Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part- 2

Module- 10

Introduction to Abrasive Jet Machining Process

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Hello and welcome to the, is manufacturing process technology part 2 module 10.

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We had finished the microelectronic processes in the earlier module where we talked in length about the different you know sort of alternate process which were first generation non predication process particularly using silicon as borough from micro electronics to fabricate micro machine structures or small structures today we are going to again discuss of a very important form of nontraditional or advanced machining which is related to the mechanical version of the marching where there are use of abrasive particles and typically machining is carried out by throwing.

Such abrasive particles on the surfaces and initiating the formation of cracks and the propagation of cracks and so therefore such processes are more I mean able to partial materials like ceramics or glasses in the industry, but not essentially limited to them they can you also use them for metals you can use them for a variety of other different materials so there is a impact that is being tailored in manner so that there is a crack which formulates on a surface and that is how such process are categorized. So let us look into the process of abrasive jet machining or AJM okay.

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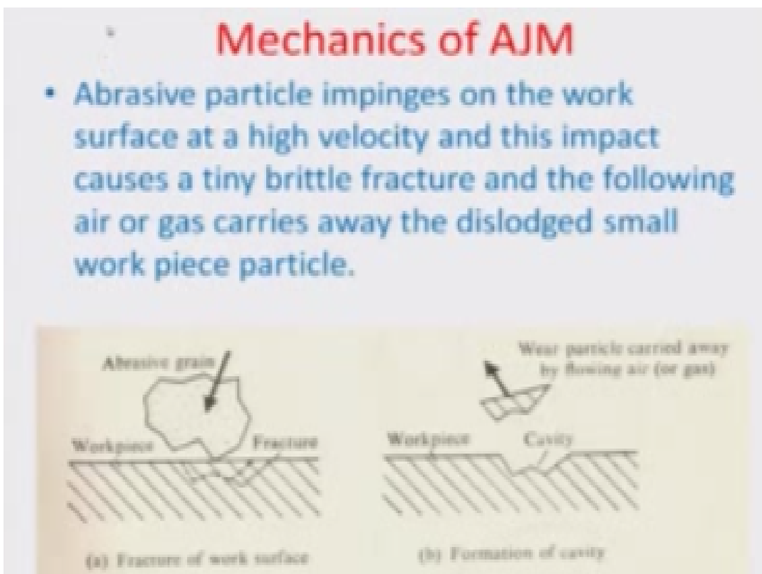

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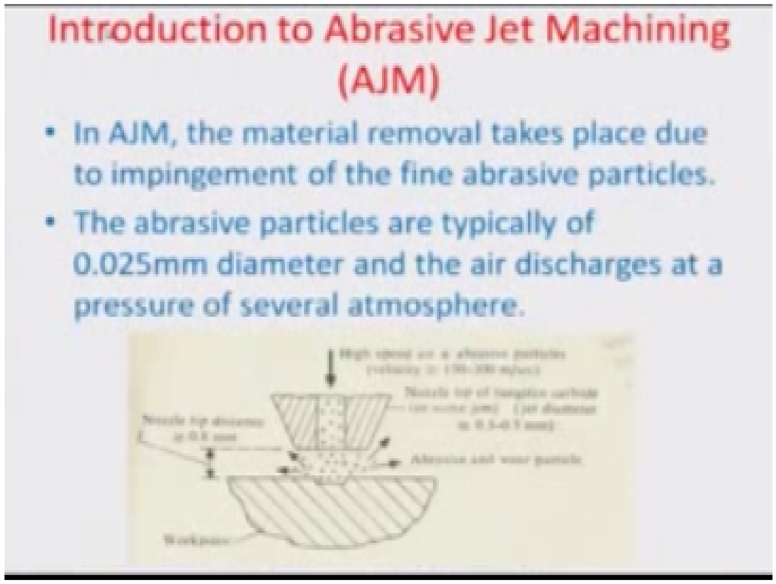

So in this particular process the material removal as I told you takes place due to impingement of fine abrasive particles let us say suppose there is a nozzle here and this nozzle is made up of something which is you know very hard material like tungsten carbide which does not get so easily influenced by the continuous abrasion provide by the influent a press of particles there is a high speed jet of air which has hoped abrasive particles by a system which will describe when we talk about the machinery and it impinges or it basically formulates a air abrasive mix which flows out from the nozzle let a high velocity of almost as high as 150 to 300 m/ s.

So therefore whenever this high pressure jet is a directed to go from a nozzle into an open atmosphere that is some kind of an expansion to the jet which happens all though the monument is to high and it gets carried for certain duration as you know as a of the same size of the jet with without much expansion but after a while it starts expanding and if we could capture that jet prior to it is energies starts getting dissipated because of the track provided by the atmospheric air I should be able to write with that jet on a top of a surface because it would impact or it would create a situation where the grains are going to impact and create dislodgement of the material okay, so let say we take this.

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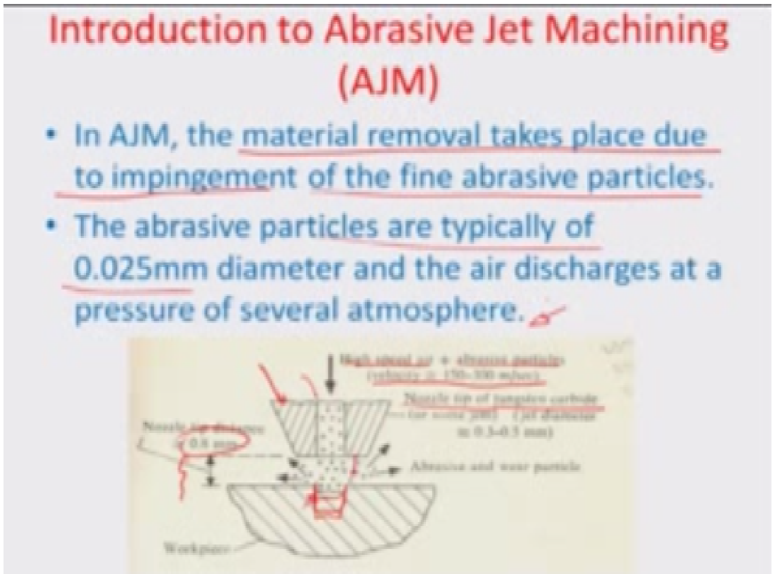

The substrate quite close about of the level of a bowl 800 microns to this particular abrasive jet so still the jet has not lost in a power because of the drag and other issues provided by the atmospheric pressure and so therefore it is you know, it produces a some kind of a zone where there is attract formulation because there is a continuity of this abrasive particles and then you know if you can proceed the nozzle towards the work piece then this one gets a expanded, so you can have different depths of cut formulated.

As the nozzle approaches this particular region up to an extent that the nozzle does not start touching this or phase that is in question, so the abrasive particles are typically of about 0.25mm diameter and the air discharges air pressure of several atmospheres, so that is how the nozzle and work piece dynamics is there in this abrasive jet machine.

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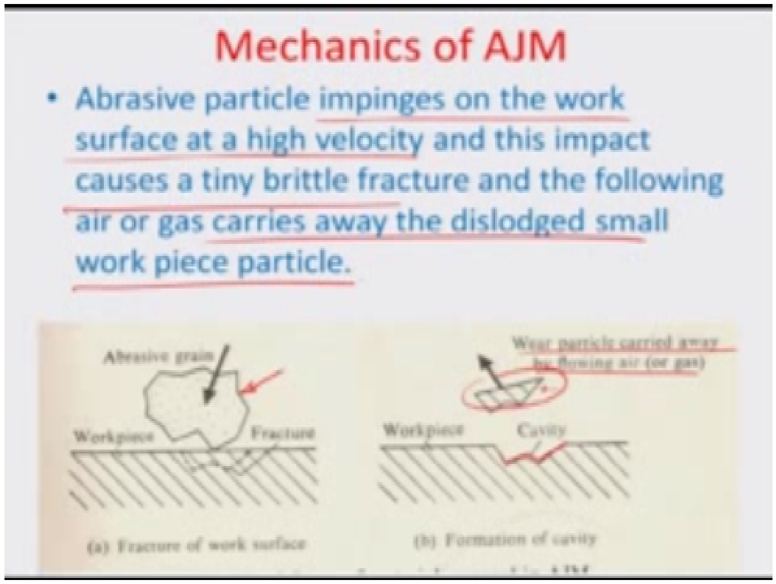

So as far as the mechanics of the AJM process goes the abrasive particle this is a for example a sharp abrasive particle with various edges and corners, as so it impinges on the work surface at a high velocity, and this impact causes a tiny brittle fracture you can see that corresponding to the shape of this abrasive particle there has been a cavity formulated because there was a certain fracture of this particular material and the form and the following you know sort of flowing here or gas which is actually there with the abrasive.

Which is responsible for flowing this abrasive carries away the dislodged small part so you have a crack formulated in the zone and whatever comes out this tip is can be carried away by the air which is flowing along with the abrasive grains so that is how you do the on the actual material removal, in case of the abrasive jet machine.

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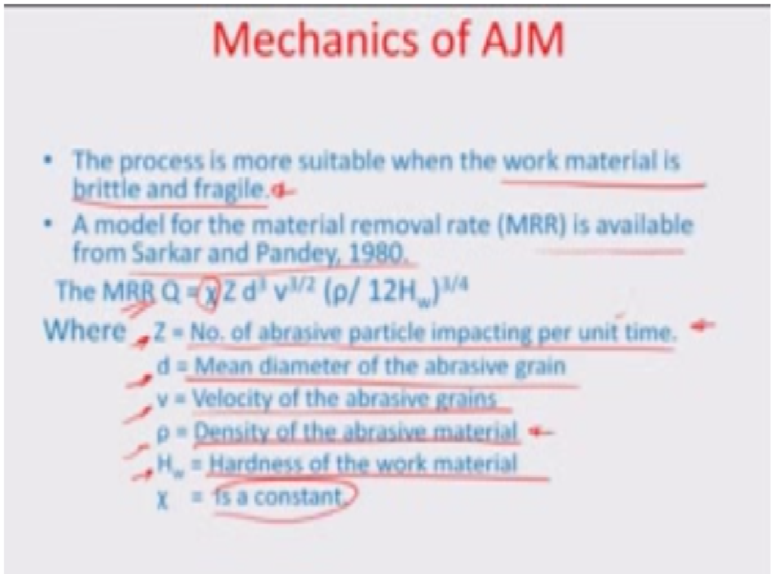

So the process is more suitable when work material is brittle and fragile, so as I told you that process were generated because the requirements in the ceramic industrial the glass industry to sort of you know use a process so you know in fact the AJM the need for AJM was sort of felt by the industry and the process was taken up by the industry because of the advent of ceramics or such brittle materials and obviously.

Although there is a possibility of applying this to many systems including metal etc the highest deficiency would come and we talk about brittle and fragile materials so the model for material removal has been proposed for this AJM process by Sarkar Pandey in 1980 which talks about the and relating this material removal rate to variety of Prospero meters like number of abrasive of particles impacting per unit time mean diameter of the abrasive grain, d the velocity of the abrasive grains v with which they are impacting on the surface the density of the abrasive material and then also the hardness of the work material and some you know constant experimental constant which comes up.

So basically you can think of the MRR of the material removal rate to be proportional to the cube of the diameter proportional again to 1.5 power of the velocity of the impacting grain and also proportional to the number of abrasive particle impacting per unit time, so intuitively it make sense why we should go in this manner to generate the MRR.

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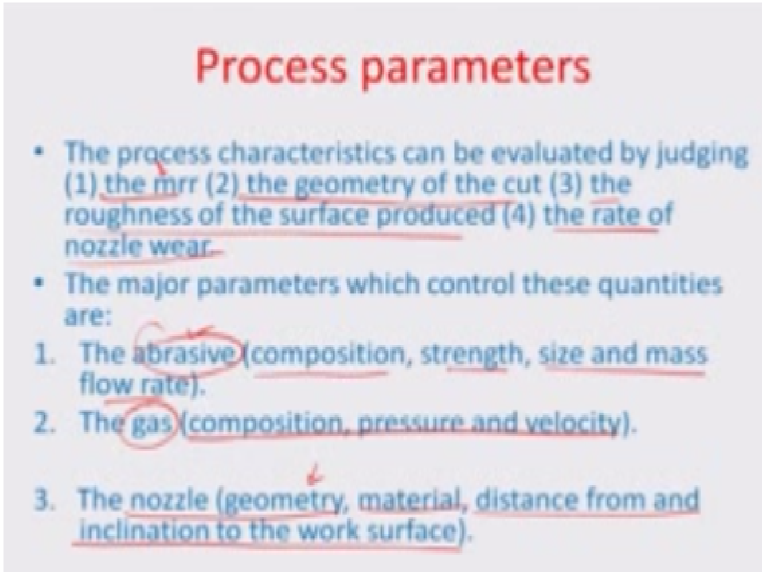

So the process parameters which are of importance here are obviously you know evaluated by judging the material removal rate or the geometry of the cut or even the roughness of the surface that has been produced in the rate of nozzle wear and the major parameters which control these quantities are the compositions, strength, size and mass flow rate of the abrasive that is the main cause of the material removal and also the composition pressure and velocity of the gas which is flowing.

Or which is the responsible for this abrasive at that high energy of impact or momentum delivery, also there is a sort of a good relation between you know the nozzle geometry which matters a lot to generate the overall shape and size of the cut or even the surface roughness the MRR and things like distance from the inclination of the work piece with respect to the nozzle is also a very, very important property along with a nozzle material for determining some of these process characteristics.

So let us look at some of these parameter and how they would the variation of that these parameters would result in the change in the process characteristics so the first you know study that has been made it is that if we really change the mass flow rate of the abrasive particle by changing the pressure and the flow rate of the gas.

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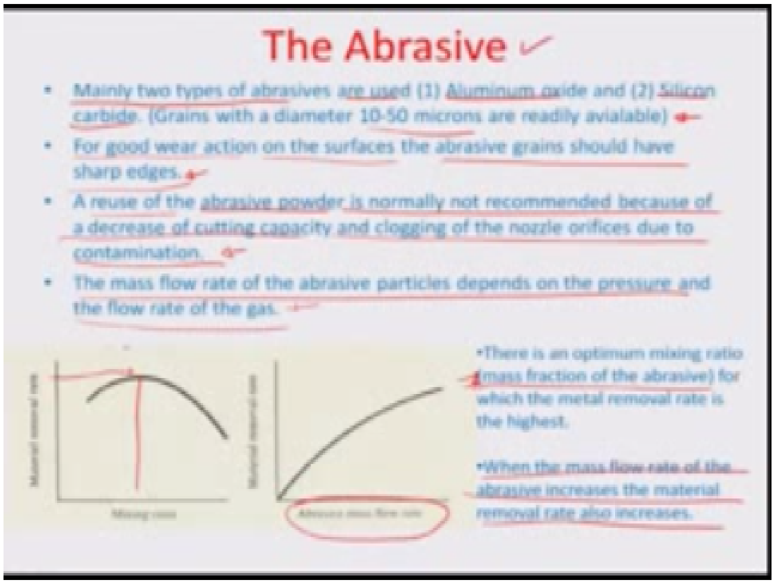

So the first important property or such important parameter which we talked about is really the abrasive and let us look at how they it really effects the process characteristics. So the mainly two types of abrasive which are used in the AGM process there aluminum oxide and silicon carbide the grains have a diameter of almost about 10 to 15 microns they are readily kind of available so also for a good where action on the surface concerned for the machining the abrasive grain should have very sharp edges.

And then the use of the abrasive powder is normally not recommended because of a decrease of cutting capacity and clogging of the nozzle orilifices due to contamination. So the mass flow rate of the abrasive particles depends on the pressure and the flow rate of the gas.

So generally because there is a, you know tendency of metal plagues or the work piece plagues to come with the flowing air and they also they thrown impressive into the collecting pit corresponding to all the different impressive grains. In fact this is done in a large chamber where whatever is bounced of the surface in terms of impressive grains falls on the base of the chamber, so obviously if you want to you know if it is not a metal that you are cutting and you want to separate it becomes little hard to separate and so therefore there is always a sort of a clogging you know which happens of nozzles or various other portions of the machine.

One of the reasons, why it is not very useful to allow the reuse you know of the abrasive powder. So if you look at the mixing ratio which is actually the mass fraction of the abrasive present in the air, there is an optimum mixing ratio over which the MRR would be the highest obviously intuitively also if you look at that if the number of abrasives prominent volume of the air is increase there is going to be cross grain collision you know which happens and which kind of jupatizes the momentum that the grains would formulate before hitting the surface.

So therefore, it has to be an optimum loading for the grains to have enough mean free path to develop that kind of impact which is able to create little fracture. So there is obviously a certain point below which even if the abrasive particle is loaded it means they are not enough abrasive particle is there and above which it is loaded there is a sort of a cross collision between the grains which would jupatizes the momentum.

So there is an optimum best of the mixing ration we will in fact do some problem examples related to calculation of the mass fraction of such a abrasive jet machining process, and the other issue is that when the abrasive when the mass flow rate of the abrasive increases the material removable also short of increases, but this is again subjected to an optimum best because you should not just completely. So if supposing you know the mixing ratio is the same and if you keep on adding the impact or hitting by, you keep on flowing the air abrasive mixture and hitting on the surface so higher is that abrasive mass flow rate at a certain mixing ratio the higher would be the material removal.

So obviously the impact keeps on increasing with the velocity as you can see in this particular case, so if supposing the mass flow rate is lower the impact would be lower if the mass flow rate is higher the impact would be higher and so that results in distinguish or differentiate metal rates. So typically you should be able to use the you know higher mass flow rate but that is mean we can keep on going on the higher side because it iterates the nozzle life and that is a very critical issue in abrasive machine in that.

If we just simply wanted to flow at higher and higher velocity is there may be oration of the nozzle at a much faster rate and the nozzle medico rate and you may need to change nozzles quickly. So there is obviously a trade of between maintain the quality of the nozzle and maintaining the higher amount of MRR, you know in a mesuentrial removal flow or removal process related to the AJM.

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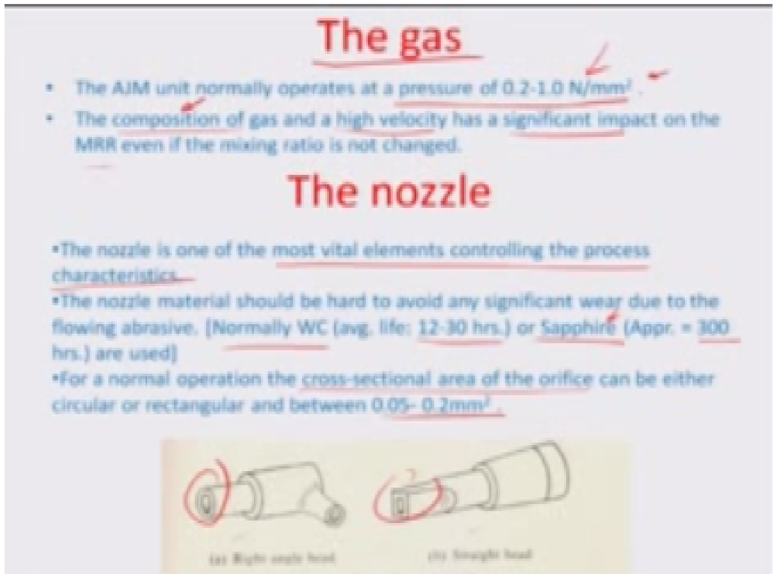

The other important aspect is the gas that is being use obviously the pressure ranges that are normally employed in the AJM process between 0.221 n/mm^2, so this is a very, very high level of pressure that is being sued to create this z or create the velocity. And the composition of the gas is also having a great impact on the MRR and so is the velocity of the gas for obvious reasons that higher velocity means higher momentum delivery and the composition should not be typically something which you know may create some kind of a, so the composition is way is more responsible for the economics of the process because obviously if you have to use different you know first of all it should not be has it does the gas that you using should be operate differently that is very important aspect.

The other aspect is that it should not have it shown corroding effect on the material that is being brought it away because obviously if you are using the gas for that purpose you have to have shield environment to flow all that. Normally these machines not really shield they quite open to atmosphere and so we need to be very careful about choosing the composition of the gas there. The nozzle is again one of the most vital element in controlling the process characteristics and as I told you the nozzle material should be typically very hard and hardness is needed because your flowing a preserve contentiously around the clock through that nozzle.

And obviously the nozzle gets titrated in terms of it shapes and size and if it gets titrated then the distribution of impact which would otherwise be there on the work piece surface as a Gaussian with the central particles being driven at the highest axel velocity and the side particles or particles limonitic from the sight of the nozzle having lower velocity okay that changes completely because of the change in the deformation in the total cross section area of the nozzle.

So normally very hard materials like tough and carbide or sapphire are used for generating this nozzles and they have average life times varying between 12 to 30 hours and approximately 300 hours for sapphire is very high life time that we are talk about when we used sapphire nozzles. But they are actually very expensive as well so for normal operation of cross sectional area for normal operation of the AJM the cross sectional area of the RFS that can be used where it is between typically 0.05 to 0.02mm^2 and there can be also differentiate shapes for the cross sectional including circular nozzle and rectangular nozzles so and so for.

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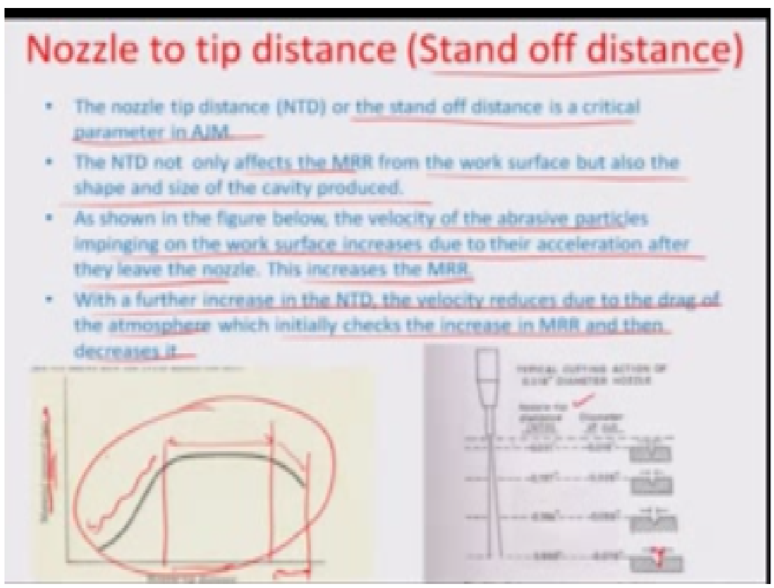

But you do have to from time to time look at the nozzle shape and size and determine whether it is suitable for carrying out a machine operation before the start of such operation the other important factor is nozzle tip distance which is very important in case of all the you know transfer though process whether it is WJM or AJM or WAJM so these are in terms of also these are also better known as stand of distance between the nozzle and the work surface.

Obviously if I look at the problem in WJM again that if the nozzle ere too closed to the work surface the amount of the time that pressure would need to kept thrown out at a certain velocity and you know certain acceleration to attain a full velocity would be very less oaky so the nozzle test to tip distance to an extend you now that the velocity should be higher with the distance obviously the velocity square is the function of the accelerate proportion.

To acceleration of the distance travel the square equal to try up to the certain distance the material flow rate would increased because the velocity is going to go higher but we should think about it that there is an aspect of divergence of the, the gasket that has been imitated from that nozzle into the atmosphere.

And this divergence also because that there is a air drag which is offer to the particle in the reverse direction because of which there is a change in the moment so the velocity does not keep on changing or increasing almost in definitely but after a certain distance has been traversed the jitters are little bit farther away from the work surface that there is a huge atmospheric drag issue which would come to the take place.

So for a certain amount of distance is you know between this critical distance were the velocity would start to fall down and this let us say this you know acceleration effect there is going to be plat owing that there is a trade of between the increase because of acceleration and the reduction because of the drag and beyond which the drag would start dominating so that the material removal rate of flow down.

So if I really plotted the MRR with respect to the nozzle tip distance for the first few spaces of distances the between the work surface and the nozzle the MRR would increase then there is a again the region of plat owing where there is a balance of trade of between the accelerated component and the drag component of two as space of particle and then obviously the drag would start dominating bringing down the MRR during this particular set of nozzle distance.

So obviously there is a trade of that has to be balanced and it has to be set up at the start of any process for obtaining the nozzle tip distance also it is mind you a very, very important it is very, very important to look at the cross sectional area of the nozzle before start of the process because the NTD may change, the NTD may change because of a change in the cross sectional area so typically the NTD or nozzle tip distance is also responsible for the overall shape of the feature which is being created because of this predict factor effect.

And as you conceive that have you go down in the nozzle gives on diverging the aspect ratio of the impression that has been made also changes squared bit the initially at the very being process of the nozzle is closer by the aspect ratio is probably higher. And the depth obtained of the brittle factor process is much larger n comparison through width but slowly the width is increases on the depth will be reduces so it comes to you know almost unit aspect ratio.

When we talk about increasing the nozzle tip distance from the work surface so the nozzle tip distance so the stand of distance is a critical parameter in AJM and not only the effects the MRR the work surface but also the shape and size of the cavity produced and you know as shown in the figure the velocity of the abrasive particle impinging on the work surface increases to due to their acceleration after they leave the nozzle this increases the MRR with the further increases in NTD the velocity reduces due to the drag of the atmosphere which initially checks the increases in MRR and then decreases it so that is what the curve here describes.

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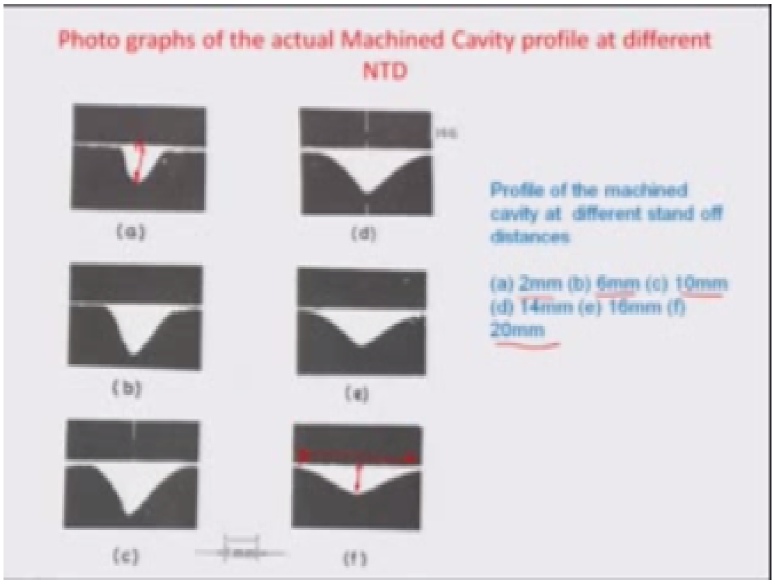

And some of the features which actually have been done realistically in a actual AJM process that has been listed here for various NTD values varying 2mm to 20mm. as you can see here that during the 2mm distance the ratio is quite high but it keeps on changing and the depth keeps on reducing, where as the width keeps on increasing, as you are changing the nozzle tip distance to all the way to about 20mm. so that is a very important component of the AJM process.

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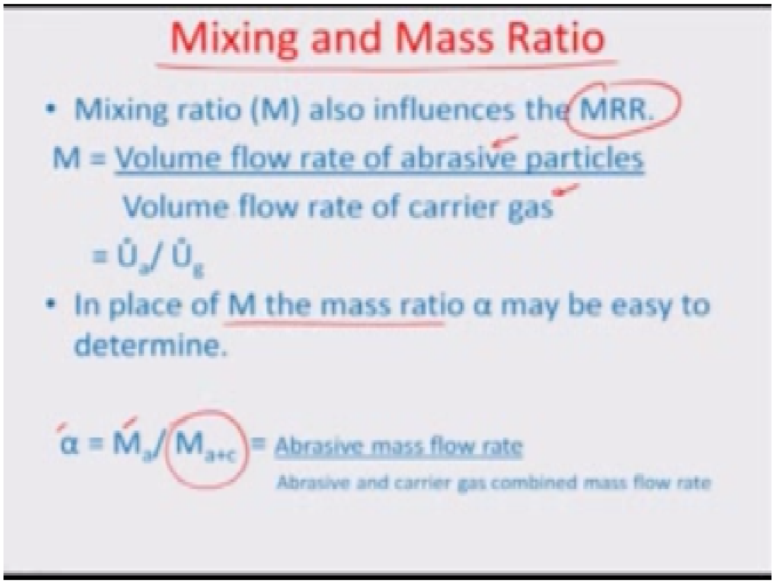

The other important aspect is the mixing in the mass ratio, obviously mixing ratio is highly influential as far as the MRR is the volume flow rate of abrasive particles or unit volume of the carrier gas and in place M the mass ratio, in place of the maximum ratio, the mass ratio M is really determined as the mass of the abrasive by the mass of the abrasive + carrier gas. So there must be relationship between the α and M. if we can just talk about density and volumes, so let us look at some of the particle problems.

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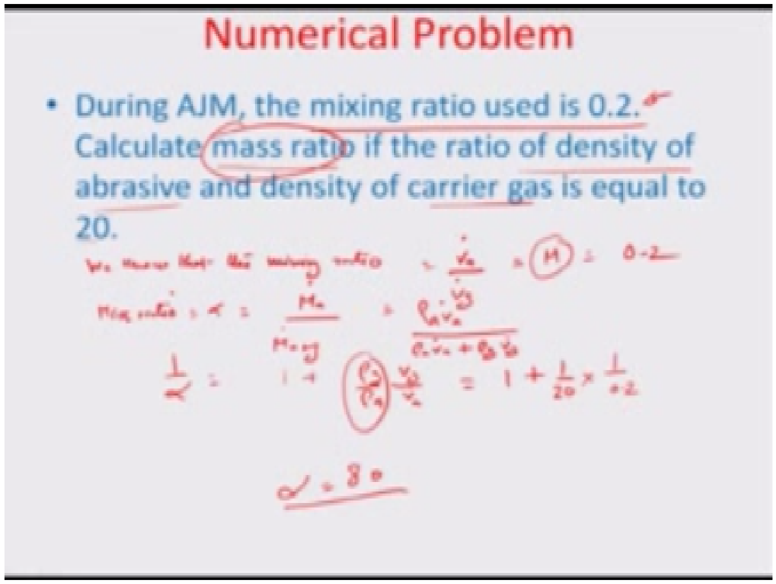

You know the medical problem which can be important from my AJM stand point, so during the AJM process the mixing ratio which is used about is 0.2. We have to calculate the mass ratio, the ratio of the density of abrasive and density of carrier gas is given to me = 20. So we know that the mixing ratio, in this case is the volume flow rates of the abrasive and the gas and you can call this M okay. And the mass ratio from earlier definition α= mass flow rates of the abrasive + that of the abrasive + gas which is used.

Which I can always write as ρ_a that is the density of the abrasive times of, the volume flow rate of the abrasive / the density of the abrasive time of volume flow rate of the abrasive + density of the gas volume flow rate of the gas okay. So this is actually the mass ratio between the abrasive and the abrasive + gas and if I wanted to simply put this or convert this in terms of what I had for the mass ratio or mixing ratio given to be 0.2 in this particular case.

Then I would just like to invert this by making this 1/α and inverse of mass ratio is again 1+ρg/ ρa, vg./ va. And if I have substitute the value here the density of the carrier gas the density of the abrasive in the carrier gas is sort of given to 20 so that of the gas to the abrasive cranes is 1/20 times of the inverse of the mass ratio 0.12. So α comes out = to be about 80 in this particular case. So I can calculate the mass ratio given the density values of the abrasive and the carrier gas and also the mixing ratio.

So such problems are very common place in AJM when you have to calculate these for doing such a process. With this I would like to sort of end this particular module but the next module we will take up some more example of the AJM and do another mechanical process which is also know as a ultra sonic machine till then good bye thank you.

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