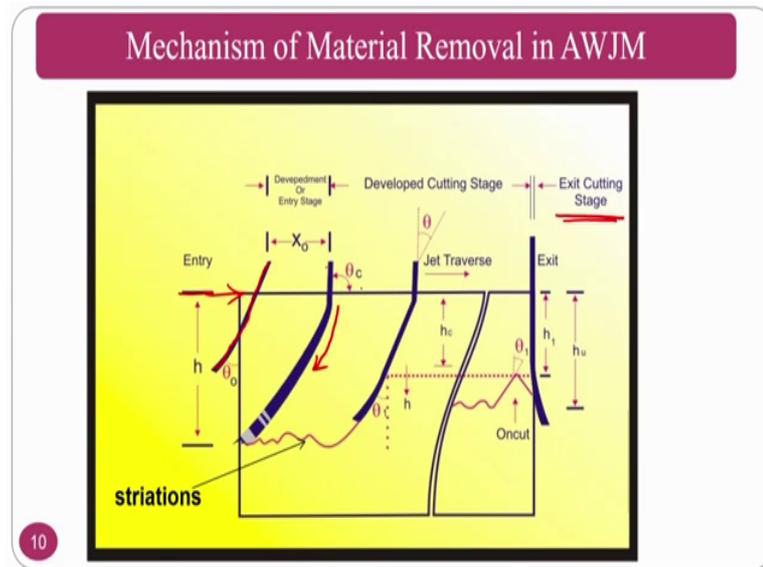
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And the mechanism of material removal if you see, as I discussed in the previous slide where the visualization is taken; so, this is the jet which is impinging on the surface where in it is following the track of the water. At higher junction what is happening it is having higher velocity as it goes down it will have a lower velocity. So, the cutting surface is taken care by the abrasive particle and the energy that is getting will be from that energy that the abrasive particles gets is from the water or the liquid that people uses.

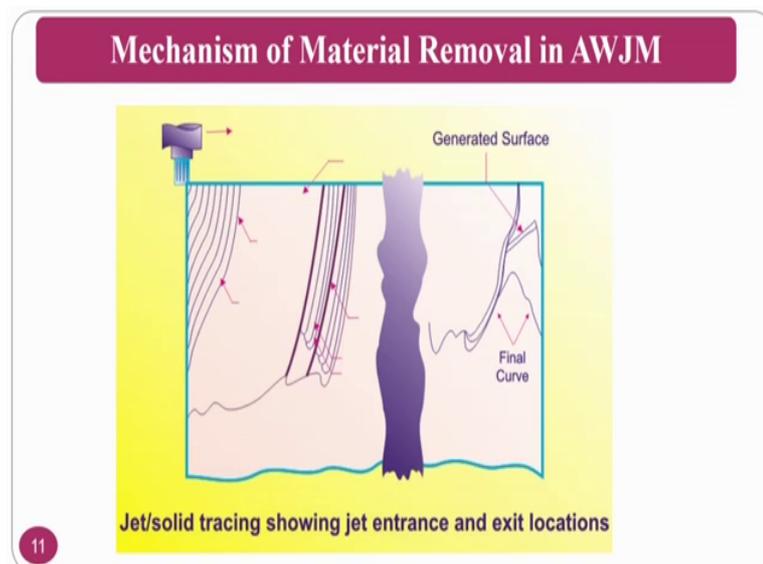
Sometimes some people may use some other oils also some of the people they have used it. So, if at all some people are looking for the research and other things you can use some of the mixing of the oils or blending of the oils and other things you can do. So, as you can see here whenever the heating is taking place with respect to the work piece what will happen this visualization which we have seen. Same visualization is done for the particle and trajectories; trajectory means the path how it will follow.

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So, as you can see the same phenomena here if you have a development or the energy storage, if you are going to use at a different jet traversing and other things, as if you are using very less energy at the entry level or something. It will go like this, but still if you give angle angular movement to it will take the path like this and so on. So, if at all the cutting jet traverse direction if you see what is happening here is at the initial stage it is the initial stage at the entry. And it moves on if you are going to increase with respect to time what it is going to do is it is going to do the different cutting action.

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As you can see here also that the mechanism is gone inside.

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WORKING PRINCIPLE

- Mixing of water jet & stream of abrasives takes place in the mixing tube
- Rapid rise in abrasives velocity occurs in the mixing tube
- When impingement of an abrasive on the work material takes place, momentum transfer ($\frac{1}{2}mv^2$) occurs.
- This leads to removal of material by erosion / shear / brittle fracture
- Pressure \approx 400 MPa jet speed \approx 900 m/s
- Cutting in upper part of kerf : erosive action
- Cutting in lower part of kerf : deformation



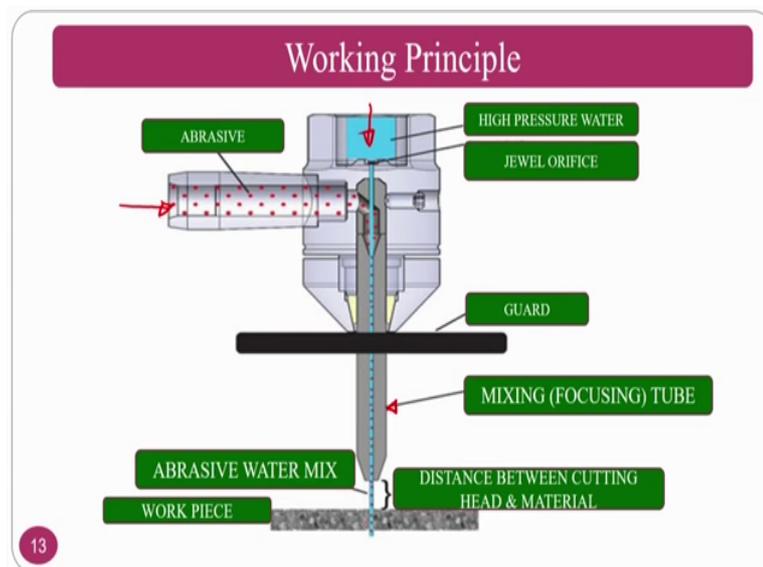
Working principle mixing of water jet and stream of abrasives takes place in the mixing tube ok. The mixing tube will be there and where the abrasive particles as well as the water will mix together and make a suspension. Rapid rise in the abrasive velocity of course, at the mixing tube because the water is coming at very high velocity. And the abrasive surfed from the abrasive feeder where this velocity of this abrasives are very less compared to this one or the pressure at which water is coming is very high. And the pressure of the feeding we may be normally in abrasive water jet machining is due to the by the virtue of the gravity.

So, because of this pressure differences and other things the mixing will takes in place in the mixing chamber. When the impingement of the abrasives on the work piece material takes place, the moment of transfer that is kinetic energy of the abrasive particles will occur and the material removal will takes place by shearing action or erosion. In brittle materials it will be like a brittle fracture, in ductile materials normally it will be like shearing action or erosion. The pressure normally will be using is 400 mega Pascal; jet speed will be like 900 meters per second which is a high. So, normally whenever you see whenever the abrasive water jet machining is operating. So, there will be a symbol of a pump it is a hand. So, you should not put if you put then gone.

So, these jets can cut your fingers and other things. So, while those people who are using this one are something this should be very careful about this particular machine. Because you close the system and I mean to say you close the doors then you operate the machine. Otherwise it will be danger whenever you the operation is going on it looks very easy, sometimes it maybe you cannot see also because the water is transparent colour. So, there may be chance of accident for that purpose you should be very careful and you just close the doors before you start the operation.

But other; however, just you can if it is a CNC controlled and other things, what you can just simulate it how the path is taking place and other things without jet. So, and once you close the doors then you can operate the machine along with the abrasive water jets. So, cutting upper part of that is nothing, but the kerf which is erosive action, at the same time cutting in the lower part of the kerf is normally by the deformation as you have seen you like this it is follows. So, here is the cutting action in this region and in this region normally it will be like a partial deformation process or something is the mechanism.

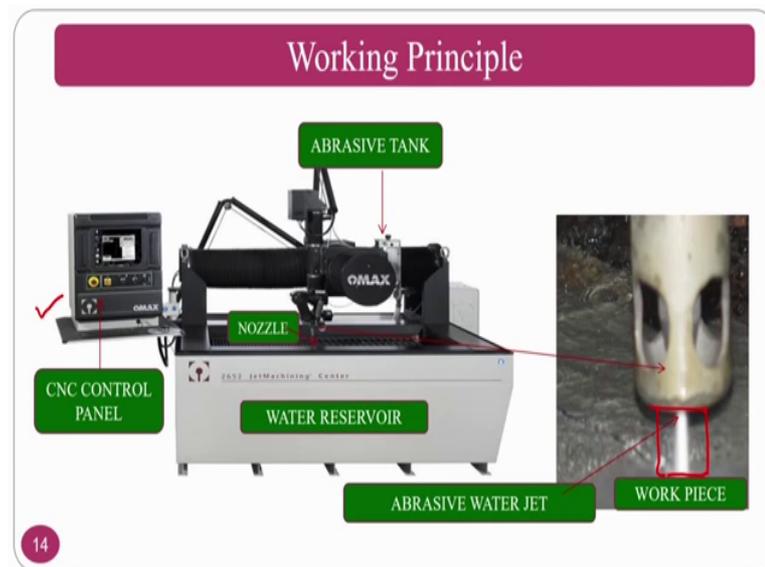
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So, working principle if you see the abrasive surfed from this, at the same time you have high pressure is a jet with high velocity which is coming from this one ok. Both will mix in the mixing tube and you have a guard into protect at the same time mixing tube is here. So, this mixing tube is length and diameter plays a major role how about the

mixing and other things and this will heat on the work piece and it will erode the material.

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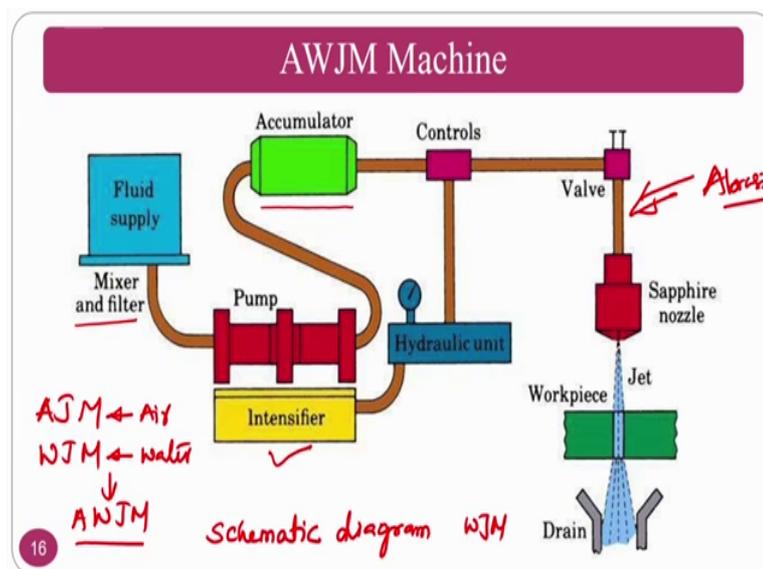
The overview of the machine if you can see here this is a CNC control panel and this is abrasive tank. I already said that abrasive tanks are slightly on higher heights because of which by virtue of gravity it will move. And highly compressed water will be sent and both will mix and comes. So, you can see here jet is coming out of the nozzle the abrasive water jet is coming out of the nozzle and it will impinge on the work piece surface.

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Now, you can clearly see the aluminum material cut by the abrasive water jets and you can see the how precisely it is cutting here in this region. At the same time it is normally straight cut is taken place here because it is a parting or some action is taking place. If at all you want to cut a complicated profiles ok; so, complicated profiles also you can cut and this complicated profiles can be program by the CNC control and other things ok.

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So, this is a schematic diagram of schematic diagram of abrasive water jet machining ok. So, you have a fluid supply that is water is coming from this particular tank and at the

same time mixture and filter will be there. Then most important part here is intensifier, intensifier increase the velocity of this particular fluid or water which is coming. And accumulator will accumulate and at the same time it will control and the send through the valve. So, whatever the pressure that you want you can control by the valve and you can get the water. So, of course, if at all I want to add the abrasive particles it you can add the abrasive particles along with the before them before the nozzle you can use the abrasive, abrasive feeding system.

So, this is the schematic diagram is explain to you the water jet machining; however, if you want add the abrasive particles if you can add so that it will convert into abrasive water jet machining ok. So, what I mean to say is abrasive jet machining you have seen where I is the medium to carry in a water jet machining water it will cut with water. So, if you club both two you will get abrasive water jet machining ok. So, the advantage of abrasive jet machining is you have the abrasives you can cut, but the only problem with abrasive jet machining is that the divergence will be there. So, the straight cutting will be there.

So, in order to counter it, what will happen? If you see on other side, there is water jet machining the capability of water to cut is very less; however, coherent nature of water is there. So, if you can combine both the things, what will happen? Energy of the abrasives at the same time coherence of your liquid can incorporate both in abrasive water jet machining and you can achieve greater performance compared to both individual performances of abrasive jet machining as well as water jet machining. That is why here you can see the water jet machining system where in if you can add the abrasive particles here; if it will become abrasive water jet machining.

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ELEMENTS OF AWJM SYSTEM

1. Pumping system
2. Abrasive feed system
3. Abrasive jet nozzle
4. Catcher

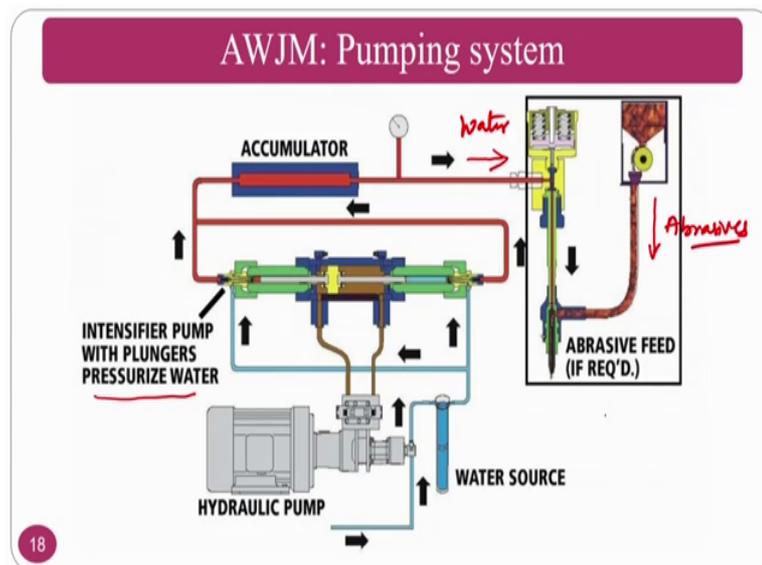
1. PUMPING SYSTEM

- Intensifier → 415 Mpa, 75 H.P. Motor (High velocity jet)

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So, the elements of abrasive water jet machining pumping system, abrasive feeding system, abrasive jet nozzle, catcher, ok. There is a pumping system if you see the intensifier normally 415 mega Pascal 7. 75 H.P Motor normally high velocity jet can be done here.

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If you see that the pumping system, pumping system is most important system to generate higher pressures of water in this one. What will what is the thing is just you take the water source as well as you just pump into the intense pump with plungers into the

pressurized water normally this intensifier increases the pressure it has its own mechanism and you send it to the accumulator where you can store this highly pressurized water then you send it to the nozzle before that nozzle what will there your abrasive feeding system is there you can feed this abrasive feeding system from here highly pressurized water is sent and from here you have the abrasives ok. So, the main important concept of here is the intensifier which intensifies is the freezer which increases the velocity of the water or it increases the pressure. So, that it can impinge on the work piece by mixing the abrasive particles and other things ok.

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Elements of AWJM System : Abrasive Feed System

- Delivers dry abrasives
- To control flow rate → control orifice diameter and suction in mixing tube
- Can not supply abrasives over long distances → uses direct slurry to feed over a long distance → more power required
- Water jet nozzle diameter → 75 to 635 μm
- For high life of nozzle → sapphire material

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Elements of abrasive water jet system the second element is abrasive feeding system it delivers the dry abrasive particles and to control the flow rate the control orifice diameter suction mixing tube will be there ok. As you have seen in a previous slide normally you have a mixing tube where it will suck as per the requirement normally if you do not control much what will happen this will sucking will be done by the virtue of gravity plus the difference between the pressures.

So, this is how the mechanism works normally there are some other additional mechanisms that you can go which can use like controlling orifice diameter and other things you can play. It cannot supply the abrasives for long distances because the pressure losses will be there in the tube. Unless direct slurry feed over the long distances nor the means that if at all I want to move the abrasive particles for longer distances

normally, what you have to do is you have to make slurry than low tube send it. The water jet nozzle normally the diameter ranges from 75 to 635 microns normally and for higher life of nozzle as I said in abrasive jet machining also, you have to go for sapphire material as a nozzle materials.

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Elements of AWJM System : Abrasive Jet Nozzle

- **Functions of a nozzle in AWJM:** 1. Mixing of abrasives & water
2. Forming high velocity jet
- **Materials of a nozzle:** WC, boron carbide, sapphire

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So, this is the abrasive nozzle or abrasive jet nozzle, the functions of nozzle is mixing of the abrasives and water that is what is taking place. Here the abrasives are coming at the same time here the compressed water is coming so both are mixing here, this is a mixing region which is a green colour and it is impinging. So practically how you can see here is this one so this is the abrasive feeding system, water feeding system, both will mix in this particular region and it will impinge on to the work piece.

So, mixing of abrasives is one of the function and the forming a high velocity jet that is abrasive water jet is another function of this abrasive jet nozzle the materials as I said tungsten carbide is can be used boron carbide also can be used sapphire is normally used. So, if at all you want for longer life like 300 hours in abrasive jet machining which you have seen sapphire will be used if at all you want to use for 30 hours or 25 hours normally tungsten carbide based nozzle jet materials can be used.

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So, these are the nozzles normally you can see and we can see the anatomy of this particular nozzles, where this is how the schematic diagram and practically how it looks like. This is for your better understanding purpose and this is a complete nozzle how it looks like as a hole ok. The same nozzle this is a same nozzle just to show you how it will be look like in a complete way ok. This is a schematic where water chamber is there abrasives are fed this is the abrasives feeding this is a water is coming with the high intensity and abrasive water jet is coming out of this one. So, this is how the abrasive water jet will come out of the abrasive jet nozzle.

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These are the other varieties of nozzles where you can play the standoff distance, the standoff distances are varied if you go for a small nozzles it will be different. You can see in this particular nozzle this is how the abrasives surfed, in some cases here is abrasives surfed some cases you can feed perpendicularly so how you want you can feed. So, there are multiple jet you can see this is the multiple one you can have a multiple abrasive jets and you have a water jet. So, this is how you can play depend on your application whether you want to go perpendicularly whether you want to go certain angle these optimization of this study also maybe a good thing.

How to feed? Assume that my water is coming like this at what angle if I can feed my abrasives can be a good study also ok. So, some people might have studied already so you can see those papers and you can study also. This is the water jet which is coming and abrasives how you can feed abrasives ok. So, if you feed against the flow normally the jet velocity maybe drastically changes for that purpose you should look into it maybe the mixing maybe better ok. So, you can compromise on the mixing ability as well as the velocity and other things you can work out to take as a B-tech student some people if you are looking at.

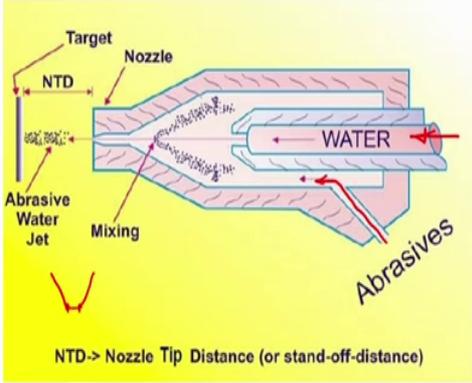
And if you have this abrasive water jet machining facility so, you can go for the optimization of the angle of abrasives feeding to the angle of the water jet coming ok. So, you can make the performance assume that your performance is surface roughness if your performance is material removal or surface morphology and other things. You can study as output responses for the angle of feeding of abrasives with respect to angle of the water jet.

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Elements of AWJM System : Abrasive Water Jet Nozzle

SINGLE JET SIDE FEED NOZZLE:-

- Simple to make
- Rapid wear of exit part of nozzle
- Non-optimal mixing efficiency of water & abrasive



NTD-> Nozzle Tip Distance (or stand-off-distance)

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The elements another element is the abrasive water jet nozzle if you see there are the single jet side feed nozzle; that means, that water is coming from here and abrasive particles are fed from here. So, both are mixing in this area you can see the mixing is taking place here and it is moving forward. So, the abrasive water jet is coming like this.

So, this is simple to make because you have the one tube and in inside you have another tube where in the water is coming abrasives are coming and mixing. And rapid wear of exit part of the nozzle; that means, that if you have a nozzle no exit part this particular portion will get weared out. So, non optimal mixing efficiency of water and abrasive particles will be a concern here.

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Elements of AWJM System : Abrasive Water Jet Nozzle

**ANNULAR JET
CENTRAL FEED
NOZZLE**

- Better mixing of water & abrasives
- Mixing is outside the nozzle
- Less accurate machining
- Cuts are wider ✓

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1 mm 1.05 mm

So, second one is annular jet central feed nozzle if you can see here, here abrasives are coming at the central previous nozzle you have seen the water is coming at the centre and abrasives are coming from the sideways. Here what is happening here is abrasives are coming from the centre and water is coming from the outside. So, now the mixing is taking place and the abrasives are coming like this. So, better mixing of abrasive particles and water will be there compared to the previous nozzle and mixing is outside the nozzle.

So, it will be better at the same time the basic problem here is less accurate machining; that means, that because of the water is coming out and abrasives. So, abrasives have a abrasives will split the water jet assume that what is happening is as 1 mm diameter water jet is coming, if you are feeding the abrasive particles at the centre what will happen the jet will try to diverge ok.

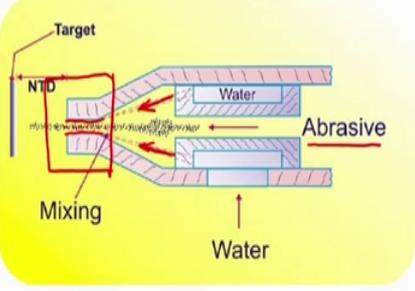
So, that is why less accurate machining will be a problem of this particular nozzle. So, that because of which what will happen the cuts are slightly wider as per the requirement. Assume that what is happening if I want this particular micro channel or mille channel what will happen you may get slightly wider one assume that instead of 1 mm channel you may get 1.05 mm or something. So, that is the disadvantage of this particular nozzle.

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Elements of AWJM System : Abrasive Water Jet Nozzle

**MULTIPLE JET
CENTRAL FEED NOZZLE**

- Centrally located abrasive feed system
- Surrounded by multiple water jets in a converging annulus
- Higher nozzle life & better mixing
- Costly & difficult to fabricate

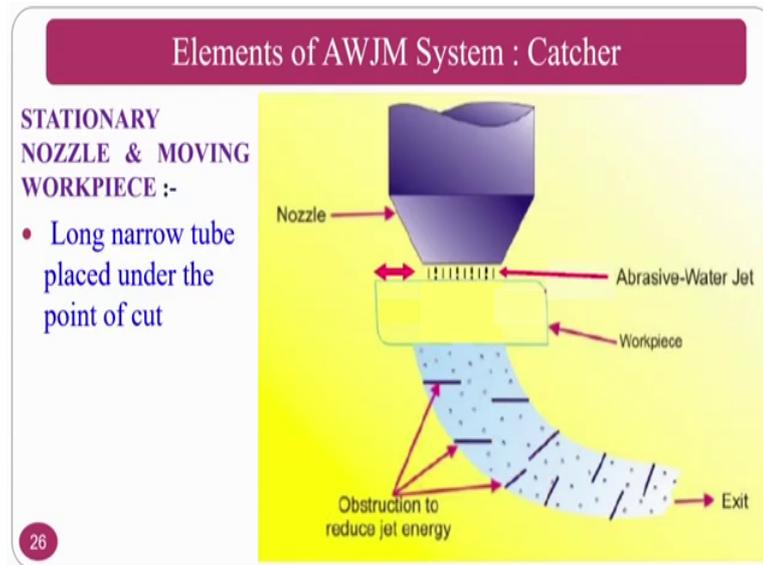


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So, another nozzle system is multiple jet central feed nozzle. If you see here you have a multiple jets of water, here jet is coming. One jet here, one jet his coming. Previous case this is a only one jet, but the water source feeding is same in the abrasives are coming at the centre ok. So, this one centrally located abrasive feeding system is there as you have seen in the previous one. Surrounded by the multiple water jet converging into annular regions and higher nozzle life and better mixing because what is the main concern here is that if the water is on outside. If the water is coming if you concentrate in this particular section what was coming like this and jet is abrasive jet is coming like this.

So, that the advantages water is in contact with the nozzle material, not the abrasives. But there will be chances of abrasives will also come into contact, but the chances here is water come mostly in contact to the nozzle so the nozzle life will increase enormously. However, this process this nozzle is lightly costly and difficult to fabricate because you have a multiple water jets and other things are there. So, you need to do lot of micromachining work and other things ok.

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The, another part of this abrasive water jet machining is catcher. So, catcher many people you know how to catch the ball in a cricket and other things. So, here also you need to catch the jet because the jet and abrasives are coming at very high velocities. If you do not properly receive it what will happen we need the cutting material or the, we need the work piece it will also cut.

So, normally what you will have is the work piece will be held and below that you will have a catcher; that means, that there will be a water tank normally are some bags where in it will absorb the velocity of the water and it will sediment the abrasive particles ok. So, the stationary nozzle and moving work piece in this is the one condition. Assume that this is a work piece that is moving in this case nozzle is stationery, but work piece is moving like work piece as you can see here it is reciprocating or traversing at the nozzle is at the same location. In this one long narrow tube is placed under the point of cut what will happen the abrasives and water is coming from here it is cutting and it has to go.

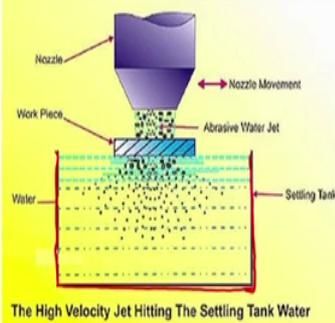
So, you as we have seen the path of the abrasive water jet, so, this will follow the similar so you will have a catcher which is a bag in the similar direction where you can see the obstruction to reduce the energy you will have all the obstructions. This bag will provided with some of the obstructions this will obstruction will obstruct the velocity of water obstruct the velocity of the jet also and it will exit. This is so one of the way of catch which is one of the way of catcher.

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Elements of AWJM System : Catcher

MOVING NOZZLE & STATIONARY WORKPIECE:-

- A water filled settling tank underneath the work piece
- Transfer of high pressure to water filled in the tank
- To collect remains of AWJ
- Flexible hose (press < 24 Mpa)
- Rigid tubing (press > 24 Mpa)



The High Velocity Jet Hitting The Settling Tank Water

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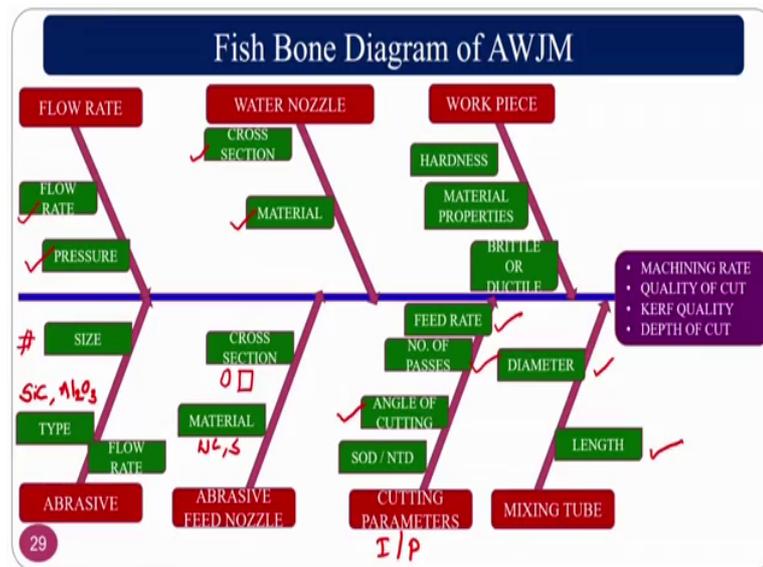
And normally what you can see in most of the abrasive water jet systems is this type of thing. Which is moving nozzle and stationary work piece the work piece is stationary and the nozzle will move. In this case what is happening here is you will have a complete water tank. Since you are using water as a carrier medium you will have similar type of water as a catching medium also. This is economic a water field settling tank underneath the work piece will be always placed and the transparent high pressure to the water field tank will be there.

To collect the remaining of abrasive water jet always you will have a flexible hose, at the same time rigid tubing. You can go for flexible hose and rigid tubing also you can use normally what you can see in many cases. There are many abrasive water jet machining people in India itself if at all you are interested; the first and primary person you can visit is professor Ramesh Babu, IIT Madras; you can visit his lab, so he is one of the expertise in this particular area, at the same time IIT Kanpur also this abrasive water jet machining is there. So, you can see not only these are the few things which I have seen in my life and in many places it is there.

So, if you go anytime for the quality improvement programs are any other things if you are a ph.D student or master student if you are doing. Try to do in the advanced areas and you can go for micro cutting as well as texturing of this jet and other things ok. So, whatever the thing is that if at all you want to go for this type of moving nozzle and

stationery work piece you just put the water tank with water. Because of water and the water jet is coming it will catch and the water has certain resistance to the jet. So, this water jet will die off once it enters into the tank.

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So, parametric analysis of abrasive water machining normally if you see the fish bone diagram; that means, that how the output responses like machining rate, quality of the cut, kerf quality, depth of cut, all will vary with respect to the work piece materials ok. So, the first parameters are the abrasives, so the size of the abrasive particle normally you mentioned by the hash symbol. Type of the abrasive particle it is whether it is silicon carbide, whether it is an alumina, whether it is diamond particle, or something is another factor.

At the same time flow rate how much flow rate your using whether you are using 1 kg per hour or 10kg per hour are the same how flow is taking place and at the same time flow rate also the same thing will be hand will here also. So, the flow rate as well as how for pressure of the water is your sending. So, the abrasive feeding nozzle material as I said whether it is tungsten carbide or sapphire or something because it will decide the life of the nozzle. And the cross-section whether the cross section is a circular cross section, whether the cross section is a rectangular or square or something.

You can decide and water nozzle the cross section of the water nozzle also plays a major role material. And since here also you can go for less harder materials. The feed rate the

cutting parameter that is input parameters normally what you can put into the machine. That is how much feed rate number of passes, whether you want to 10 passes to cut the material. If the thickness of the material is too high you have to go for more and more number of passes.

Angle of cutting whether you want 2 dimensional you just go perpendicularly; whether if you want to 3 dimensional structures, you have to give certain angle of to the nozzle and the state standoff distance or nozzle tip distance. That means, that how much distance that you have to keep with respect to the work piece material assume that this is a jet and how much distance this is the work piece this is the jet so whether you want to go for 5 mm, whether you want to go for 50 mm are this distance you can also play. The work piece material the work piece hardness, if the hardness is very high normally the material removal will be very less.

The material properties like yield strength and other things brittle or ductile, if the material is brittle the mechanism of material removal will be brittle fracture then fragments in the ductile material just shearing action will takes place. So, mixing tube normally mixing tube length plays a major role as well as a diameter. If the length is too high what will happen or the length is too long the velocity of jet will die. If the diameter is very high then the mixing also will takes it is own time or something.

So, these are all the parameters that will affect the output responses some of the papers whenever we review or we see so some of the students write output parameters and other things be careful about the parameter and response ok. When I called this flow rate, abrasives, abrasive feed, nozzle water, nozzle work piece, material properties, cutting parameters, and mixing tube, these are all parameters. Parameters means what you can change what operator can play these are the parameters that you can change. Responses means which you cannot play, these are the things that are come are the outcome of the process ok. So, the responses is only you can observe you cannot vary those by varying the input parameters you can vary the output response.

The a responses means these are the responses that you have to take note down that is all you cannot vary ok. So, that is the difference between input parameters you can vary the parameters that is why it is called input parameters. If you want to say output parameters that is a wrong word I cannot say completely wrong some people uses it still so that is

my observation what I learnt from my professor. So, output response is please do not use the word output parameters because parameters is what you can change responses is what you cannot change output is what you will observe input is what you vary ok. So, that is a difference between input parameters and output responses.

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PROCESS PARAMETERS

- Water → flow rate and pressure ✓
- Abrasives → type, size and flow rate ✓
- Water and abrasive jet nozzle → material and design
- Cutting parameters → feed rate and stand-off-distance
- Work piece material
- Mixing tube → diameter and length
- Angle of cutting
- Traverse speed
- Number of passes

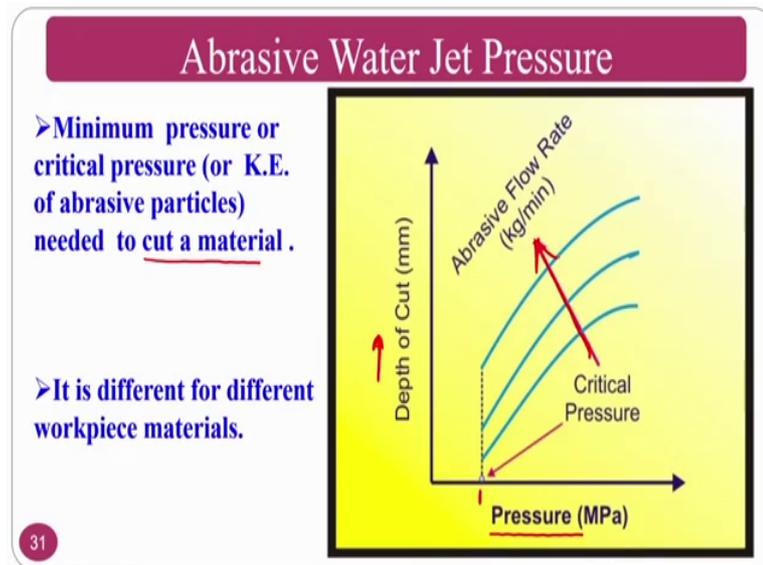
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Process parameters water flow rate and pressure, but we have seen abrasives type, size and flow rate. These are the parameters from the fish bone diagram all the parameters which we cannot take. So, some of the parameter which are important sometimes you see you do the design of experiments and you come up with percentage contribution of input parameters. What you have a set of fish bone diagram input parameters, among which what you have you just see the percentage contribution of each input parameters which are playing a major role those are to be considered. So, from the literature what the thing what the parameters observed is water flow rate and pressure play a major role abrasive type size and flow rate play a major role water and abrasive jet materials and design.

Cutting parameters like feed rate and standoff distance plays a major role and work piece material whether it is brittle material or ductile material mixing tube diameter as well as length as I said this is a measure. And angle of cutting whether you want to cut a 3 dimensional or 2 dimensional and another thing. Traverse speed how fast, whether if your nozzle is moving? How fast the nozzle has to move? If the work piece is

reciprocating or traversing, how fast the work piece has to move and the number of passes. If at all I want to cut thick materials so I need to go for more number of passes.

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So, abrasive water jet pressure; so minimum pressure which is nothing, but the critical pressure ok. So, need to start the cutting of the material this is a critical pressure you see the picture this is the critical pressure. So, critical pressure means beyond which the material starts cut ok. So, if you see here the pressure is there abrasive water jet pressure, the depth of cut at this particular point 1, there is no depth of cut that is why that particular point is considered to be critical pressure. As you increase the pressure what will happen all the curves are increasing; that means, that depth of cut is increasing. Because if the pressure increases, whatever what is happening the kinetic energy of the abrasive particles that gains from the water will increase, because of which what will happen your depth of cut will increase.

If you increase the abrasive flow rate; that means, that more and more number of abrasives are there. What will happen? That more and more cutting at this will come into picture so the material removal takes place. In the first case you observe any one curve as your abrasive water jet pressure increases, what will happen the kinetic energy of the abrasive particle will be more. That is why all the curves will increase if you see across the curves like, but the arrow is showing this particular arrow is showing. So, if you are

abrasive flow rate increases what will happen number of abrasives coming into contact with the work piece will increase so, the depth of cut also will increase.

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WATER JET PRESSURE

CRITICAL PRESSURE(P_c):
Below this pressure the stresses developed in the workpiece are lower than yield stress

- Below this pressure no cutting takes place.
- Different for different work piece materials
- Depends on work piece properties (hardness, ductility, etc.)

Above A Definite Jet Pressure: Machined depth tends to stabilize

Relationship with Machined Depth: Steeper with higher abrasive flow rate

Increased Pressure will Lead To

- ✓ Lower efficiency
- ✓ Higher nozzle wear rate

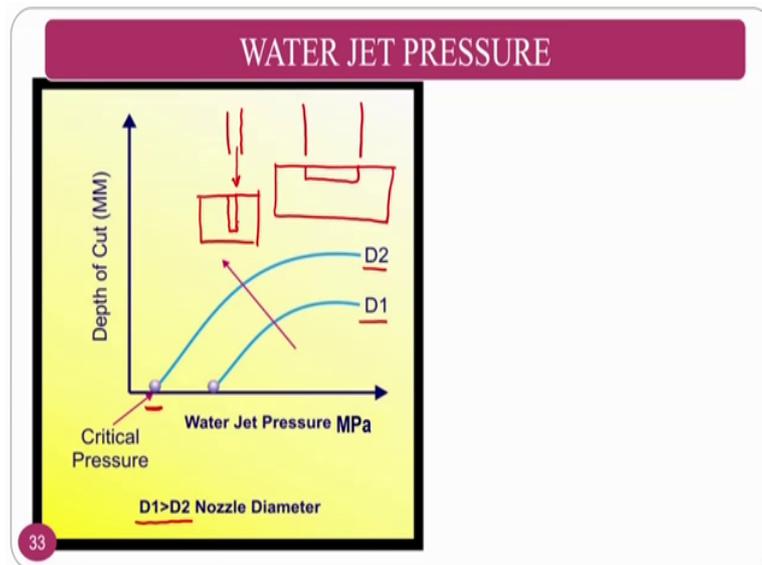
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So, water jet pressure; critical pressure as I said as we have seen in the previous slide below this pressure stresses developed in the work piece material are lower than the yield stress; that means, that the material removal will not take place because the yielding itself is not taking place. Now, below this pressure low cutting takes place because yielding of the material is not taking place. Different for different work piece materials this critical pressure if at all I want to cut the hard materials like stainless steel you are critical pressure will be different. If you want to cut aluminium the critical pressure will be different that is what depends on work piece properties that is hardness and ductility and other things.

About a definite jet pressure what will happen the machining depth tend to stabilize because after certain value it is start stabilizing relationship with the machine death. Steeper with the higher abrasive flow rate the normally what I what I mean to say if you are going to have more flow rate what will happen more and more of material removal we takes place more and more steep it will go. Increase pressure will lead to lower efficiency at the same time higher nozzle wear rate. Because if you are going to increase the pressure of the abrasive water jet what will happening is? These abrasives may colloid each other at the same time the impingement of this abrasives on the nozzle

surface or the I mean to say nozzle inner surface will be more and the wear rate of the nozzle will increase.

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Water jet pressure if you see in this one the critical pressure the critical pressure is nothing, but where the material removal is yet into start. So, as you increase the water jet pressure same thing the kinetic energy of the particle will increase that is why it will increase. Normally if you see that D1 and D2, if the D1 is more than D2 the depth of cut is more; that means, that if you are diameter is more what will happen the width of the cut will be increased.

What I mean to say if this is the nozzle diameter in another case this is the nozzle diameter and the abrasive flow rate is same if you say at the abrasive flow rate is same what will happen here. Whatever the abrasives are coming, it will cut the work piece steeper; that means, the depth will be steep. Here what is happening this is the work piece for the same flow rate you may achieve this much depth only. Here what you are going to achieve is this much depth that is what the depth of cut in the smaller diameter will be high.

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Water flow rate

In abrasive jet machining where gas (usually air) is used as a propelling fluid, only small mass flow rates of abrasives (up to 100 g/min) can be achieved.

AWJM, water is used as a propelling fluid which enables high abrasive flow rates (0.1-5 kg/min) to be achieved, and makes it possible to accelerate abrasives to high velocities (over 300 m/s).

Abrasive water jets are more suitable for cutting as compared to gas abrasive jets because of more coherent jets.

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So, the abrasive jet machining where the gas is used as a propelling fluid abrasive water jet machining you will have the water. Normally water enables high abrasive flow rate normally 0.125 kg per minute, which is a very high value. Can be achieved and it is possible to accelerate the abrasive to the velocities over the 300 meters per second. If that is a velocity then it can cut the materials like stainless steel, it can cut the aluminum, it can cut even glass and other brittle materials also.

Abrasive jets are more suitable for cutting the compared to the gas abrasive jets because of the more coherent jets. That is what I was telling is compared to the jet what is happening in this condition is the jet is coherent. I mean to say in an abrasive jet what is there, once it comes out of the nozzle there will be a chance of diverging because air is there. In the other condition if it is coming water is coming what is happening is you get a perfectly coherent one I mean to say not hundred percent just you will get a coherent D1 in a straight line you will get because of which what is happening is you will cut a perfect cut into the material.

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Water flow rate

Water flow rate (Q) is proportional to square root of pressure and square of diameter of the nozzle.

$$\dot{Q} \propto \sqrt{P} \qquad \dot{Q} \propto d_n^2$$

Increase in water flow rate beyond a certain value may result in insignificant gain in particle velocity, higher pressure losses in supply lines, unacceptable environmental conditions (in mining or constructional applications), and in some cases with reduced machined depth

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So, the water flow rate is proportional to square root of the pressure and the square root of the diameter of the nozzle ok. So, increase in water flow beyond the certain value may result in significant gain in the particle velocity. Higher pressure loses the supply lines and acceptable environmental conditions and other things. If you are increasing beyond certain value the pressure what is happening is the particles will collide each other and loses their velocity. At the same time this will impinge the abrasive particles on the inner walls of the abrasives inner walls of the nozzle so it will damage the nozzle also.

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Abrasive Particles

- Abrasives are those materials used in operations such as grinding, polishing, lapping, honing, pressure blasting or other similar process.
- Abrasives come in different particle or grit sizes depending on how much material needs to be removed.



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Abrasive particles abrasives are those materials which are used normally if you see here normally in the abrasive jet machining the economically is granites sand silica, these are the type of abrasive particles will be used. Abrasives come in different particle sizes, that are the grit sizes depend on how much material you want to remove. If the material removal is very high you have to go for coarser one if your material removal rate is less then you have to go for final.

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Abrasive Particle Size

Optimum particle size

- **Finer particles ->>> for shallow depth of cut**
- **Coarse particles ->>>>for high depth of cut**
- **Different abrasive sizes for different depth of cut**

ABRASIVE MATERIALS:

Machined depth $\rightarrow \phi(\text{type of abrasives})$

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If you are going for final then the cut off that machining is much finer and you will also get the surface finish. Optimum particle size the finer particles normally used for the shallow depth of cut, the coarse particles for high depth of cut. And different abrasive sizes for different depth of cut you can use abrasive materials normally machine depth is a function of type of abrasive particles. That means that if at all I want to go for if at all I want to go for higher depth of cut then you have to go for much harder work piece material much harder abrasive particles.

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Abrasive Particles Size

Commonly used abrasive particle size ranges from 100-150 grit.

There is an optimum particle size for a particular workpiece material and also for a particular nozzle mixing chamber configuration.

Grit Size	Relative Coarseness
8-24	Coarse ✓ ○
30-60	Medium ○
70-180	Fine ○
220-1200	Very Fine .

 Grit

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If I want to cut deeper cuts, then I have to go for the much harder abrasive particles. As you can see the grit size normally 8 to 24 considered to be the coarse; that means, that very big size of abrasive particles. Then 30 to 60 you will say that is the medium, 70 to 80 will be fine. At the same time 220 grit size to 1200 grit size will be like very fine ok. Normally people will measure in terms of seem and other things which I have explained in the grinding process. This particular seeming and other things is number of the abrasive particles passing by the sea will say the grit ok. This particular one portion is nothing, but a grit one grit the commonly used abrasive particles are in the ranges of from 100 to 150 grit. And there is an optimum particle size for a particular work piece material and also for particular nozzle mixing chamber configuration. Normally if at all I want to do particular operation then I have particular nozzles specification, particular abrasive particles, and other things.

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Abrasive Flow Rate

- Machined depth $\propto (V_p^2 m)$
- Above $\dot{m} \rightarrow$ reduced Depth
- Increase in $\dot{m} \rightarrow \uparrow$ wear of mixing nozzle
 \downarrow mixing efficiency

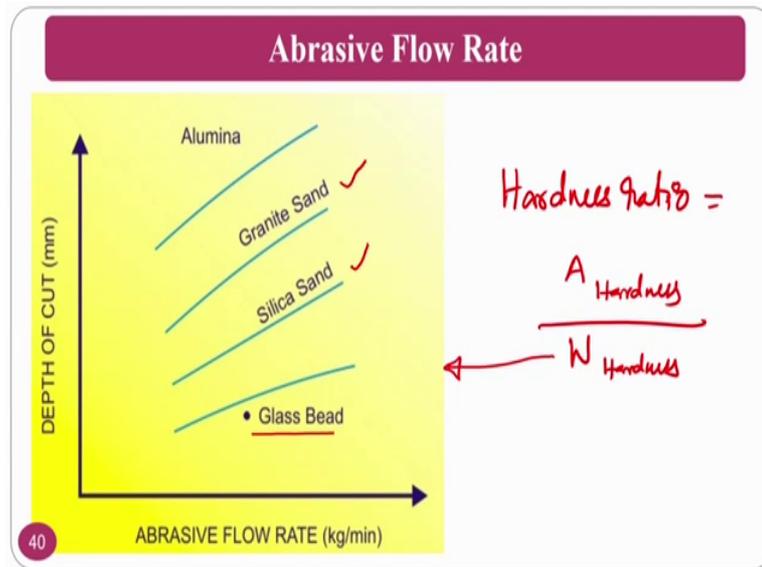
SELECTION OF THE TYPE OF ABRASIVE

- Cost of abrasive ✓
- Nozzle wear rate ✓
- Environment considerations ✓
- Machining rate ✓

So, abrasive flow rate normally machined in depth will be proportional to the velocity of the flow rate and normally mass flow rate is very high with reduces the depth if the mass flow rate is very high; that means, the abrasives are more and more abrasives are coming to the nozzle. So, the abrasives will collide each other and there will be a loss into the velocity carrying. And in case of machine flow rate wear of mixing nozzle will takes place at the same time mixing efficiency will reduce. That means, that mixing will be high the way rate of the nozzle will be high.

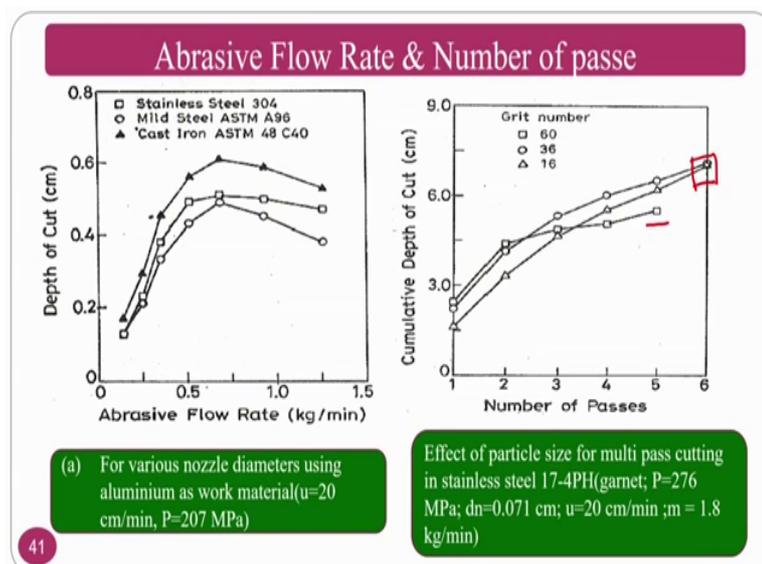
Because of the more and more abrasive particles are coming in contact with the inner walls of the nozzle. At the same time mixing efficiency will go down because the abrasives particles will collide each other and may move a part are some ok. Selection of the type of abrasives normally it will be done based on the cost of the abrasive particle nozzle wear rate at the same time environmental considerations and machining rate. If I want more machining rate normally hard machining rate should be very high; that means, that your abrasive particle hard test should be much higher compared to your work piece hardness.

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So, so the abrasive flow rate if you see the abrasive flow rate normally the depth of cut as I said if at all I want to cut a mild steel material. If glass beads very less than the silica sand, granite sand and alumina; if at all I want to go then I have to choose a better hardness value that is called hardness ratio as I spoke in the previous slide. So, hardness ratio is nothing, but abrasive particle hardness was by the work piece hardness. So, this hardness should be much bigger, if the value is more; that means, that abrasive particle hardness is high for the same work piece material here. If you are hardness of your abrasives is increasing then the depth of cut that you can cut will be normally increasing.

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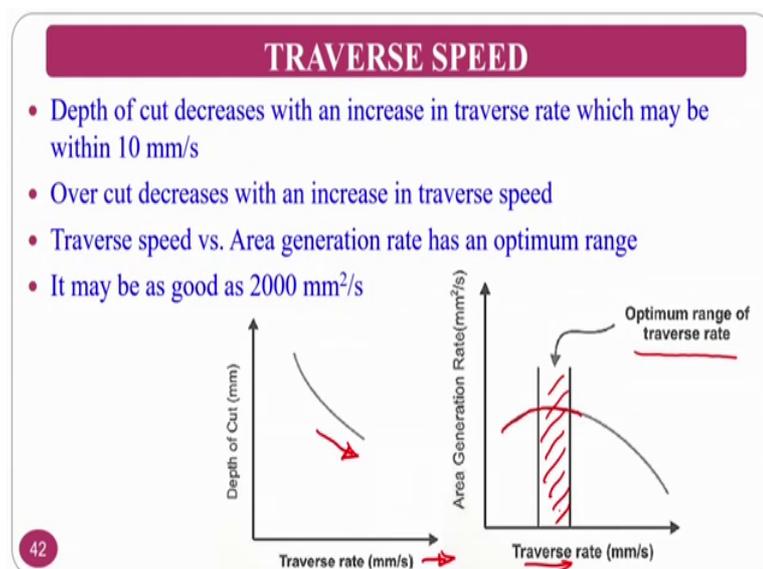


Abrasive flow rate verses number of faces if you see the depth of cut the abrasive flow rate if the abrasive flow rate is as the abrasive flow rate increases what is happening here is for the cast iron which is a brittle material the depth of cut is very high. The mild steel and the stainless steel stainless steel is much harder ductile material compare to the mild steel that is why the depth of cut in the stainless steel is good. At the same time mild steel is lower because the mild steel is a ductile material there will be a always chance of accumulation of this particular materials.

At the same time number of passes as the number of passes increases as I said you are depth of cut cumulative depth of cut will be continuously increasing. If you see the grit number if the grit number is increasing; that means, that abrasive is becoming final and final in that circumstances what is happening here is you are going to perfect cuts the surface roughness what you are going to get is good in that circumstances. If you see here the grit number is 60.

So, that cumulative depth of cut is very less, at the same time if you see for the 36 and 16 you are going to achieve approximately same cumulative depth of cut. That means, that if you are abrasive particle is big is if the grit number is less; that means, that abrasive particle is slightly bigger. If the abrasive particle is coarser what is happening is depth of cut that you are going to achieve is higher.

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Traverse speed depth of cut decreases with respect to increasing that traverse rate. That means, that if you are traverse rate is increasing. That assumes that my nozzle is moving at the same time work piece is stationary in that is case. If the velocity at which the nozzle moves what will happen if nozzle movement is very fast the sub insufficient time will be there for cutting the work piece material. T is why the depth of cut will decrease. So, over cut decreases with increasing traverse with; that means, that we do not have insufficient you do not have sufficient time to cut that is why the over cuts will be always reduces.

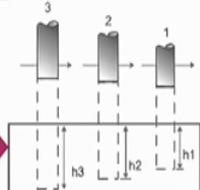
So, traverse speed versus area generation rate has an optimum range; that means, that if you see the traverse rate versus area generation that is how much area your cutting. So, initially it will be less gradually it will increase then it will decrease. So, as a operator what you have to do is you have to choose optimum range of traverse rate. So, that in this region if you are going to operate what will what are you going to get is you will going to get more many more depth of cut.

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Number of Passes

- **Multiple passes** → Single water jet with multiple passes ✓
 → Multiple tandem jets with single pass ✓
- Each jet makes an additional depth of penetration. Jet 1 gives h_1 mm, and jet 2 gives $(h_2 - h_1)$ mm and jet 3 gives $(h_3 - h_2)$ mm as additional depth of cut
- Increase in number of passes → cumulative depth
- Kerf acts as a local mixing chamber

Multiple tandem jets With single pass

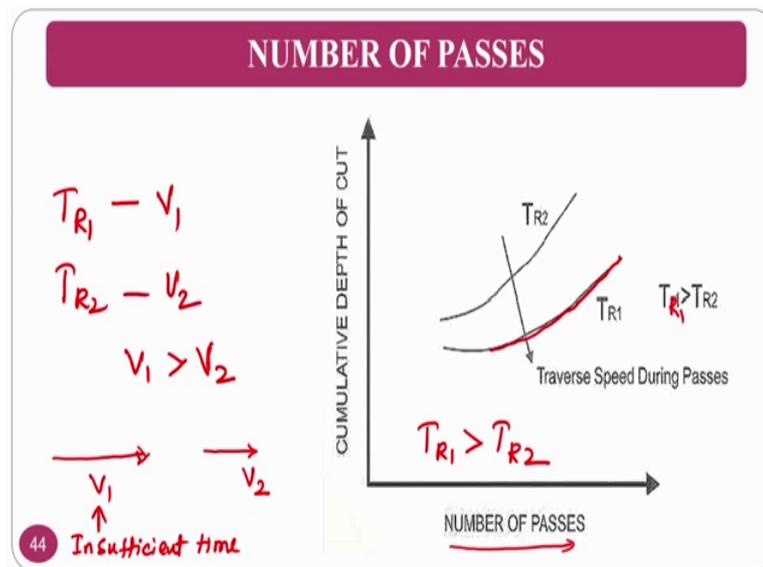


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Number of passes if the number of passes are multiple passes single water jet with multiple passes is possible. Multiple tandem jet with single pass is also possible each jet makes an additional dept of penetration. Normally jet 1 if you see the picture here so jet 1 gives h_1 and jet 2 gives the h_2 . Normally h_2 minus h_1 mm and the jet 3 gives h_3 minus h_2 mm.

This is the additional depth in terms of multiple tandem jets with single pass to increasing number of passes normal accumulated depth will gradually increases. So, the kerf acts as a local mixing chamber ok. So, this is about the multiple tandem jets with a single pass. So, you can see the h_1 , h_2 , h_3 is the depth with respect to the jet 1, jet 2 and jet3 that is explained the above.

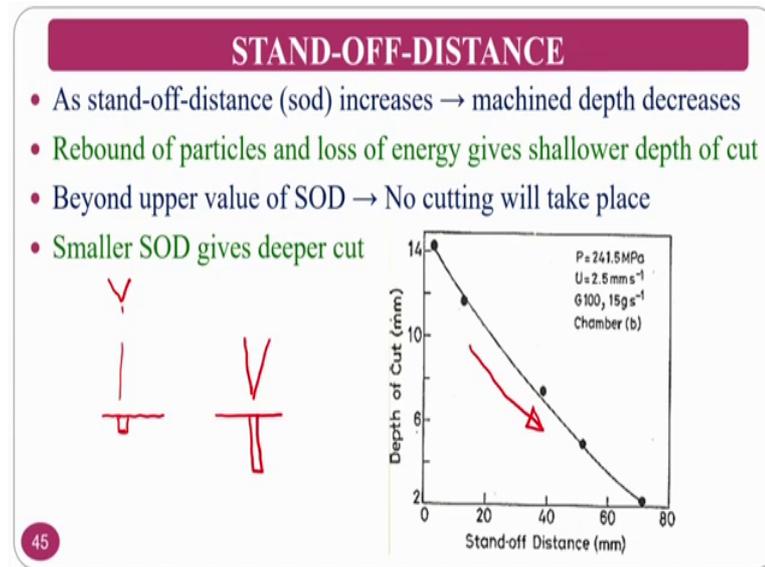
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So, the number of passes if you see the number of passes as it increases cumulative depth of cut; obviously, it will increase. And if you see the traverse speed, if the traverse speed is high what will happen it has insufficient time to cut the material. That is why if the traverse speed is very high what is happening is TR_1 is greater than TR_2 . In that circumstances what is happening is TR_1 ; that means, that in the in these TR_1 case the nozzle is moving at faster rate.

So, it has insufficient time to cut TR_1 velocity 1 TR_2 is velocity 2. So, velocity 1 is part higher than velocity 2; because of each what will happen here is the movement of the nozzle is very fast. In this case v_1 the movement of in the other case it is less because of which what will happen the here in this condition what the insufficient time is there to cut the material compared to v_2 that is why you are TR_2 will give you more material removal in terms of depth of cut.

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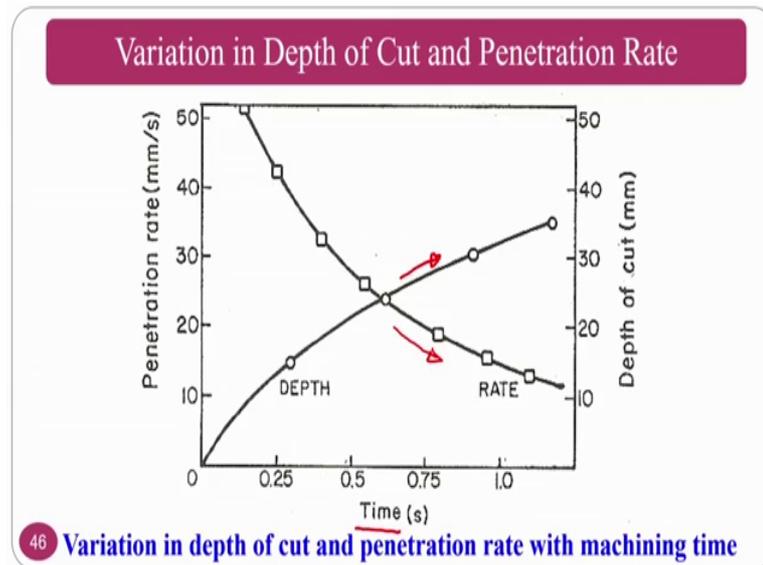


Standoff distance is sometimes in the some of the textbook we will say nozzle tip distance also if the standoff distance is increases what is happening is the distance between nozzle exit and the surface work piece surface will increase. If you are going to increase what will happen? The velocity is the pressure that is carrying the pressure difference will be more and more. And if the pressure difference is reduces gradually if it the distance is increasing then the depth of cut will be gradually reduces.

So, at the same time rebound of the particles and loss of energy gives the shallow depth of cut if the distance is now if the distance is more beyond upper value of standoff distance no cutting will take place. If the standoff distance is too high the pressure that carries from the nozzle exit will be dramatically reduces. Because of which there will not be sufficient energy for the abrasive particle to cut the material. The smaller standoff distances gives the deeper depth of cuts; obviously, if the nozzle distance and the work piece is too nearer what will happen it can cut deeper and deeper holes.

If the nozzle distance and this will be very high what will happen the velocity that will carry, the kinetic energy will be very less. So, it may cut very less depth of cuts. So, the kinetic energy will play a major role in terms of standoff distances if the kinetic energy of the particle is very less as the standoff distance increases. What will happen? The depth of cut achieved is very less.

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Variation in depth of cut with the penetration rate as you can see the penetration rate will rate means always it is a function of with respect to time. If you see that time with and the depth cumulative depth normally will gradually increases if you are machining time will increase; obviously. So, if you see the penetration rate if the penetration rate is if the time increases.

What is happening is the penetration rate; that means, that hardness of that particular surface will gradually increases because indenting strain hardening takes place and the surface at that particular position will goes on increase. At the same time if you are depth increases, what is happening? The nozzle tip distance of the standoff distance will also increase because of which, what will happen is the penetration rate will decrease.

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AWJM: Process Performance

- Can cut thick materials → 200 mm
- Kerf width decreases as w/p hardness increases
- Machined surfaces → no thermal / mechanical damage
- Machining of glass → stray cutting leads frosting of surface

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The process performance of abrasive water jet machining it can cut thick materials about to 200 mm, which is a good amount of depth of cut kerf width. The decreases with the work piece hardness increase increment; that means, that if the work piece hardness increases what is happening is the kerf width decreases. And machined surface no thermal and mechanical damage because there is no heat generation and other things. Machining of the glass normally stray cutting leads to frosting of the surface; that means that you can make some surface texture also along with the machining.

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AWJM: Advantages

- Practically no dust,
- High cutting speed,
- Multidirectional cutting capacity,
- No fire hazards and No thermal or deformation stresses,
- High quality of machined edge,
- Easy adaptation for remote control,
- Recycling of abrasive particles,
- Low power requirements,
- Almost no delamination,
- Reduced striations.

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So, the advantages of this particular process this is practically no dust as some of the people says at this particular point of time, I remember one of the scientist was explaining in one of the developed countries what is happening here is the dust generation. Suppose there was as asbestos company or some company the cutting was done with a slit sauce; that means, that very thin grinding wheels because of the this mechanical action what is happening is dust production is very high.

So, environmental concerns came and the company has to forcibly closed; for that purpose what is happening is later the same company came up with abrasive water jet cutting and water jet cutting techniques where if you instead of cutting with the slit sauce, now they are cutting with a water jets are abrasive water jets. Whatever the dust that is generated in the slits sauce based machining here it is not generated because the dust also carried away are captured by the water. That is a beauty about this process and this process is sustainable from the environmental point of you that is the beauty about this process.

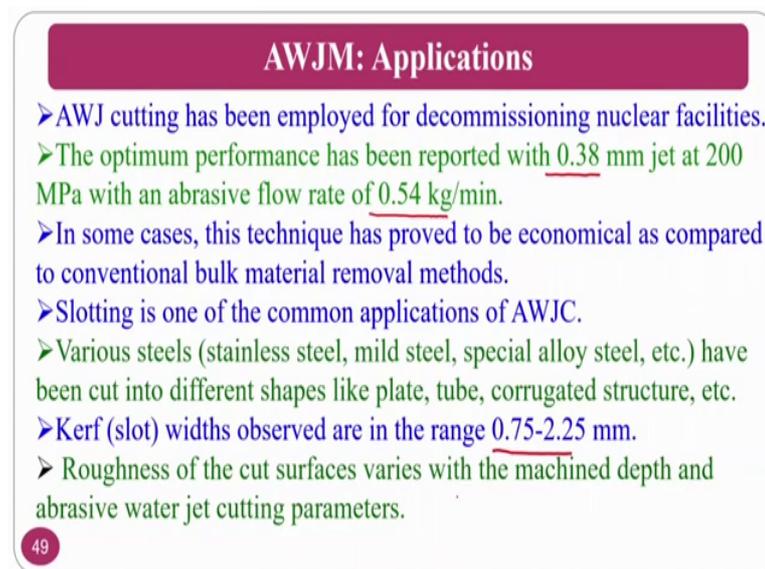
So, you should understand the environmental aspects also of this abrasive water jet machining. In this aspect I would like to appreciate this particular process from the operators point of view from the environmental point of view who are leaving around the surroundings. High cutting speeds you can cut with high speeds compared to abrasive jet machining compared to water jet machining the multidirectional cutting capacity you can cut in any direction inclined direction perpendicular to the surface and other directions no fire hazards no thermal or deformation stresses because water will act as a coolant as well as lubricant high quality of machined edge; that means, that there will not be any radio using or something because you are jet is moves along the direction of what you are giving because the jet is coherent enough so that we will get the perfect machined edges.

Easy to adapt and for the remote control; that means, that you can operate it inside the chamber or inside the system by controlling the CNC. Recycling of abrasive particles will be always there because there will not be adherence of work piece chip materials to this one because you have the water which lubricates abrasive particles and as well as coarse the workpiece material. So, there will not be any high temperature generation as well as the adherence of the workpiece material to the abrasive materials. Low power

requirements; if the power requirements are very low because you are a penetration depth is high compared to your abrasive jet machining.

If at all I can achieve 20 mm with abrasive jet machining if my power is P1 same 20 mm depth you can achieve less than P1 in abrasive water jet machining. That means, that your power requirement compared to abrasive jet machining power requirement compared to water jet machining will be always less in term in case of abrasive water jet machining. And almost no delamination and reduces the striations also.

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AWJM: Applications

- AWJ cutting has been employed for decommissioning nuclear facilities.
- The optimum performance has been reported with 0.38 mm jet at 200 MPa with an abrasive flow rate of 0.54 kg/min.
- In some cases, this technique has proved to be economical as compared to conventional bulk material removal methods.
- Slotting is one of the common applications of AWJC.
- Various steels (stainless steel, mild steel, special alloy steel, etc.) have been cut into different shapes like plate, tube, corrugated structure, etc.
- Kerf (slot) widths observed are in the range 0.75-2.25 mm.
- Roughness of the cut surfaces varies with the machined depth and abrasive water jet cutting parameters.

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Applications if you see abrasive water jet cutting can be employed for decommissioning of nuclear facilities, which is one of the good thing. Normally nuclear facilities and other things are very delicate to do the decommissioning and other things so if this particular process can do that application. So, the optimum performance has been reported normally with 0.38 jet at a 200 mega Pascal with the abrasive flow rate 54 k g per minute, this is one of the this is one of the researchers conclusions.

In some of the cases this technique has proved to be economical compared to the conventional bulk material removal method. That means, that conventional make grinding are conventional cutting under these the energy maybe very high and amount are the cost of the production also very very high. So, compared to this compared to that process abrasive water jet machining is economical.

Slotting is one of the common applications various steels, like stainless steel and other special alloys can be cut by abrasive water jet machining. Kerfs width normally observed are in the ranges of 0.75 to 2.25 mm which is a very good. If at all you are going for macro cutting or the milli cutting, roughness of the surface is very with respect to depth of cut and.

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AWJM: Applications

- ✓ Paint removal
- ✓ Cutting soft materials
- ✓ Cutting frozen meat
- ✓ Textile, Leather industry
 - Mass Immunization
 - Surgery
 - Peening
 - Cutting
 - Pocket Milling
 - Drilling

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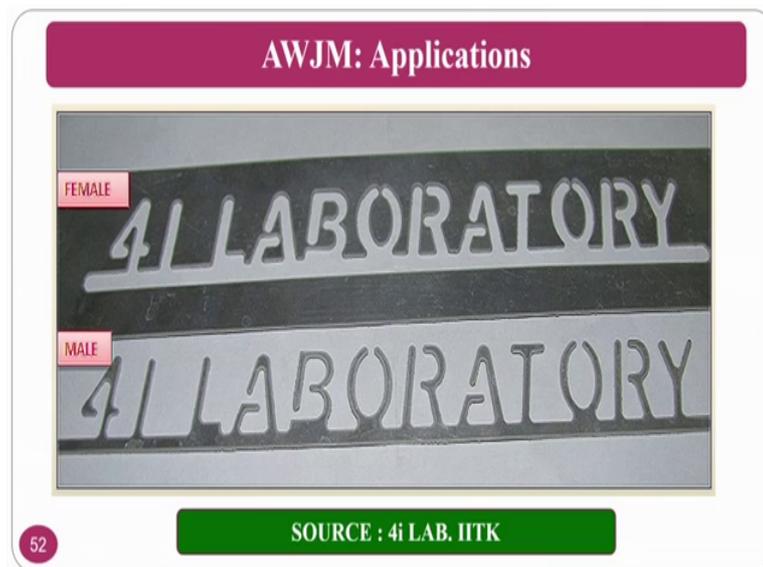
So, if we can see the applications normally you can use for the paint removal, cutting of soft material, cutting of the frozen meat, textile. Normally this you can cut the frozen meat and other things you can cut using not with abrasive water jets. You can cut with water jets and you can use for the peening cutting and other things.

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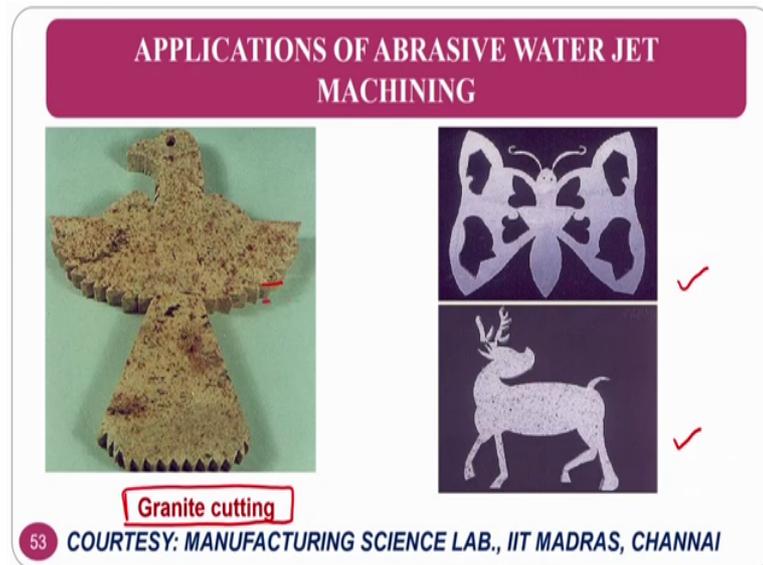
These are the some of the applications that are cut by the abrasive water jets very very fine cuttings also can be done using the CNC controls.

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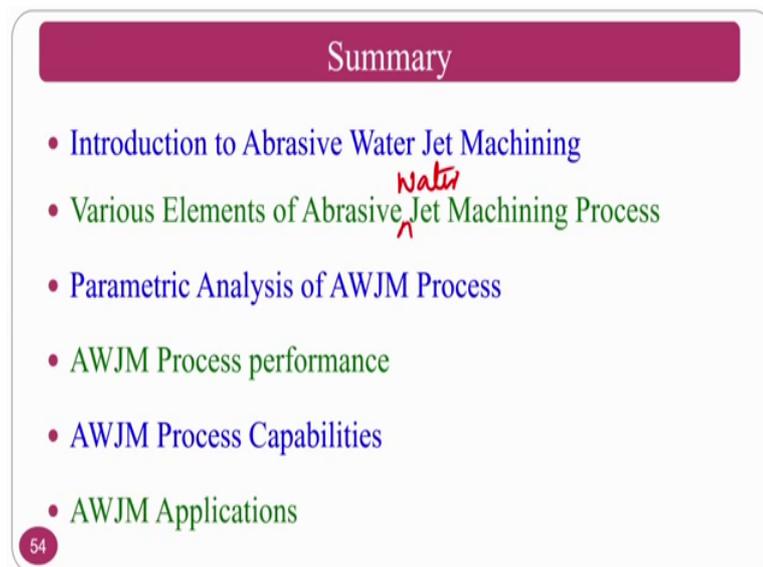
This is what the taken from professor V K Jains laboratory, which is a manufacturing lab and this particular cut is available as I said that up IIT Kanpur has this abrasive water jet cutting and in the 4 L laboratory.

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So, applications you can see this is the one of the application that is taken from IIT madras, thank you, to the professor Ramesh Babus. And these are the delicate cuttings you can see the butterfly or you can see the deer and all this things can be cut on metals. At the same time it can also cut on granite you can see the thickness of these particular surfaces. You can cut a very beauty full sculpture on the granite also.

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Summary of this particular class, you can see introduction to abrasive water jet machining is studied. Yeah various elements of abrasive jet machining, various elements

of abrasive water jet machining, is done. And parametric analysis of abrasive water jet machining process, process performance abrasive. Water jet machining process capabilities, and applications, we have seen. So, I am very thankful for Professor V K Jain for this sharing his slides generously without any hesitation. Because most of the slides I have prepared from Professor V K Jain slides. So, I am very thankful to Professor Vijay Kumar Jain once again for his kind support by sharing some of the slides.

Thank you, for your kind attention.