Advanced Machining Processes
Dr. Manas Das
Department of Mechanical Engineering
Indian Institute of Technology Guwahati
Module - 02
Lecture - 04
Abrasive Jet Machining

Okay introduction to the course on advance machining processes. Today we are going to discuss on a new type of advance machining process which is mechanical type of advance machining process that is called abrasive jet machining process.

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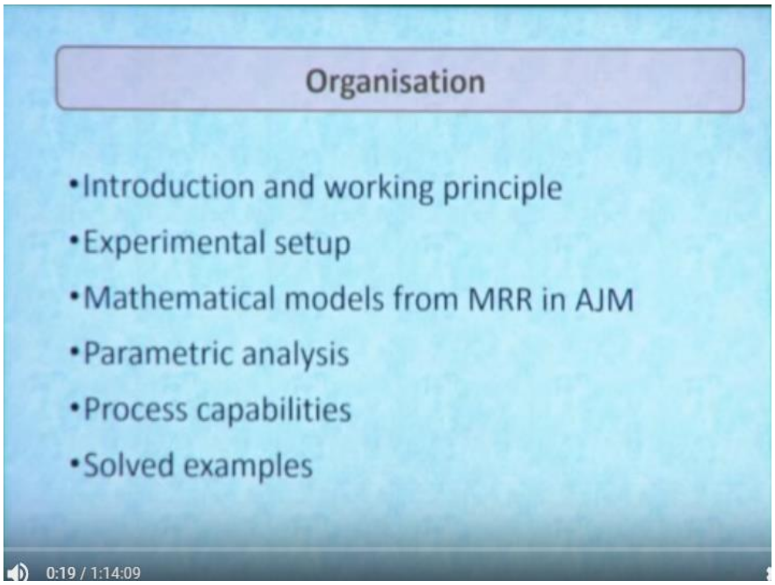

So this is the organization of my lecture. So first we shall discuss we shall introduce the process and then I shall discuss that what is the working principle of advanced this abrasive jet machining process. Then I shall discuss that experimental setup of abrasive jet machining. What are the different components of abrasive jet machining process. Then we shall discuss some mathematical modelings for calculating the MRR, material removal rate in abrasive jet machining process. Then we shall discuss the parametric analysis.

There are different parameters are there which buffers the process okay so what are the effects of different parameters on the material removal rate accuracy and different other (()) (00:56). Then we shall discuss about the process capabilities. What are the things we can do, what are the different applications of this abrasive jet machining process and after that we shall discuss some solved examples okay. So we shall take some examples and we shall discuss how to solve different kind of examples okay.

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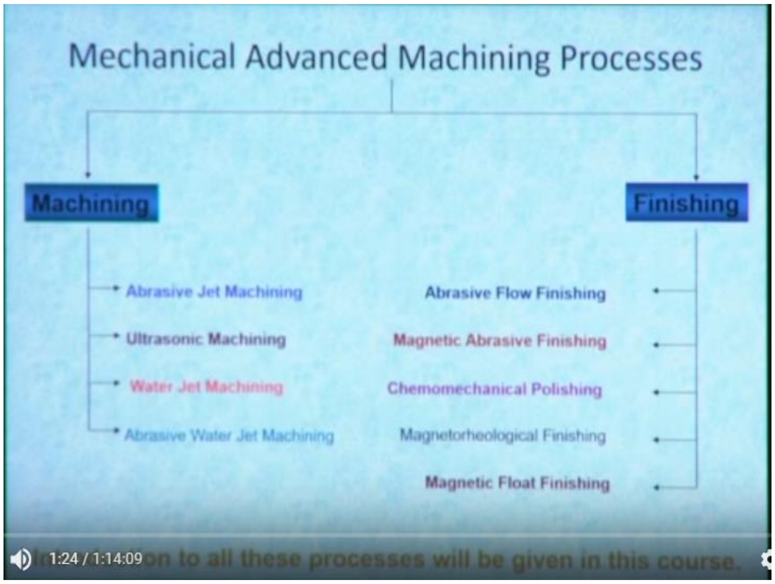

So now introduction to the process okay. So this is the mechanical type advanced machining process this abrasive jet machining, See it is a mechanical type of advanced machining process. So other mechanical type of advanced machining process are abrasive jet machining, abrasive jet machining, then ultrasonic machining, then water jet machining process, then abrasive water jet machining process okay.

So there are different finishing processes also, mechanical type finishing processes also okay. So these are basically nano finishing process. So these finishing processes are abrasive flow finishing process or AFM process, magnetic abrasive finish process or MAF process, chemomechanical polishing process or CMP process, magnetorheological finishing process or better known as MRF process and magnetic float polishing process and it is known as MFP magnetic float polishing process or magnetic float finishing process and this process is used for polishing balls which is used in (()) (02:32) okay.

So these are the different kinds of machining process mechanical type of machining process advanced machining process and finishing processes. So introduction to all these processes will be given in the due course.

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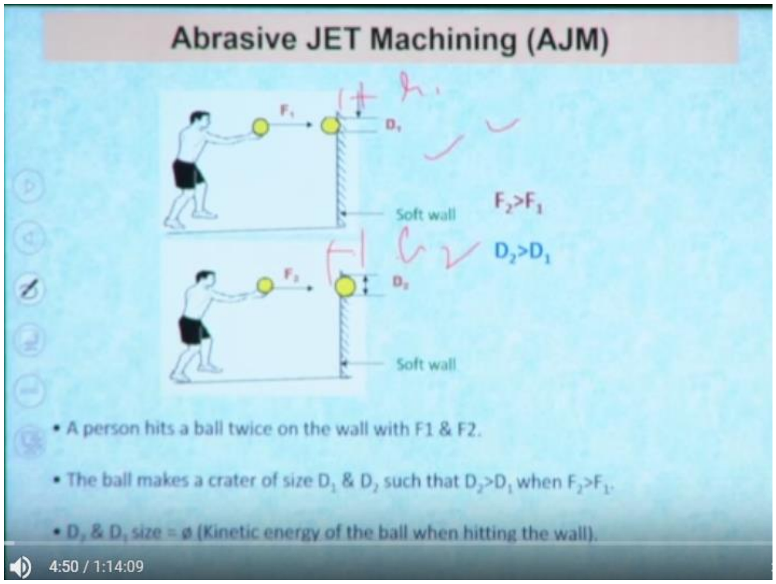

Now there is an interesting thing so we are going to discuss here. So to understand this abrasive jet machining process so we have to understand this one.

Suppose there is a person which is throwing balls. So first one in the first case he is throwing with a force of F1 and in the second case that same person he is throwing the same ball with a different force F2 and both the cases actually he is using same ball okay. So first case he is using force F1 and in the second case he is throwing a ball with force F2 okay.

So we can see from the figure, first figure you can see there, so here this diameter of indentation into that wall is D1 and it is indenting suppose it is indenting h1. So this is h1 here in the first case. But in the second case when he is throwing the ball with a force F2 which is very higher than F1, so this diameter of indentation is also bigger. Also this depth of indentation in the second case also it is higher so it is in this in this case he is hitting h2. So from this figure you can see that so h2 is this depth of indentation into the wall by the second second case with force F2 is higher than the depth of indentation h1 with the force F1 okay.

So a person hits the ball twice on the wall with a force F1 and F2 and the ball makes crater of different diameter D1 in the first case and second case with a greater diameter of D2 okay. So in this case D2 is greater than D1 when your force F2 is greater than F1.

So this diameter of depth of indentation this h1 and h2 and diameter of indentation of crater diameter also depend on so what is the kinetic energy. So at what kinetic energy or at what velocity that person is hitting the ball towards the wall.

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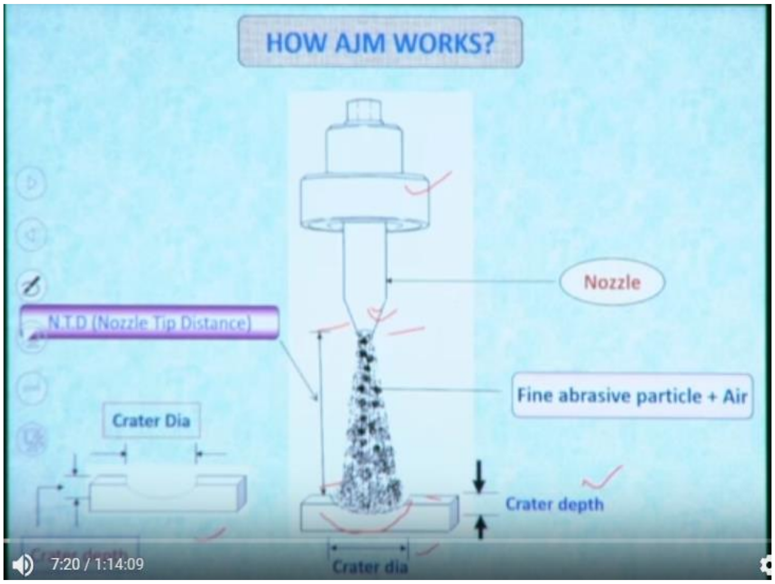

So in this figure we can understand or this working principle of abrasive jet machining process. So here this is the nozzle here. So this is the nozzle tip here. So through this nozzle air and abrasive particles. So you can consider air as a media okay. So instead of air you can consider any kind of inert gas also okay so like nitrogen, argon, helium, so any kind of inactive gas you can consider as the base media and the abrasive particles. So these abrasive particles are actually in the micron size. So these abrasive particles it is homogeneously mixed inside a mixing chamber, it is coming outside through this nozzle okay.

So from here to here this is called nozzle tip distance or stand of distance okay. So these abrasive particles in the base media of air, it is coming with a very high velocity. So this abrasive velocity or air velocity here around 300 meter per second or more than 300 meter per second okay. So this fine abrasive particles and air mixture of this it is coming outside through this nozzle with a very high velocity.

When it is impinging into that workpiece surface it is generating a crater here, so it is generating a crater inside the workpiece surface. So here this distance from here to here this distance is called nozzle tip distance or we can consider this one as a stand of distance also okay. So here this is the crater there, this is the crater there okay. So due to this impingement of this abrasive particles into the workpiece surface it is generating a crater. So it is the shallow crater is generated. So this one is the crater depth here and this is the crater diameter, it is generating here okay.

So now in this figure so this is an accelerated view of that crater whichever is generated into the workpiece surface okay. So you can see that this is a suppose if you consider a circular nozzle, in that case a hemispherical crater will be generated and in case of suppose if you consider a square nozzle square cross-section nozzle so in that case that crater will be of this crater will be so you have to mention this crater in terms of this width of this crater okay and when you are using a circular cross-section nozzle in that case a hemispherical crater will be generated so it can be represented by a diameter of this crater diameter and crater depth.

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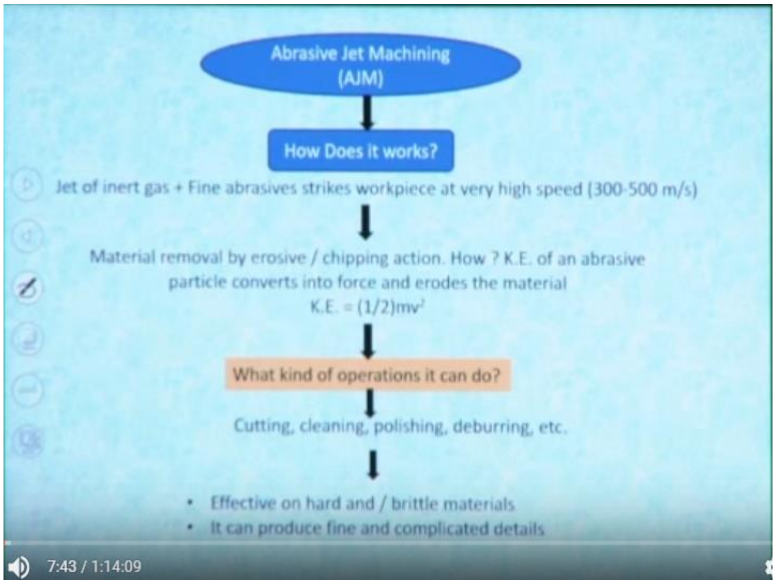

So now what is the working principle of abrasive jet machining process. In abrasive jet machining process high velocity abrasives in a media of air it is impinging on the workpiece surface okay so when it is impacting on the workpiece surface it will make a brittle fracture or it will generate a small crater into the workpiece surface.

So this small crater thousands of craters are generated because of hitting of thousands of abrasive particles per second. So this thousands of small small craters are generated and after some time it will take the profile of the cross-sectional area of this nozzle okay. So it will take the profile of the cross-sectional area of the nozzle okay. So it will make a hole or it will do the machining operation on the workpiece surface okay. So abrasive jet machining how does it work?

So jet of inert gas plus fine abrasive particles strikes the workpiece surface with a very high velocity 300-500 m/s. So because it is coming with a very high velocity because of their kinetic energy okay so it it stores the energy. It is in in the form of kinetic energy (()) (08:55) this abrasive particles are touching impacting into the workpiece surface it will erode the surface erode the surface of the orifice surface and because of this heating operation okay so it will erode the materials in terms of small small chips. So this kinetic energy can be calculated as half mv square where m is the abrasive particle mass, mass of individual abrasive particles and v is the velocity of individual abrasive particles okay.

So now kinetic energy of one abrasive particle is like this okay so now thousands of abrasive particles are hitting into the workpiece surface and it will remove the vacuum from the workpiece surface. So what kind of operation it can do. So it can do the cutting operation, cleaning operation, polishing operation, and also deburring operation. So these are the different operations can be done by a high velocity jet of abrasive particles.

So here one thing is that I want to explain so this deburring operation is that suppose we are doing a drilling operation. So after drilling operation if we are making a through hole after drilling operation suppose this is the workpiece you are making a hole, so this is the grill door so after making the hole at the end at the end of this workpiece okay so after making the hole so you are making along this direction so at the end actually this kind of bars actually generated.

So these bars actually has to be removed otherwise this when this workpiece is is assembled with another workpiece so these bars actually will not allow to make them propelling air okay. So also it may also damage or make a cut marks into the operator to the operator who is doing this drilling operation or assembling operation.

So before using this part for assembling for the with another component these bars has to be removed so this process is called deburring operation. This abrasive jet machining process is very good for removing this kind of bars so it is useful for deburring operation. We can use this one in polishing, for cutting operation, and for cleaning operation also okay.

So for different operations we have to use different velocity of jet because for erosive action or for making the brittle fracture we need the different kinetic energy or different velocity or different kinetic energy of this abrasive particles. So this process is very good or effective for hard and brittle material okay. So it is not that much effective for the for the ductile material okay. So it is very good for harder material. So we shall discuss later how this process is very good for brittle material, why it is not good for ductile material.

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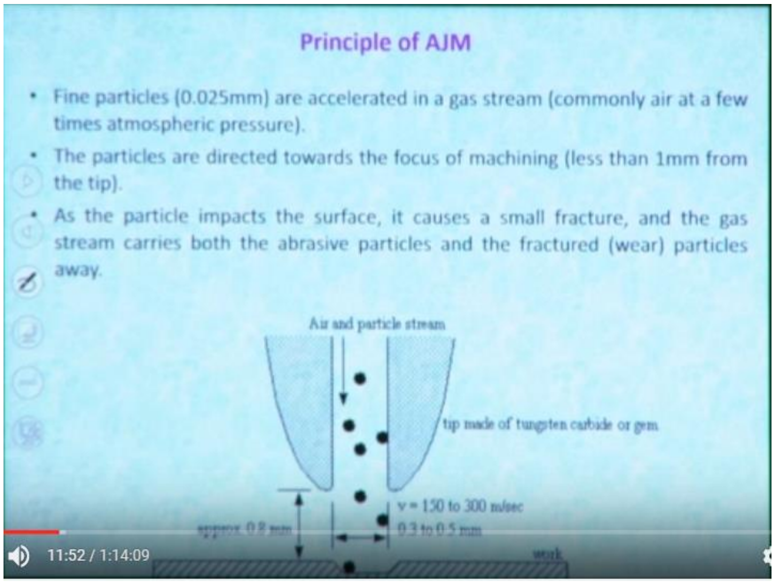

So this is the principle again. So fine abrasive particles in the size of this abrasive particles is the 25 micron here are accelerated in a gas stream of inert gas propelling air is used. So so this atmospheric pressure is at a very few times higher than the means this pressure of this jet is few time higher than the atmospheric pressure. The particles are directed towards the focus of machining less than 1 mm from the tip so this stand of distance it is less than 1 mm. So in this figure it is shown it is 0.8 mm okay.

So now if we increase the stand of distance what will happen? So this accuracy will be reduced okay. So so when this particles are in the gas medium or air medium when it is coming it is coming with a very high velocity 150 to 300 meter per second and this radius or diameter of the this diameter of this nozzle okay so this nozzle diameter it is coming through a very small diameter okay. It is 0.3 to 0.5 mm and also this nozzle tip distance or stand of distance it is maintained less than 1 mm okay.

So when this high velocity jet is coming so it will do the machining actions. So this particle impacts to the surface it causes a small fracture okay and gas stream carries away the both the abrasive particles and also the whatever chip forms due to the fracture. So these both the things are actually carried away by the high velocity jet of air.

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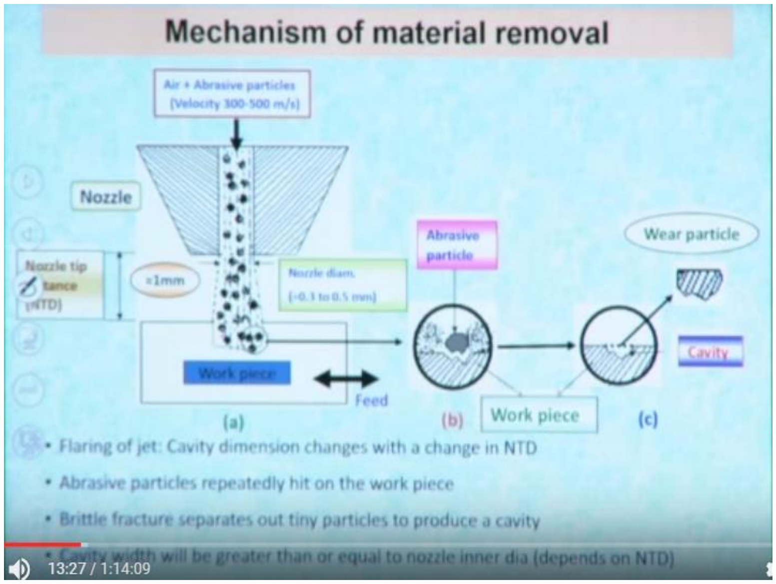

So again it is shown in this figure. So it this is the nozzle here. So the abrasive particles from air is coming with a very high velocity. So this distance nozzle tip nozzle diameter is 0.3 to 0.5 mm. This stand of distance is 1 mm here okay. So this workpiece actually this nozzle actually it is fixed to the machine or this workpiece is actually attached to a CNC table okay.

So if this workpiece is attached to a CNC table okay so it can be moved in x direction, it can be moved in the y direction okay. So in this x and y direction if this table is moving, so on this table we have fixed our workpiece. So any kind of cross-section can be machined by this abrasive jet machining process. Also this nozzle also can be tilted with a with a normal so it can be tilted also.

So by tilting this nozzle any 3D surface also we can derive okay. So these abrasive particles when it is touching to the impacting into the workpiece surface here it is shown here so it is making the brittle fracture from the workpiece surface and this shape of the abrasive particle it is suppose this is the tool here or this is the this is the abrasive particle here so this wear particle actually taken out from the workpiece surface it is carried away with the jet of airs.

So there is a flaring of jet, flaring of jet means this this air abrasive particles it is coming with a very small diameter. When it is in contact with the air so there is a divergence of this gas okay. So there is a divergence of this gas. Suppose if we increase the stand of distance here so in that case what will happen if we increase the stand of distance in that case due to this divergence of this gas this air and abrasive particles actually it will flare okay.

So this based on your stand of distance what will happen? Your diameter of this workpiece or crater diameter will also increase okay. So if we now increase the increase the stand of distance your this crater diameter rule also increase proportionally. So these abrasive particles repeatedly hit on the workpiece surface brittle fracture separates out the tiny particles to produce the cavity. Cavity width will be greater than the equal to the nozzle diameter. So because of this clearing action of this abrasive and air jet so this cavity diameter or crater diameter will be greater than the diameter of the nozzle.

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So there are 2 mechanisms I told that on this it is useful for hard and brittle material. So because of this in brittle material these are the mechanism occurs, indentation rupture, elastic-plastic deformation, critical plastic strain, radial cracking and propagation of surface energy criteria. So these are the things during brittle erosion process particle impact produces different types of gas and chipping with negligible plastic deformation.

So because of this brittle fracture so and because of these operations okay so materials are easily removed on the brittle workpieces. But in case of ductile material, so this brittle fracture will not will not happen but in case of ductile material also there is nominal material removal rate happens because when these abrasive particles are impacting into the workpiece surface repeatedly into a small area so there is a strain hardening will occur okay.

So there is small plastic deformation into the same into that localized zone and when more many abrasive particles are impinging or impacting into the small area there will be a more plastic deformation and after some time there will be a strain hardening into that area okay. So it will become so if the strain hardening of material so after some time it will become brittle into that localized zone and when next the abrasive particles hit into that zone because of this it will become it has become hard so it will remove the material because of this brittle fracture okay.

So this is the procedure for ductile fracture. During impact when the yield strength of this material is locally exceeded plastic deformation takes places in the vicinity of the impact. After multiple impacts a plastically deformed surface layer may form near the eroded surface and therefore the yield strength of the material increases due to the strain hardening.

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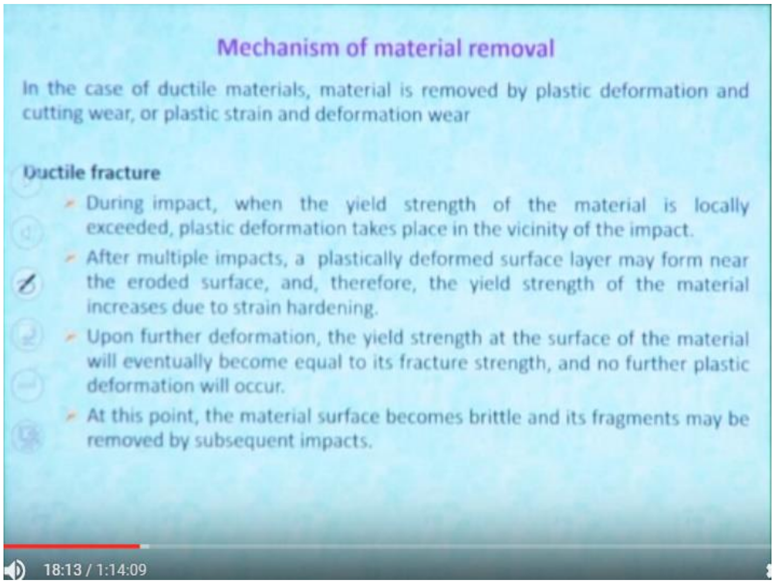

Upon further deformation the yield strength at the surface of the material will eventually become equal to its fracture strength and no further plastic deformation will occur. So at this point material surface becomes brittle and its fragments may be removed by subsequent impacts.

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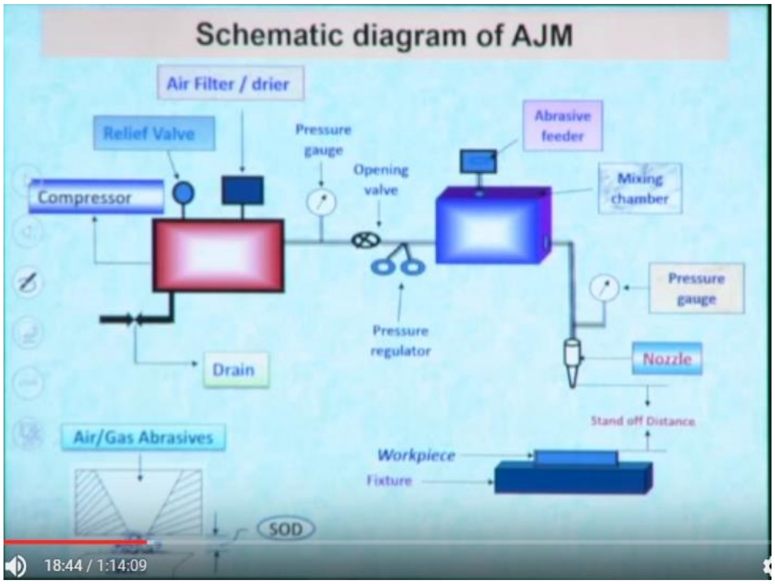

So now we shall discuss what are the different components of abrasive jet machining okay, so experimental setup of abrasive jet machining process okay. So now this is the schematic diagram of this process. Here we can see that so here we need a compressor. So why we need a compressor because to generate the high velocity jet we need a very means we need a compressed air okay. So for making this for generating this compressed air okay we need a compressor.

So this is the compressor here where pressure which is multiple of means very high pressure is generated in in this compressor okay which is multiple of atmospheric pressure okay. So here there is a relief valve so when this pressure is more than a certain critical value through this relief valve so this highly pressurized air can be removed okay released so there is a drainage also is there to release the high pressure air okay.

So now one more thing is that there is the air filter drier. Why we need air filter drier because when this compressor actually it is taking air from the atmosphere so in that atmospheric air there may be some moisture content may be there okay. So if there is some moisture content is there so because of this moisture when abrasive particles are mixed into that mixing chamber with that moist air okay so at that time what will happen these abrasive particles will be agglomerated.

When this agglomerated abrasive particles are coming through or exiting through the nozzle at that time because there is a very small gas small diameter is there it will hit the inner surface of the nozzle okay. When it will hit that agglomerated particle will hit the inner surface of the nozzle it will damage the it will it will do the wear wear out of this nozzle okay. So this life of the nozzle will be reduced. Also when this agglomerated particle coming outside and it will hit the workpiece surface because of this a lump material of abrasive particles okay so it will remove unevenly from the workpiece surface. So air filter and drier is required to remove the moisture from the air.

So there is a pressure waves is there to control the pressure a compressed air which is coming outside the compressor okay. So there is a opening valve is there and pressure regulator is there pressure regulator to regulate the pressure which is coming from the compressor. Now there is a abrasive feeder is there.

So abrasive feeder is required to feed the quantity of the abrasive flow rate into the mixing chamber. So there is a mixing chamber. In that mixing chamber so this is the mixing chamber here. In that mixing chamber abrasive particles are coming from this abrasive feeder and compressed air is coming from this compressor.

So here there is a homogeneous mixing of this abrasive particles and air is there okay. So now this abrasive particles are feeded into this compressed air from a feeder. So this feeder maybe a vibratory kind of feeder maybe there okay. So this vibratory feeder is it can be fed through a cam mechanism okay through a cam mechanism it can be this vibration can be generated. So based on this vibration your this abrasive flow rate can be maintained into this compressed air okay.

So now from this mixing chamber when this homogeneous homogeneously mixed abrasive is coming is coming and again the valve pressure regulator is there to regulate the pressure of air abrasive mixture. Now after that there is a nozzle is there. So this it is this abrasive here homogenous mixture of abrasive and air it is coming through this nozzle here and this is the workpiece ultimately it will hit the workpiece.

So one interesting thing is there actually. What I told in this last slide, so because this abrasive particles this divergence of this abrasive particle. So it is coming in contact with the air okay outside this nozzle so there is a flaring of this flaring of this abrasive mixture okay. So there is a divergence of this abrasive workpiece mixture.

So suppose you are doing a very accurate cut in that case to reduce the flaring action we have to reduce the depth of this stand of distance or nozzle tip distance. So we have to maintain the nozzle tip distance in case of cutting of accurate accurately cutting of the workpiece okay so you have to reduce the nozzle tip distance as less as possible okay.

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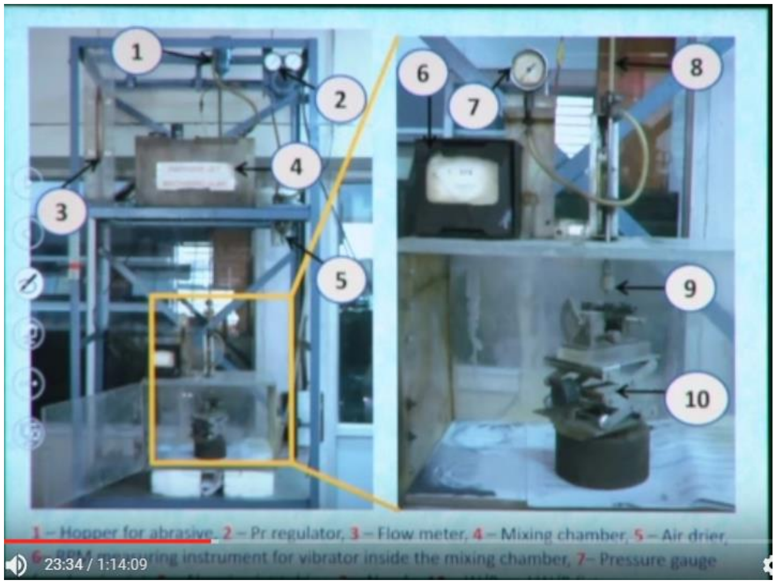

So this is the experimental setup available at IIT Kanpur okay. So this valve here this is the abrasive hopper okay. So here there is a mix means abrasives it is kept abrasive over here so there is a vibrating mechanism is there. So 2 is the pressure regulator here 2 to regulate the pressure from coming from the compressor and 3 is the flow meter okay. So this is the flow meter of this compressed air and then 4 is the mixing chamber. In this mixing chamber this air and abrasive particles are homogeneously mixed.

Then 5 is the air drier here to reduce the moisture, to remove the moisture from the compressed air, air coming to the compressed air and 6 is the this 6 is the RPM measuring machine measuring instrument for vibrator inside the mixing chamber. So in that mixing chamber actually one vibrator is kept to regulate the flow rate of abrasive okay, 7 is the pressure gauge here again okay and now this 8 is the nozzle here. So this is the nozzle, so this is the nozzle, 9 is the nozzle and this 8 is actually it is a connecting pipe okay. So through this connecting pipe actually air abrasives are coming and 9 is the nozzle here and 10 is the workpiece holder.

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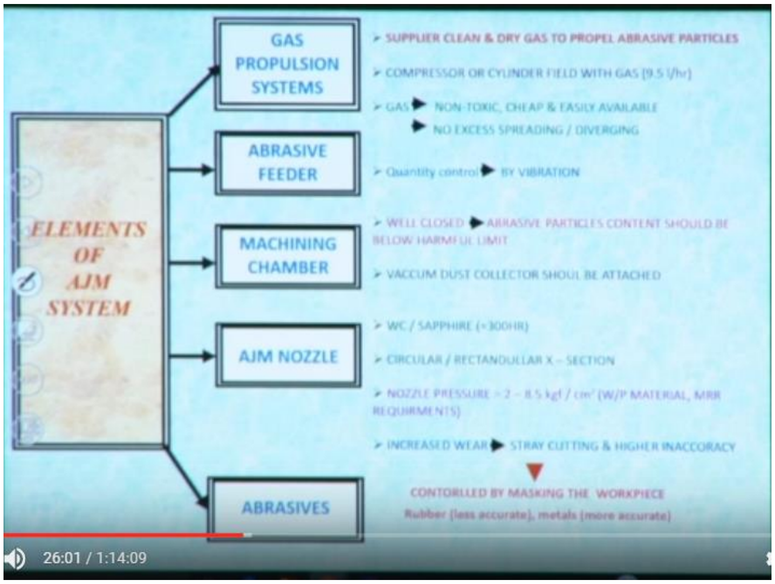

So what are the different elements of abrasive jet machining. So first one is the gas propulsion system. Second is the abrasive feeder system. Third one is the machining chamber and then fourth one is the abrasive nozzle and fifth component of this abrasive jet machining process is abrasives okay so these are the different components.

So in this gas propulsion system supply of clean and dry gas to propel the abrasive particles are carried out. So here there is a compressor or cylinder filled with gas here 9.5 l/hr of gas is required. So gas should be non-toxic okay. So it should be non-toxic, it should not create any reactions to the workpiece okay. Also this whatever whoever is the operator is there he may be in contact with this gas okay so if it is toxic gas it may generate the problem health problem to the operator. So this gas should be non-toxic and it should be cheap.

So because 9.5 l/hr this much is the requirement for this gas okay so if it is not cheap then this machining cost will be very high. So that is why generally air is used actually for this gas and it should be easily available. So no excess spreading or diverging. So here to consider a gas which is not spread so there is a which does not have a diverging property. So this gas should not spread very much okay. So in that case inaccurate cutting will be there okay tipper cutting will be there. So to reduce the tipper cutting you have to choose a gas which has less spreading or diverging property.

So quantity control, so this abrasive feeder, this use of this abrasive feeder is to control the quantity of abrasives into the mixing chamber by vibrating okay. So one cam mechanism is used okay so to vibrate the abrasive feeder. So this machine chamber it should be well closed. So abrasive particles contained should be below the harmful limit and vacuum dust collector should be there inside that machining chamber so because after machining these abrasive particles may be crushed okay so now dust particles may be generated so these dust particles if it comes to the operator okay so it will generate the health hazard to the operator okay.

So that is why this there should be a, this machining chamber should be closed properly closed.

So whatever dust particles are generated, so it should not come outside this machining chamber. Also so this there should be a vacuum dust collector to collect the whatever dust is there, it should be collected. Now AJM nozzle, so nozzle is the main thing.

So here high pressure gas is coming okay so while exiting this nozzle there will be high velocity gas okay. So inlet to this nozzle is high pressure gas okay so and the outlet to this nozzle is high velocity gas. Because we do not need high pressure gas we need a high velocity gas to increase the kinetic energy.

So there are different kinds of nozzles are used. So among these nozzle material tungsten carbide and then sapphire is used. So sapphire has actually very high life. So it has 300 hour of life. So this abrasive nozzles this air nozzles abrasive jet machining nozzle there are different configurations are there. Based on our requirement so we can use circular cross-section or we can use a rectangular cross-section or we can use any kind of cross-section to make the prototype of the workpiece to be machined okay into the workpiece.

So nozzle pressure is generally maintained 2-8.5 kgl per cm square. So this pressure actually varies okay so based on material, what kind of material we are going to machine and what will be the material you (()) (29:22) okay so based on that so what is the material removal rate, what kind of material we are using, what kind of accuracy you are we need so based on these parameters actually we have to select the pressure, nozzle pressure.

So to reduce the increased wear of stray cutting or and so because of this actual stray cutting this whatever material is cut on the workpiece surface okay so it maybe may not be accurate okay. So this is due to the stray cutting okay. So this stray cutting can be actually stray cutting can be controlled by using the mask. By masking actually we can control the stray cutting.

So this rubber may be used. So this is less accurate okay and metals like stainless steel plate may be used on the workpiece surface or we do not need any machining. Suppose this is the jet is coming so from this nozzle this jet is coming so this is the nozzle. So this jet is coming here so this is the workpiece surface and we need drilling on this portion. So we can put a mask over here okay so we can put a mask over here so that in this zone there will not be any machining although jets are impacting into the surface okay. So by that way so by using a mask we can control the we can control the stray cutting of the by this abrasive jet machining process.

So different elements of abrasive jet machining we are discussing now. So now last element is the abrasive particles. So this is the this abrasive particles are actually impacting into the workpiece surface because of this impacting of this abrasive particles machining is going on okay. So there are different kinds of abrasive particles. So this is based on their actually hardness okay. So alumina is the soft material, soft abrasive particles. Silicon carbide is harder than this alumina okay.

So there are other abrasive particles are there glass beads, sodium bicarbonate, etc., boron carbide, diamond okay. Based on the requirement actually different kinds of abrasive particles are used okay. So different abrasive particles has they have their different hardness. So if we are using harder material so we have to use the harder abrasive particles.

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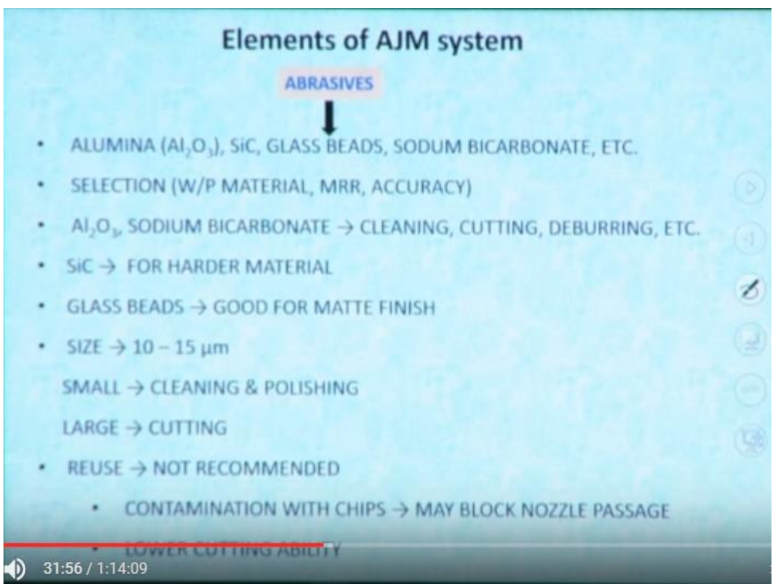

So selection of this abrasive particles entirely based on your workpiece material and also it is based on material removal rate. Suppose if we want to get a higher material removal rate we have to select bigger size abrasive particles and harder abrasive particles. Suppose we need a high accurately high accurate machining so in that case we have to reduce the abrasive particle size okay.

So by reducing the abrasive particle size we can make a accurate workpiece surface okay. So there are different abrasive particles, they have different applications like alumina or sodium bicarbonate. These are used actually for cleaning purpose. Cutting, deburring, mostly these are actually because they are very soft abrasive particles mostly they are used for cleaning, cutting, deburring operations.

Like silicon carbide it is very it is used for very harder material because its hardness is very high its hardness is more than aluminum oxide. Glass beads it is used for matte finish okay. Size of this abrasive particles are like 10 to 15 micron, these are smaller size. So this smaller size abrasive particles are used for cleaning and polishing purpose okay. Suppose some layers of grease is there on a workpiece surface this layer of grease or oil layer can be removed by this abrasive jet machining process okay so in that case we shall use smaller size abrasive particles because in that case this kinetic energy will be less so we need a less kinetic energy to remove the grease or oil here from a workpiece.

Large size abrasive particles are used for cutting because we have to do the brittle fracture high brittle fracture so we need a large size, bigger size abrasive particles. So use of this abrasive particles are not recommended because this abrasive particles are very cheap so that is why it is not used. Also when this abrasive particle is impacting into the workpiece surface most of the abrasive particles become actually crushed so that is why they do not have the this they do not have the same shape okay so it it becomes small size abrasive particles okay so this what about the sharp edge is there. It will become worn out okay.

So this same abrasive particles are also not used. So also this tiny chips are actually generated from the workpiece surface because of brittle fracture. These chips are actually mixed or mixed with the abrasive particles and it is taken away by the high pressurized high velocity jet okay. So when these chips are actually formed these chips actually it is bigger than its shape its size is bigger than this abrasive particles so this is the this is the formation of this chip when if we reuse it so this chip will clog into the abrasive into the nozzle okay.

So if it is clogging into the nozzle so in that case what will happen? So it will damage the nozzle okay so because this nozzles are actually very costly okay so that is why we do not want this nozzle to be clogged by because of this chipping action so so reuse of this abrasive particles are not recommended. Also these abrasive particles have lower cutting ability because this it will be worn out after some time.

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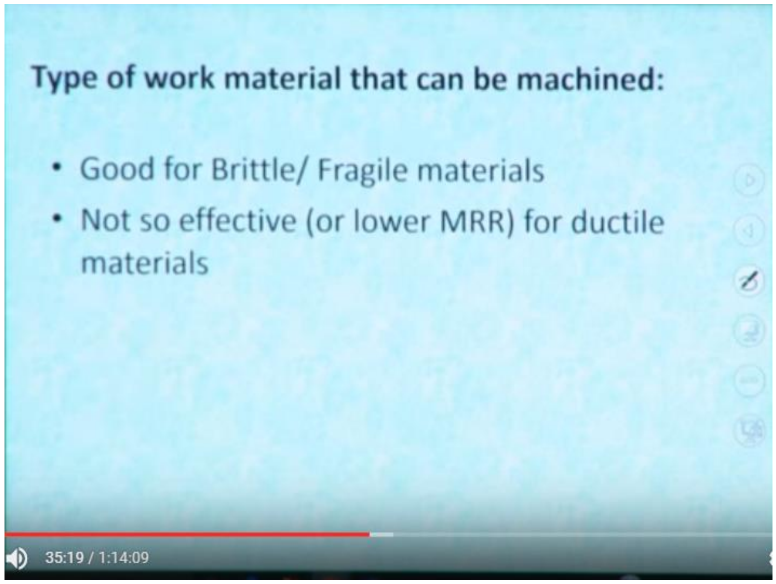

So type of work material can be machined so already I told so very good for brittle and fragile materials. Also it is good for machining thin materials also because there is no direct contact of this tool to the workpiece. Only these abrasive particles are in contact with the workpiece. Also there is no heat generation because whatever heat is generated although it is very less it is taken away by the high velocity jet of air. So this process is not so effective for machining of ductile materials.

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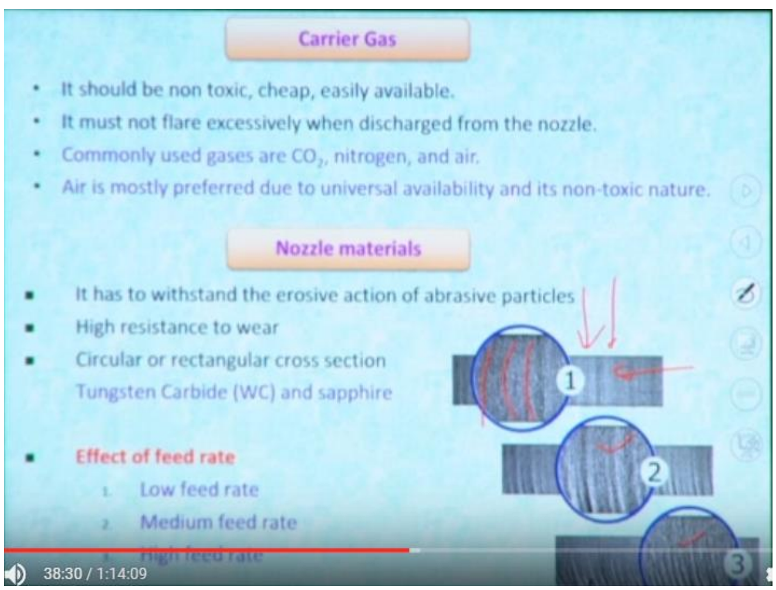

So carrier gas, so what are the properties of this carrier gas. They should be nontoxic, cheap, and easily available. It must not flare excessively when discharged from the nozzle. So commonly used are carbon dioxide, nitrogen, and air. So here one thing I have to mention that oxygen is not used as a carrier gas because it has a very high fire hazard okay. So that is why oxygen never used as a carrier gas in case of abrasive jet machining. So air is most mostly preferred due to the its universal availability and nontoxic in nature.

So nozzle material it this nozzle also should withstand the erosive action of this abrasive particles. Because this high velocity jet of abrasives it is also impinging or impacting into the side of the nozzle. After some time it will wear up. So these nozzles has a certain life. So it should have, this nozzle material should have high resistance to wear. It has a circular or rectangular cross section. So there are different kinds of nozzles nozzle materials are used. First one is the tungsten carbide and second one is the sapphire.

So one interesting thing I am going to show here so this effect of feed rate feed rate means at what rate actually this workpiece actually moves in x or y direction. So because this this workpiece is fixed on a table xy table and this is table is moving in x and y direction depending on the what kind of workpiece you are making okay.

So at what rate this table is moving in x and y direction that is called the feed rate. So here there are 3 examples are there. One is at low feed rate because this abrasive jets are actually moving vertically. So here you can see this this striation marks are there and this table actually it is moving along this direction, in this x direction okay so vertically this abrasive jets are coming and this table is actually moving in x direction okay. So this is the case 1.

Here we can see that at low feed rate in case 1 actually this striation marks is actually very less but when you are using high feed rate okay so this is the medium feed rate this one is the high feed rate. At high feed rate we can see that this striation marks are actually prominent. So because we are moving this jet abrasive jet with a very high velocity okay so this kind of striation marks are actually generated in case of abrasive jet machining process.

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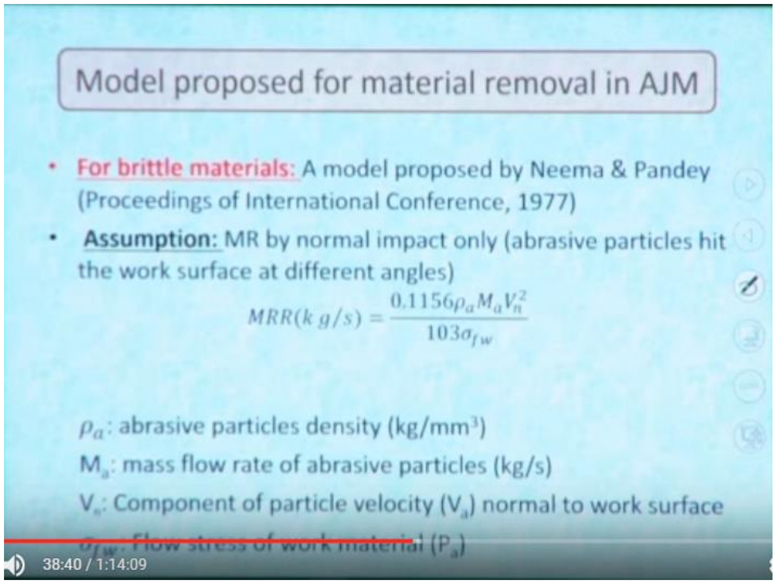

Now we shall discuss some models of material removal mechanism or abrasive jet machining process. So there are 2 models we shall discuss. So first one is the for brittle materials. So this one is this model was actually proposed by Neema and Pandey in 1977 and it was actually published in Proceedings of International Conference okay.

So this assumption is that material removal by normal impact only okay so they are considering only normal impact by this abrasive particles. They are not considering any inclined impact of this nozzle actually vertically normal to the workpiece it is not inclined okay. So that is why material removal is by normal impact only and abrasive particles hit the workpiece surface at so abrasive particles does not hit the workpiece surface at different angles, only that only at 90 degree normal angle it this abrasive particle will hit into the workpiece surface.

So material removal rate in kg /s it can be given as 0.1156 this rho a M a then Vn square 103 sigma f w okay. So here sigma f w is the flow flow stress of this workpiece material, flow stress of this workpiece material, rho is the abrasive particle density, M a is the mass flow rate of abrasive particle.

So at what rate actually this abrasive particles are mixing into the mixing chamber or into the air. So this is the mass flow rate of this abrasive particle is given as M a, component of particle velocity normal to the work space that is Vn is the normal velocity okay component of particle velocity normal to the workpiece surface that is the Vn here.

So here from this equation we can calculate if we know the density of this abrasive particles and then mass flow rate of this abrasive particle and normal velocity of this abrasive particles and flow stress of this workpiece material we can easily calculate the material removal rate.

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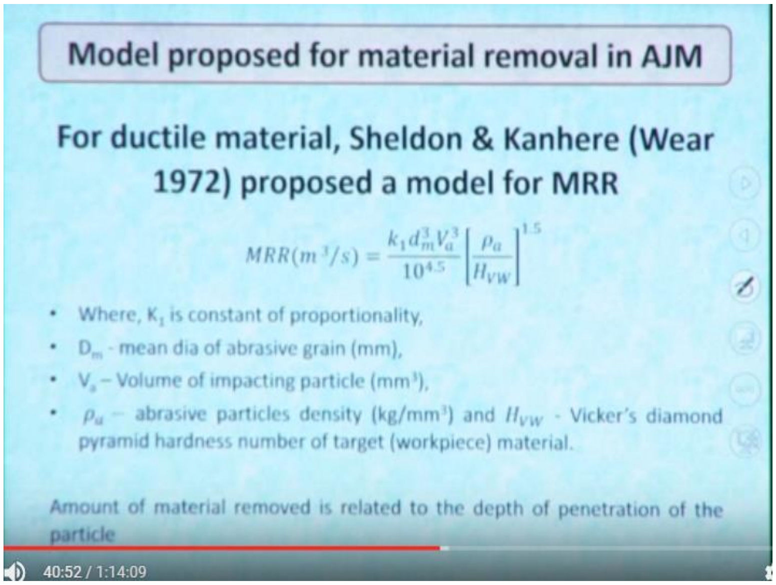

So for ductile material also Sheldon and Kanhere they proposed a model for calculating material removal rate for ductile material. So it is published in Wear in 1972. So here material removal rate it is it is proposed in this this is millimeter cube it should be millimeter cube. So this material removal rate is millimeter cube per second. So equal to k1 d suffix m cube then V suffix a cube by 10 to the power 4.5 multiplied by rho a by Hvw.

So here k1 is the constant of proportionality, d m is the mean diameter of this abrasive grain and then volume of impacting velocity is V a, rho a abrasive particle density, and Hvw is the Vicker's diamond pyramid hardness number of target material. So amount of material removed is related to the depth of penetration of this particles.

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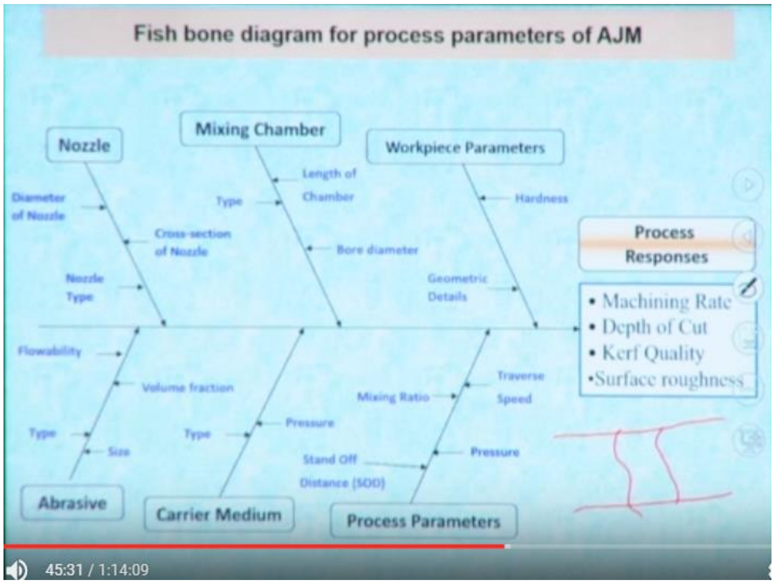

So now we have to do the parametric analysis. What are the different first we have to find out what are the different parameters are there and then we have to select what is the effect of parameters on process performance. So this is the fish bone diagram for this process parameters for different process parameters in abrasive jet machining process.

So here first one is the nozzle. So nozzle if we put the nozzle first thing will come what is the nozzle diameter okay. Then what is the cross section of this nozzle? Is it circular cross section or it is rectangular cross section and then nozzle type. So this nozzle is tungsten carbide or sapphire what kind of nozzles we are using. Second one is the abrasive. So abrasive type, size, and volume fraction flow (42:49). So these are the different parameters for abrasives okay.

So now third parameter is the carrier medium. So this carrier medium, type of this carrier medium, then pressure of this carrier medium okay. After that this fourth parameter is the mixing chamber. Mixing chamber, length of the mixing chamber, type of mixing chamber, bone diameter of this mixing chamber okay. Then workpiece parameter is workpiece hardness, workpiece geometric details okay.

So now machine process parameters are there. What are the parameters we can control, we can use to control the machining process okay. So first one is the stand of distance, second one is the mixing ratio. Mixing ratio is volumetric flow rate of this abrasive divided by volumetric flow rate of air. So that will give the mixing ratio. So this mixing ratio we can change by changing the volume flow rate of this abrasive particles okay.

So second parameter is the stand of distance or nozzle tip distance. So by changing this stand of distance we can change the machining condition.

Other one is the traverse distance, traverse state. At what state actually we are moving the workpiece. Then so another parameter is the pressure. So from this compressor actually we are generating the compressed air. So this pressure can be regulated from the compressed air or pressure regulators also there so from there also we can regulate the pressure.

So these are the input parameters for this abrasive jet machining process. So what are the output parameter? Output parameter is the machining grain. So this machining grain already we have discussed. It can be calculated as material removal rate or it can be calculated as penetration rate. Suppose you are making a hole. So what is the volume of material is removed that can be presented as millimeter cube per second.

So that is called volumetric material removal rate or penetration rate means when you are making hole at certain rate actually this distance, the depth of hole actually it is increasing. So that is called the penetration rate. Kerf quality. Kerf quality means when suppose you are making a blind hole or through hole okay so suppose this is the workpiece this kind of hole cross section, so after making the hole through hole we can take a cross section of this hole so how accurately it should be perfectly straight line.

So how accurately we are making this kind of holes so that is actually will give the kerf quality. So in this case if you see it is not a straight line like here. So this so this is actually kerf inaccurate kerf is generated kerf is generated. So this kerf quality actually based it depends on the different machining parameters. Also fourth one is the fourth output parameter is the surface roughness. So after machining after cutting the workpiece so we can we can generate we can measure the surface roughness or that surface also will depend on the different parameters okay. So these are the different parameters for the abrasive jet machining process. So we shall discuss one by one of these parameters.

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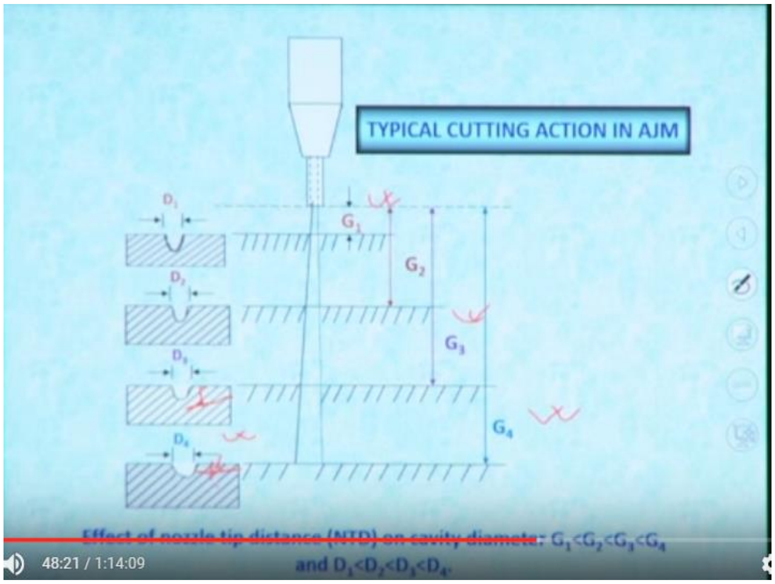

So here typical cutting action of this abrasive jet machining. Suppose if we there are different stand of distance is there. So this distance is stand of distance. First we shall consider this G1 is the stand of distance. So stand of distance we have discussed from the bottom of the nozzle up to the workpiece surface the distance between these is actually is defined as the stand of distance what I told that. So this stand of distance is less than 1 mm. It is maintained less than 1 mm to reduce the flaring action.

Now we can see that if we increase the stand of if we if we consider this stand of distance as G1 which is less okay so in that case diameter of this crater diameter is generated as D1. Also you can see this one this diameter is less but this depth of indentation is very high okay. So now if we increase the stand of distance in that case actually D2 or diameter of crater diameter also increases okay or stand of distance they remain almost same.

Now if we consider this G3 as the stand of distance here so in that case diameter of indentation or crater diameter also now increases but here this depth of indentation so this is the depth of indentation here this depth of indentation slightly reduces. It is less than in case of this G1 as the stand of distance. But when we are using G4 as the stand of distance in that case crater diameter is D4 and also in that case this depth of indentation also reduces okay. So if we want to if we want to make a very high accurate kerf in that case we have to we have to reduce the depth of stand of distance okay.

So effect of nozzle tip distance or stand of distance on cavity diameter okay so G1 is less than G2 less than G3 and less than G4. So G3 is the less than G4. So in this case D1 is the less than

D1 D2 less than D2 is less than D3 and D3 is the less than D4. So in case of this D4 stand of distance this diameter of indentation is high.

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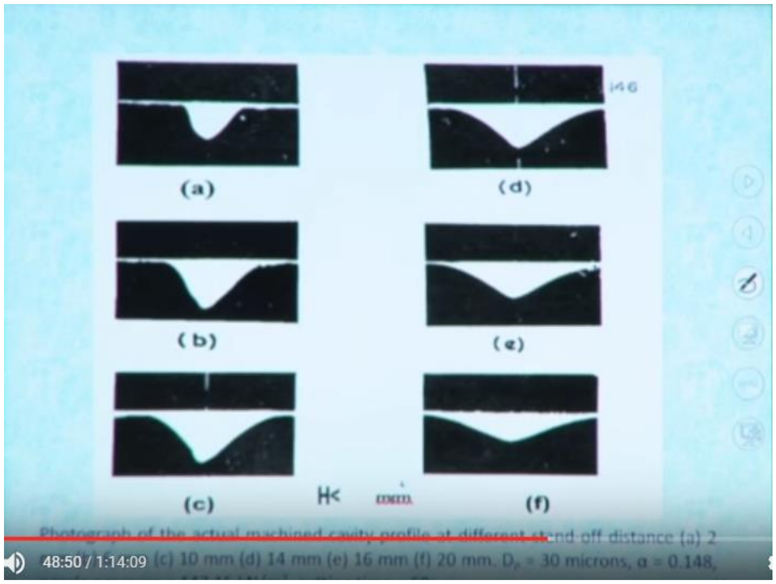

So this is the results shown means reported by different researches okay so based on the stand of distance. So this is the a, in case of this stand of distance is 6 mm you can see that this shallow one is less this shallow hole so although this hole is shallow but this it is not that much shallow okay. So now d is the actually stand of distance is 10 mm. In case of c stand of distance sorry in case of a stand of distance is 2, b is 6, c is the 10, d is the 14 mm, e is the 20 mm 16 mm and f is the 20 mm is the stand of distance. So here stand of distance is high, 20 mm and a case the stand of distance is less.

But from these 2 figures we can see from a and f we can see that in case of this f your diameter of indentation or crater diameter is very high because of this flaring of this abrasive jet but in case of a this flare or crater diameter is less.

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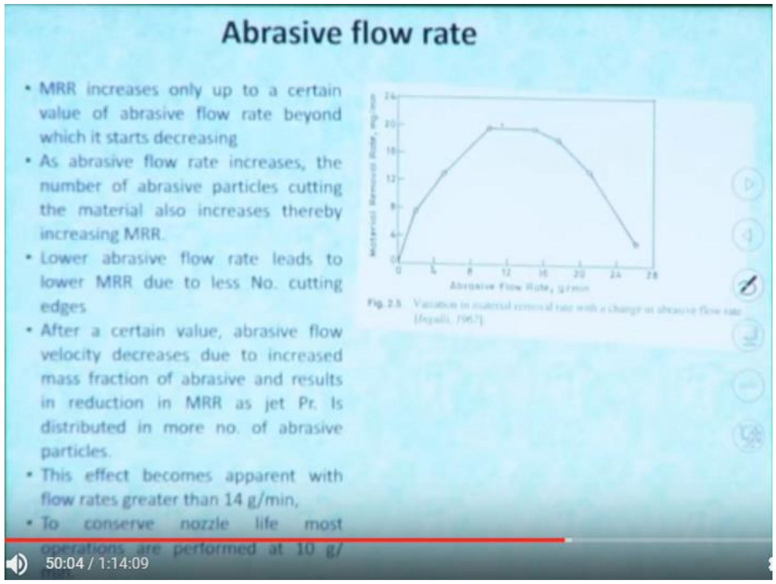

So now individual effect of individual process parameters we shall discuss one by one. So first one is the abrasive flow rate and in y axis we are checking the material removal rate mg/min. So now if we increase the abrasive flow rate we can see that this material removal rate also increasing and after some time it will it will release the optimum material removal rate with the increasing the abrasive flow rate but after after increasing means after reaching that maximum abrasive flow rate okay so there is a stall so it will become constant for a certain time and if we increase the material removal rate or sorry abrasive flow rate beyond this optimum value here suppose this is the optimum value of abrasive flow rate it is around 12 okay g/min so beyond that optimum abrasive flow rate if we increase the abrasive flow rate beyond that you can see that this material removal rate reduces.

So when you are increasing the abrasive flow rate then more number of abrasive particles are coming out okay so because of this more number of abrasive particles are there it will because of this more chipping action your material removal rate will also increase. But when you are increasing the abrasive particles beyond a certain value, certain optimum value, in that case what happens same energy same pressure actually it is kinetic energy is same pressure is pressure is constant when we are increasing the abrasive particles. Same pressure is distributed among the same means same energy is distributed among the abrasive particles okay.

So as the more number of abrasive particles are taking part into the into the machining so in that case what will happen individual abrasive velocity will reduce okay. So MRR increases only after a certain value of abrasive flow rate beyond which it starts decreasing here okay. As the abrasive flow rate increases, the number of abrasive particles cutting the material also increases thereby increasing the material removal rate. Lower abrasive flow rate leads to the lower material removal rate to less number of less low cutting edges okay and after certain value abrasive flow rate decreases abrasive flow velocity decreases okay so if the abrasive flow velocity decreases this the kinetic energy will also reduce and there is a reduction in material removal rate as jet pressure is distributed in more number of abrasive grits okay. So this effect becomes apparent with flow rate of this 14 g/min. So this is the critical flow rate of this abrasive particles okay.

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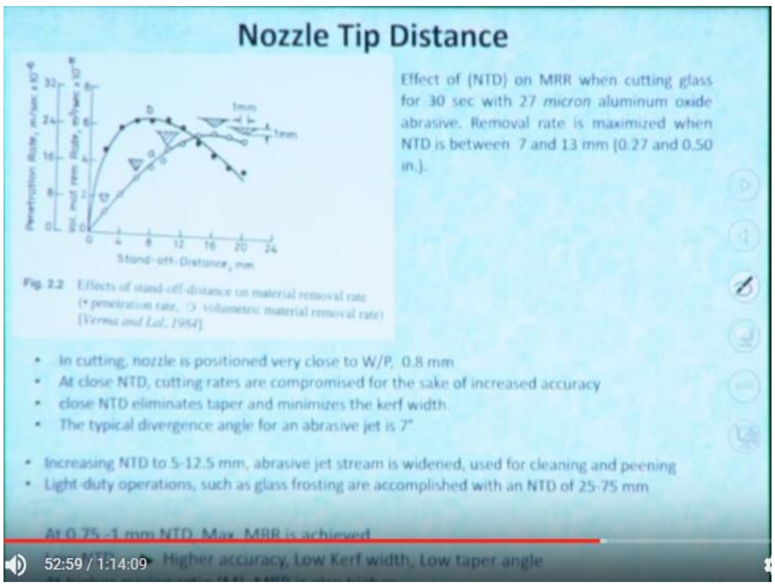

So now this is the effect of nozzle tip distance okay. So on penetration rate, so penetration rate already we have discussed. Penetration rate while we are doing the impacting by this abrasive jet machining. So penetration means this depth of indentation will increase okay so with time. So this is the penetration rate. So it is mm/sec. So what is the depth what is the depth increasing depth with time so that is called the penetration rate.

Now so this is the in cutting nozzle is positioned just for cutting actually nozzle is positioned very close to the workpiece at 0.8 mm. At close nozzle tip distance cutting rates are compromised for the sake of increased accuracy okay. So if we increase the if we decrease the stand of distance, if we reduce the stand of distance, your abrasives actually they do not get that much space for generating the kinetic energy okay.

So that is why although we are getting the high accuracy but your material removal rate will be compromised or reduced okay. So close nozzle tip distance eliminates taper okay so if you reduce the nozzle tip distance this taper into the workpiece will be reduced and also minimizes kerf rate so kerf whatever the kerf is generated it will also reduce or less shallower holes will be generated. The typical divergence again so because of this divergence or flaring so this divergence again is 7 degree in case of abrasive jet machining.

So increasing nozzle tip distance from 5 to 12.5 mm, the abrasive jet stream is widened, the stream is widened and used for cleaning. So this widened stream is used for cleaning purposes and for peening purposes because there in widened stream this abrasive jet velocity actually reduces so their kinetic energy is less. So it can be used for cleaning or peening okay.

So light-duty operations are glass frosting. So glass frosting, what is glass frosting? Glass frosting means when this abrasive jet impact into the glass material it this glass actually although it is a transparent material if it heat the glass material this abrasive jet so it will remove the surface and it will remove the surface fracture it will generate the surface fracture into the workpiece surface and whatever this glass surface it will become opaque okay. So this opaque glass actually these are generated for making the (()) (55:45) okay.

So from inside actually it can be seen you can view but from outside actually nobody can see although this you can use the same glass, transparent glass okay. So this is how glass frosting or also you can write your name or whatever maybe by using that abrasive jet machining okay on a glass. So this is called glass frosting okay. So less velocity jet or higher stand of distance can be used for this glass frosting operation with a nozzle distance of 25 to 75 mm.

Now we can see that if we increase the nozzle tip distance or stand of distance this penetration rate increases okay. So initially this kinetic energy will increase so that is why this finished penetration rate increases and after that it will reach the optimum stand of distance or nozzle tip distance okay.

So after it reach the optimum nozzle tip distance if we increase the stand of distance then your penetration rate will reduce after that this penetration rate will reduce because if we increase the nozzle tip distance beyond a certain value because of this air interaction, interaction of air okay with the abrasive jet with the abrasive jet okay air abrasive jet, it interact with the outside air okay. So so it will flare out okay. So its velocity will reduce.

So after a optimal stand of distance its kinetic energy reduced so that is why your penetration rate will also reduce okay. So at 0.75 to 1 mm nozzle tip distance maximum material removal rate is achieved okay. Low nozzle tip distance is required for higher accuracy, low kerf width, and low taper angle and higher mixing ratio material removal rate also if we increase the mixing ratio in that case also material removal rate will also increase. So so if we increase the mixing ratio even material removal rate will also increase.

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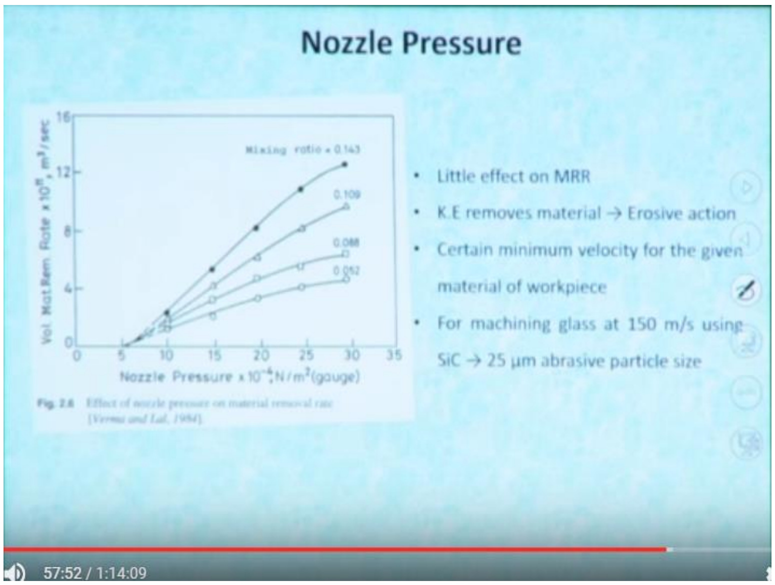

So nozzle pressure, so nozzle pressure has a little effect on material removal rate. So this kinetic energy removes the material so because of this kinetic energy this erosion takes place on to the workpiece surface. Certain minimum velocity is required. So this is called the critical velocity. So this is the critical pressure. Certain minimum critical pressure is required.

So why this critical pressure is required? Because you need certain pressure to generate the cutting action to takes place okay. So it needs a certain pressure to generate the certain kinetic energy or certain velocity to generate to the abrasive particles. So that certain kinetic energy to generate the certain kinetic energy we will need a certain pressure. So that is why at 0 actually at 0 pressure nozzle pressure so this machining cannot start.

So it takes suppose in this case it takes 10 gauge pressure okay. So 10 gauge pressure to generate the cutting to takes place okay. So kinetic energy removes the material by erosive action. Certain minimum velocity for the given material is required for cutting action. For machining glass 150 mm/sec using silicon carbide of 25 micron abrasive are used okay.

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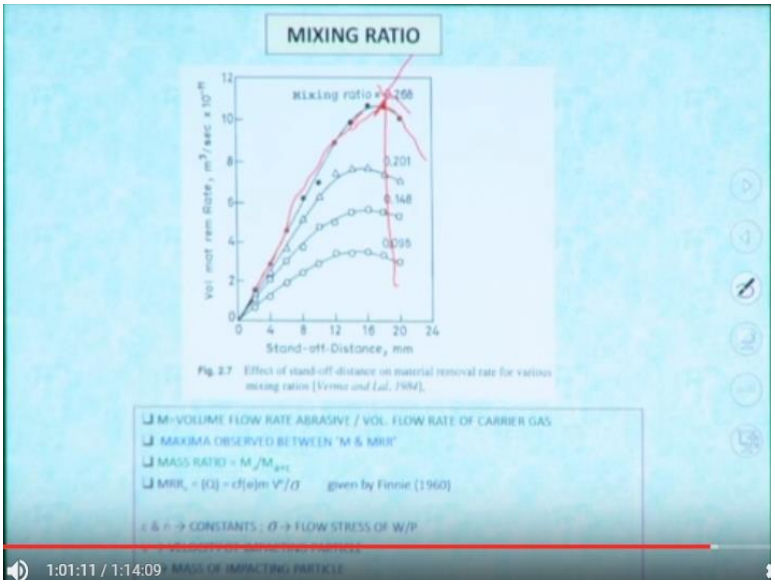

So this is the effect of stand of distance again with the volumetric material removal rate. Now you can see here if we increase the mixing ratio, so what is the mixing ratio is volumetric flow rate of abrasive particle by volumetric flow rate of air okay. So volumetric flow rate of abrasive particle and with the volumetric flow rate of air if we increase the mixing ratio okay by increasing the mixing ratio your material removal rate will also increase okay. So stand of if we increase the stand of distance it will increase material removal rate will increase and after that it will reach an optimum level and after that it will reduce okay.

Now if we increase the mixing ratio means more abrasive particles are mixing into the chamber okay, your material removal rate it will also increase. So this volume flow rate of abrasive particle by volume flow rate of carrier gas will give the mixing ratio. Maximally is observed for a certain means between per certain M. Maximum material removal rate is observed and instead of mixing ratio we can calculate the mass ratio also.

So mass ratio is volume flow rate of this abrasive by volume flow rate of abrasive plus carrier gas. So how to calculate this material removal rate okay so it is volumetric material removal rate it is can be calculated as Q equal to c as a function of theta. So theta is the impingement angle. So earlier we have considered the vertical nozzle. So this nozzle can be inclined with the vertical axis okay so that will give the impingement angle and m is the mass of the impacting particle, v is the velocity of this impacting particle and sigma is the flow stress of this workpiece material and a and c is the constant here.

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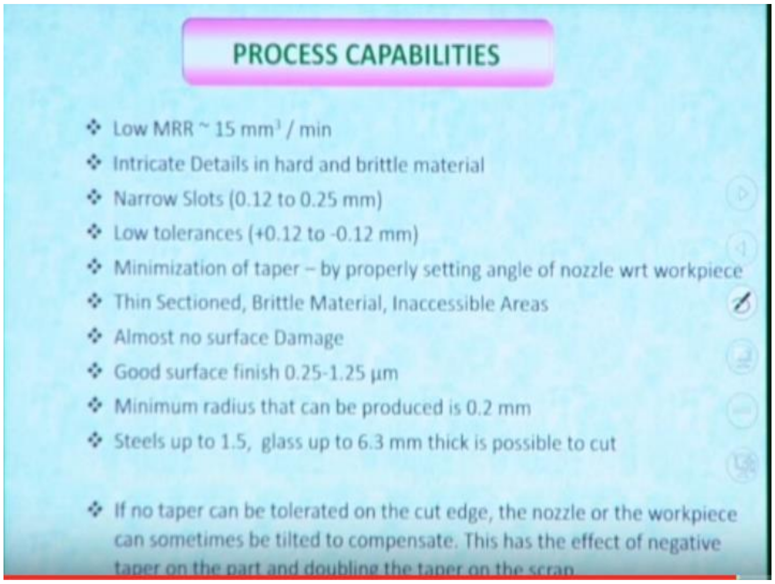

Okay, process capabilities. So process capabilities it has a very less material removal rate 15 millimeter cube per minute. So low material removal rate. So intricate details in hard and brittle materials. So it can generate intricate details on hard and brittle materials because abrasive particles need not touch means tool does not touch the workpiece surface like in conventional cutting or milling operation while tool detect it as the workpiece surface.

So here abrasive particles which is in the micron range submicron range this abrasive particles are touching to the workpiece surface and also this nozzle diameter is also very less 0.3 to 0.5 mm. So intricate details can be generated on hard and brittle materials. So narrow slots also can be generated 0.12 to 0.25 mm, this kind of slots are generated.

Normal slots obtained on this abrasive jet machining surface is plus minus 0.12 mm and minimization of taper can be done by properly setting angle of nozzle with respect to the workpiece and then thin sectioned brittle material inaccessible areas. So inaccessible areas also can be done by this abrasive jet machining.

Almost no surface damage okay, no heat affected zone because whatever heat is generated, minimum heat is generated that is carried away by the flowing of air. So that is why very less heat affected zone is generated and it can generate very good surface finish 0.25 to 1.25 micron surface finish can be generated.

So minimum radius that can be produced is 0.2 mm in case of abrasive jet machining. Steels up to 1.5 mm, glass up to 6.3 mm thick is possible to cut by the abrasive jet machining process and if no taper can be tolerated on the cut edge the nozzle or the workpiece can sometimes be tilted to compensate. This has the effect of negative taper or the part on the part and doubling the taper on the scrap.

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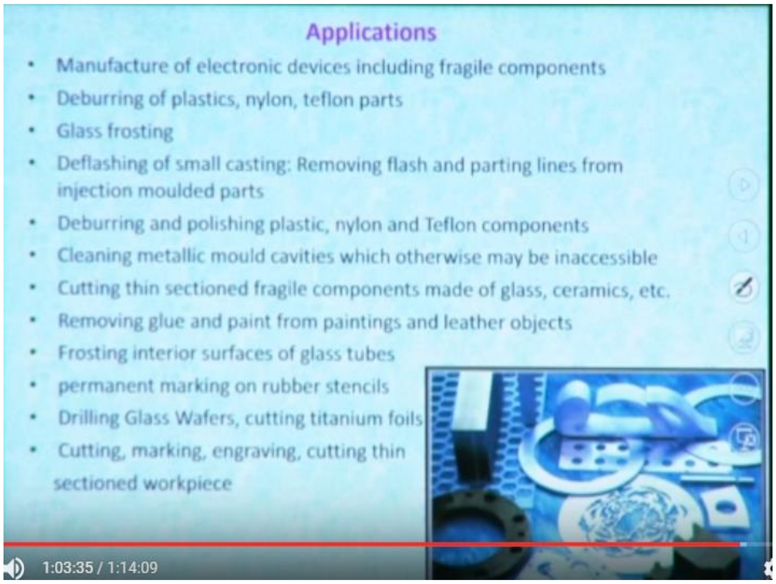

So these are the applications for abrasive jet machining process. So these are the components, intricate components you can see. So these are the components are generated. These are the components are actually generated on using abrasive jet machining process okay.

So these are the components are generated on abrasive jet machining process okay. So these applications these are the small small components, intricate components are generated on aluminium sheet. So these are the applications. Manufacture of electronic devices including fragile components. Deburring of plastics, nylon, teflon parts.

Glass frosting already I told for making the opaque glass this glass frosting. Deflashing of small castings. So after casting you can see small small bars small small (()) (1:04:37) are actually left after casting operation. So that can be removed by deflashing operation. So that is that can be done by this abrasive jet machining process with very high depth of or stand of distance is in a very high stand of distance also using low pressure okay.

So this deflashing of small casting removing flash and parting lines from the injection mould parts. Deburring and polishing of plastic, nylon, and teflon components. Cleaning of metallic mould cavities which otherwise may be inaccessible. So inaccessible mould cavities can be polished by this abrasive jet machining process.

Cutting of thin sectioned fragile components made of glass, ceramics. Removing of the glue and paint or cleaning of this glue and pain from the paintings and leather objects can be done by abrasive jet machining process. Frosting of interior surface using glass tubes of glass tubes. Permanent marking on rubber stencils okay can be done by this abrasive jet machining on a rubber workpiece we can make a permanent marking or (()) (1:05:52) by using the abrasive jet machining using less pressure. Drilling on glass wafers, cutting of titanium foils. Cutting, marking, engraving, cutting thin sectioned workpiece can be done by this abrasive jet machining process.

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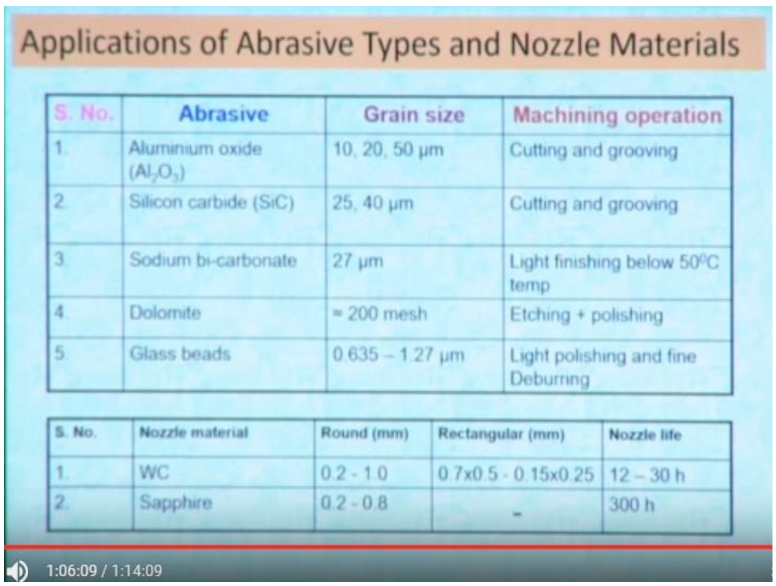

Applications of Abrasive Types and Nozzle Materials

S. No.	Abrasive	Grain size	Machining operation
1.	Aluminium oxide (Al_2O_3)	10, 20, 50 µm	Cutting and grooving
2.	Silicon carbide (SiC)	25, 40 µm	Cutting and grooving
3.	Sodium bi-carbonate	27 µm	Light finishing below 50°C temp
4.	Dolomite	≈ 200 mesh	Etching + polishing
5.	Glass beads	0.635 – 1.27 µm	Light polishing and fine Deburring

S. No.	Nozzle material	Round (mm)	Rectangular (mm)	Nozzle life
1.	WC	0.2 - 1.0	0.7x0.5 - 0.15x0.25	12 – 30 h
2.	Sapphire	0.2 - 0.8	-	300 h

So different abrasive particles have different applications okay like if we consider aluminium oxide as the abrasive particles with grain size of 10 micron 20 micron and 50 micron so these are used for cutting and grooving operation. Silicon carbide which is harder than the abrasive aluminium oxide abrasive particles with a 25 to 40 micron is also can be used for cutting and grooving operation.

Sodium bi-carbonate its diameter is 27 micron. So it is used for light finishing below 50 degree centigrade temperature. Then dolomite is also used with 200 mesh. It is used for etching and polishing purpose. Glass beads of 0.635 to 1.27 micron are used for light polishing and fine deburring operations.

So these are the different nozzle materials. This is the tungsten carbide and sapphire. Tungsten carbide it has a life of 12 to 30 h and it is round tape it is 0.2 to 1 mm or rectangular tape 0.7 to

0.5 to 0.15 cross 0.25. So this is the dimension of this tape rectangular tape. So it has a life of 12 to 30 h but in case of sapphire its life is 300 hours okay. So sapphire mostly generally is used with round cross section with 0.2 to 0.8 mm diameter.

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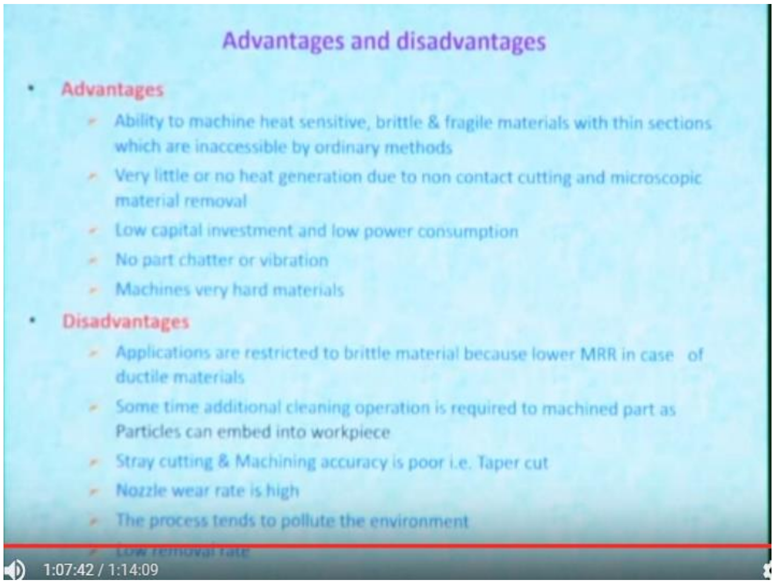

So there are some advantages and disadvantages of this process. Advantages are machine is heat sensitive. So heat does not means heat is not generated. Whatever heat is generated it is taken away by the carrier gas. Very little or no heat generation to non-contact cutting and microscopic material removal very small small material removal is there.

Low capital investment. So only that consumable is that actually is this nozzle. So nozzle is costly. Other than other things other components of this abrasive abrasive jet machinings are not that much costly. So that is why capital investment is less. No part chatter or vibration like in conventional machining process there vibration or chatter marks are generated. So that kind of things are not there in abrasive jet machining. Machines very hard materials. So very hard materials can be machined.

What are the different disadvantages. Applications are restricted to only brittle material. So it is not suitable for machining ductile material. So for ductile material this material removal rate will be very less. Sometimes additional cleaning operation is required to machined part as particles can embed into the workpiece surface and stray cutting and machining accuracy is poor. So that is why because of this stray cutting taper cut is generated.

Nozzle wear rate is very high very high because abrasives are actually passing through the nozzle. So wear rate of this abrasive these nozzles are very high. The process tends to pollute the environment because these particles are coming with a very high velocity. In the mixing chamber it is not properly cleaned, it is not properly locked, these abrasive particles, crushed abrasive particles will come outside and also it has a very low material removal rate.

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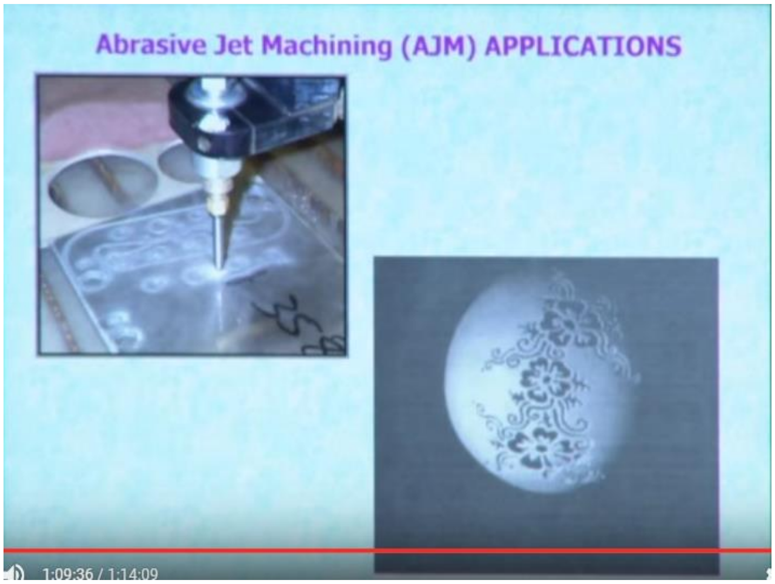

There are 3 applications you can see using this abrasive jet nozzle this kind of complicated details you can generate into the so these complicated details also you can generate into the workpiece. So this kind of complicated details can be generated into the workpiece. So here is the example of abrasive jet machining. So these kind of design can be generated on a egg shell okay. So on an egg shell actually these kind of design is generated.

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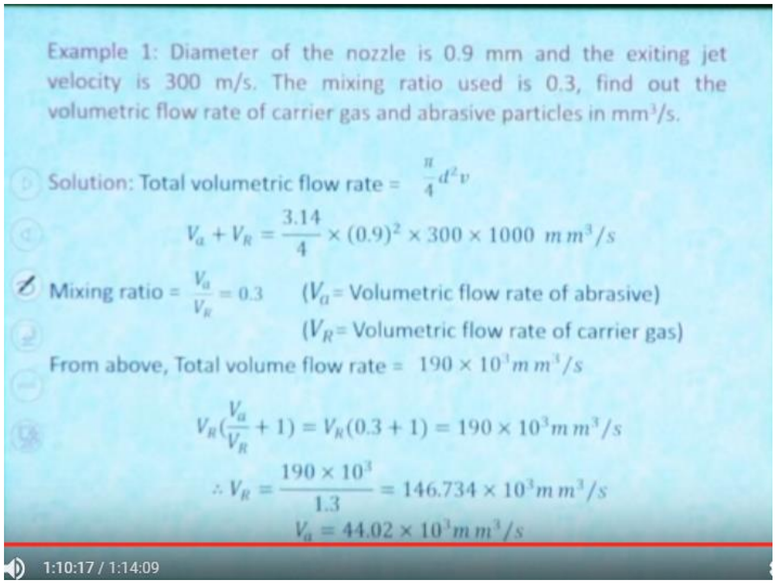

So now we shall discuss some solved example and we shall discuss some question bank. Now here it is shown that diameter of a nozzle in a in an in a certain abrasive jet machining process the nozzle diameter is considered as 0.9 mm. Although it is in 0.325 mm nozzle diameter but here it is considered 0.9 mm diameter nozzle is used. The exiting gas jet velocity is 300 m/s. The mixing ratio is 0.3. So mixing ratio is volumetric flow rate of abrasive by volumetric flow rate of this carrier gas. So that is 0.3.

So now we have to calculate the what is the volumetric flow rate of carrier gas and what is the volumetric flow rate of abrasive particles used. So now total volume of flow rate volume flow rate can be calculated is pi by 4 d square into velocity of this abrasive jet okay abrasive air abrasive jet abrasive jet is will give the total volume flow rate. So volume flow rate it is the summation of total volume flow rate is the summation of abrasive and VR is the volume flow rate of this carrier gas.

So this volumetric flow rate is pi by 4, 3.14 by 4, d is the 0.9 mm, is the nozzle diameter and then velocity is 300 m/s. So 300 into 10 to the power 3 it will give millimeter cube per second okay.

Now mixing ratio is equal Va volumetric flow rate of abrasive by volumetric flow rate of VR or carrier gas is given as already given as 0.3 mm sorry 0.3 okay. Now total volume flow rate from this equation can be calculated. It is calculated as 190 into 10 the power 3. So now if we take from this equation if we take VR as a common, so VR equal VR multiplication of Va by VR plus 1 okay. So here if we multiply this VR with this second term so it will be Va plus VR which is equal to 190 by 190 into 10 to the power 3.

Now if we take the VR as common okay it will be Va by VR which is 0.3 plus 1 into VR will give the 190 into 10 to the power 3 millimeter cube per second. So from this equation we can calculate this VR as 146.734 into 10 to the power 3 mm/s. Now Va plus VR equal to 190 into 10 to the power 3. So if we know the VR then we can easily calculate the Va also, volumetric flow rate of abrasive. So it is asked here.

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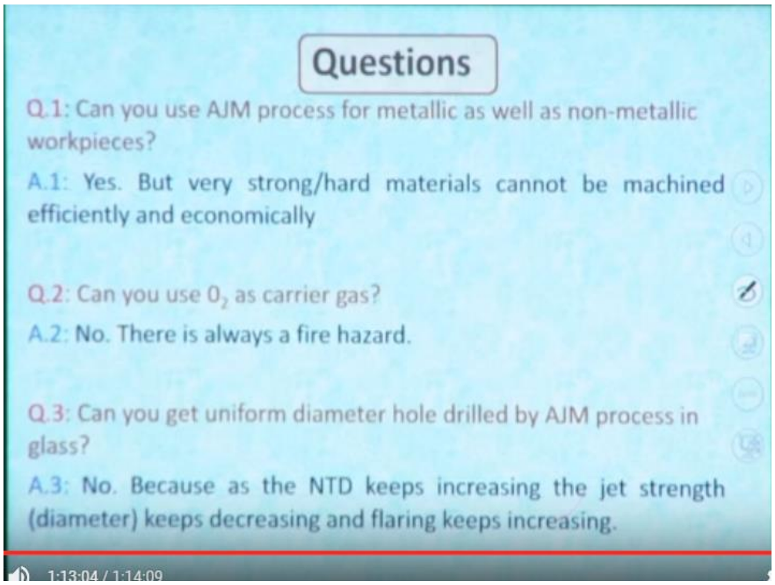

Question, can we use abrasive jet machining process for metallic as well as non-metallic workpiece, yes. So it can be used for metallic and non-metallic but this workpiece should be strong and hard materials. So workpiece should be very hard.

Can you use oxygen as the carrier gas? So it cannot be used because of this fire hazard. Can we get uniform diameter hole drilled by AJM process in glass? No because of this as the nozzle tip diameter keeps increasing the jet dimension the jet strength actually keeps decreasing and flaring keeps increasing. So that is why we cannot use nozzle tip distance we cannot we cannot get the same workpiece by using the nozzle tip distance.

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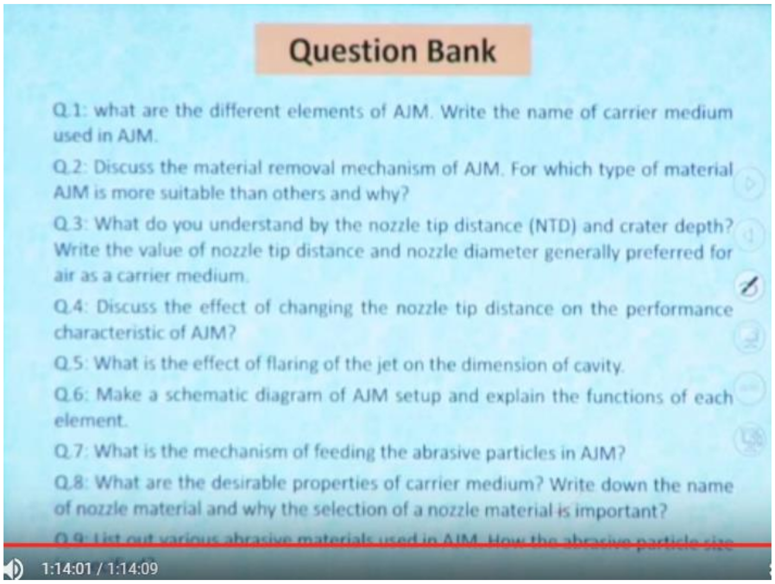

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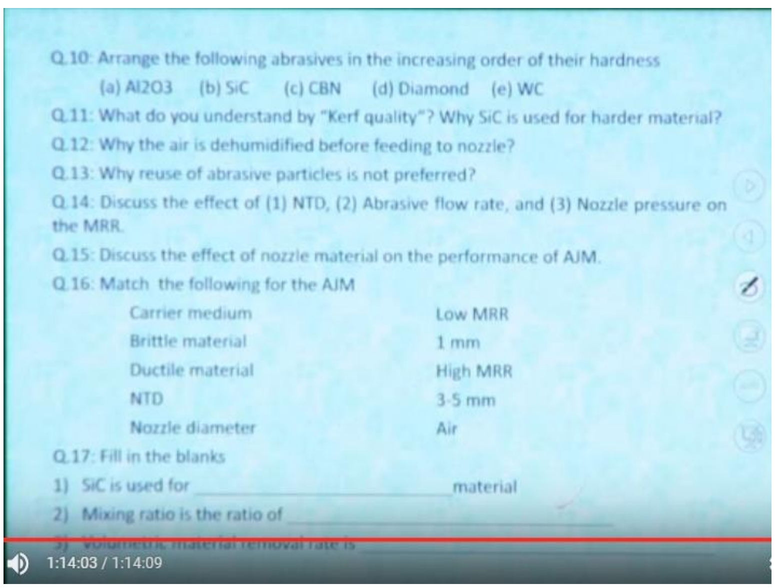

So these are the question banks, different question banks for this abrasive jet machining process okay.

Thank you.