Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Manufacturing Process Technology – Part- 2

Module- 11
Ultrasonic Machining Process

by
Prof. Shantanu Bhattacharya
Department of Mechanical Engineering,
IIT, Kanpur

Hello and welcome to this manufacturing process technology part 2, Module 11.

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We were just disusing about the various mechanical removal processes like restive jet machining and in that context we had actually try to learn how the AJM process really works.

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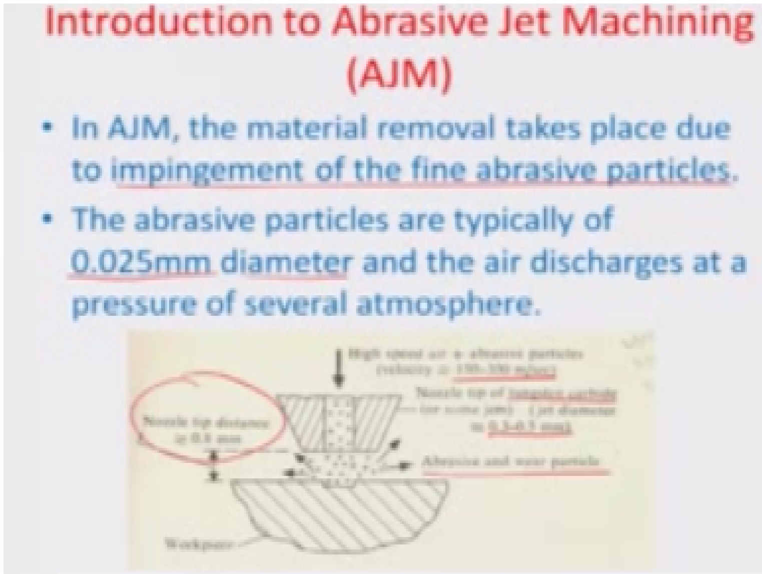

And the material removal on the AJM take place due to the impingement of the fine abrasive particles and the abrasive particles are typically about 0.025 mm diameter and that makes it about 25 microns and the aired charges at a fresher of about close to almost tends of atmospheres the jet speed of the air is about close to 150 to 300 m/ s the tip is made up of a material which is hard and tough so that there is no abrasion so typically tungsten carbide it is a fire these are some of the materials which are applied in the making of some nozzle tip the jet diameter is typically about 0.3 to 0.5 mm.

That makes it about 300 to 500 microns and this is very important parameter called nozzle tip distance which means that how much this is the nozzle less from the surface which is being machined and you know this really is an optimized distance because there is certain distance for which the MRR is the maximum I will talk in details about this latter as we go along the process but the idea is that air and abrasive together they fall with a straight jet into the surface and creates lot of where on the surface. Typically the work piece is brittle fracture okay.

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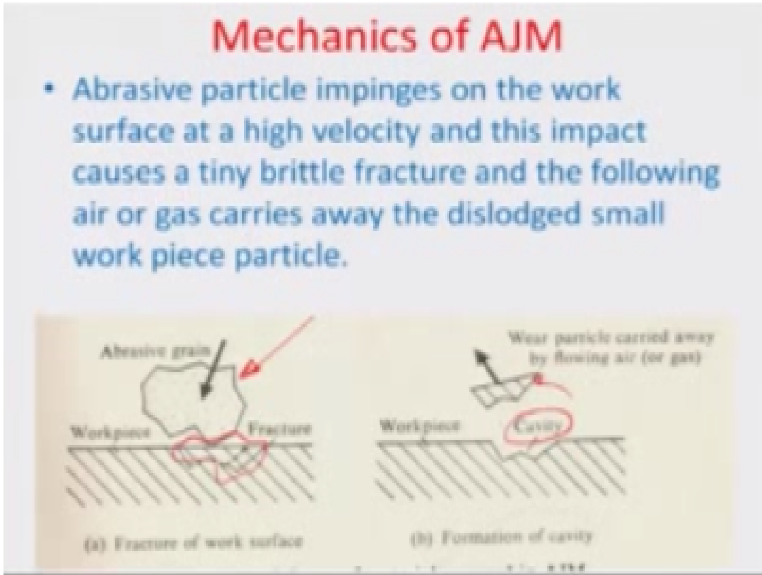

So the way that material removal takes place here is that there is let us say this is abrasive grain which is otherwise sharp in all corners and it comes at certain velocity and strikes on the work piece, so it creates a fracture region and this fracture gets further removed by flowing from the gas or the air that carries the abrasive and gets bounded back from the surface so it carries away the ware particle and creates a cavity on the work piece and this fracture by fracture cavity by cavity there is a material removal which takes place from surface.

So if I look at the process parameters of AJM for first time a module was suggested by Sarkar and Pandey in the year 1980 which talks about MRR to the related to the various you know different process related parameters like number abrasive particles impacting per unit time given by term z the diameter of the abrasive grain mean diameter give by term d the velocity at which abrasive grain falls on to the surface and then also it is ratio of the density of the abrasive material to the H of the work material Hw okay.

So that ratio is also pretty critical for purpose of determining the MRR and the various order of matured analysis which is done for the various parameters and ultimately the MRR is related is directly related to the first power of the number of abrasive particles impacting front area the 3rd power of the diameter about 1.5 power of the velocity and the density to H is ratio it is about ¾ 0.75 is a power.

So that is how the variation happens the term ζ here is a constant which actually also comes from experimental monitoring of a MRR with respect to all the z parameters so this is actually an empirical formula which more comes out because of you know some recessional analysis done on the actual process but I even doing the USM process would like to do some geometrical derivation which may result in some identical kind of formulation for the particular MRR that is in question.

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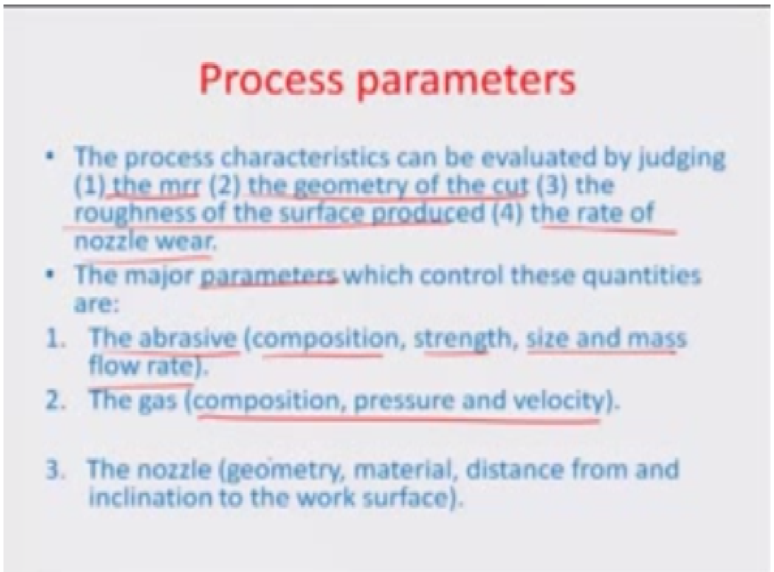

So the process characteristics can be evaluated by judging the material removal rate, the geometry of the cut, the roughness of the surface that is produced, the roughness of the rate of nozzle wear and these are mostly the four main characteristics related to any abrasive jet machining crosses and the major parameters for which controls such characteristics, quantities are the abrasive itself. Where the composition matters is the strength of the abrasive matters, at which the abrasive was flowing in the particular gas sample that matters.

The gas again where the composition pressure is velocity makes a difference and further the nozzle and the nozzle material, where the geometry of the nozzle, the material of the nozzle and of course the nozzle tip distance the distance from the work piece and so it is inclination with respect work piece so these are some of the major parameter issues, which actually control this process characteristics like a mirror the cut geometry you know the surface roughness so rate of where and the nozzle and so on so forth.

So let us look individually and some of these different aspects related to the AJM process and try to figure out how the change in the different parameter result in changing the process characteristics that we are trying to analyze, so when we look at the abrasive mainly there are two different types of abrasives which are used.

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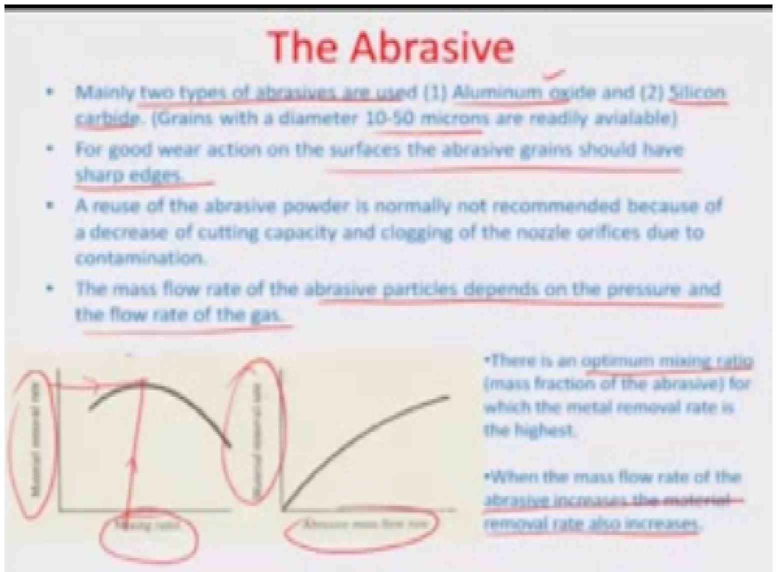

One is of course the aluminum oxide L to 3 which is again very hard as a material and there of course silicon carbide, typically grains with the mean diameter of 10 to 15 microns and deployed there also readily available commercially for only this purpose where either you use them for you know the abrasive jet machining or the abrasive water jet machining, but there is again a mixture or a slurry created between the abrasive and the water the water rest of air is the throwing medium of particles to particular work surface.

Also for good where action on the surfaces the abrasive grain should have sharp edges or use of the abrasive powder is normally not recommended because obviously if you think of the sharpness of the edges as you do different fractures or subsequent fractures, keeping on decreasing so the grain sharpness would decrease the functional time if you are cutting you know using the same abrasive grains every time and so what would typically happen is that because of the decreasing in this capacity.

Of cutting there would be a slow MRR and there is also a tendency of clogging the nozzles we because of which again the nozzle shape geometry image change with time and then you know the estimated profile that is suppose to make the impression of the cut or the fracture would change as function of time which is actually lot very good have or sort of very good process deviation and that needs to be controlled called frequently so the mass flow rate of the abrasive particles they of course depend on the pressure and the flow rate of the gas and there is something called an optimum mixing ration can think of it supposing keeping on loading the abrasive on to the air or in case of.

Abrasive what the jet machine in the, there is a certain limit up to which the loading would take place as well as the mean free path would be could in for the particles to individual momentum ultimately it is momentum which is getting you know transferred on the work piece which results in the impingement of the fractures, so if supposing the particles are too closely loaded because of the high density of the particle in the air or the mixing ratio is probably high.

So in that event you may not be able to realize much momentum transfer because there would be into gain collegians and such collegians are to be avoided as far as possible whenever we talked about this grain throw kind of process mechanical move of material is in involved through fracture, so the mass flow rate of the abrasive increases in material removal rate increases as you can see here but few time to t change the mixing ratio there is only an optimum based up to which the MRR would be the highest.

Beyond which there would be a again I into gain collegian and reduction the mean free path resulting and slowly you know degrees in the MRR value so there is a platoing optimum which happens in terms of mixing ratio whereas in case some mass flow rate it is almost a direct proportionality which is away so that is regarding the abrasive in the weight flows.

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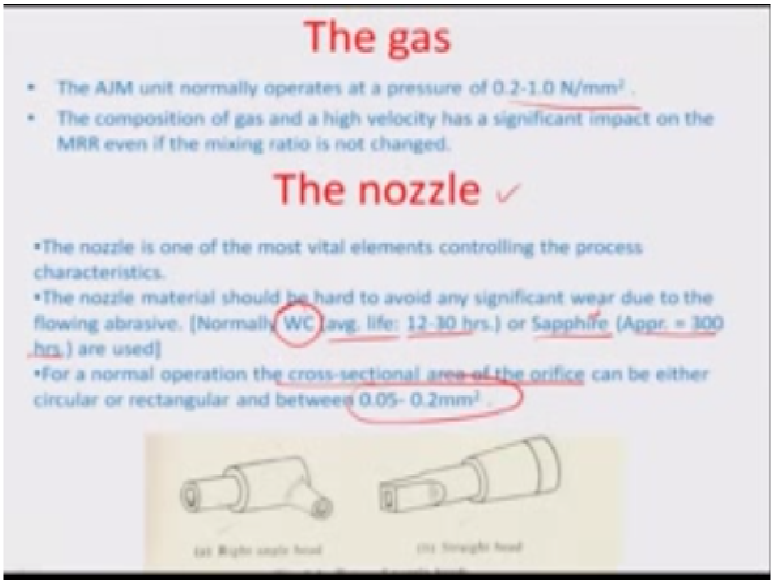

The gas of course is a very pretty important constituent of the abrasive jet machining so typically the pressures that a AJM normally operates the range of 0.2 to about 1 N/m^2, the composition of the gas and the high velocity as a significant impact on the MMR even if the mixing ratio is not changed, fine one large it is important to avoid to having a corrosive gas because all though sometimes deliberately corrosive gasses used because you want to piece of the material but in this particular case because it is open chamber process.

It is better idea not to play around the gas too much and make it like environmentally or not affecting the operator. So obviously should be non corrosive as far as possible. Talking about the nozzle it is one of the vital elements which is responsible for again controlling almost all the process characteristics. The nozzle material should avoid any significant wear, it should have good working life time probably because you know there is continuous flow of the abrasive the gas and there is always a tendency of the abrasive to change the nozzle orifice so it is important to match the hardness of the nozzle material in a manner so that such opening with time does it take place so average life time of some of the conventional materials which are used for nozzles like it is a disturbance tungsten carbides about 12 to 20 hours.

If you are using a sapphire nozzle although it is more expensive but the approximate life time increases about 300 hours it is higher the tungsten carbide it is more durable and for all practical purposes the cross section area of a nozzle or an orifice is held between 0.05 to 0.2mm^2 that can be right angled or straight at nozzles with various cross sections like circular or square cross section but you know the idea is that you have to keep while initiating the process every time.

You have to keep a close watch on the nozzle orifice and if you see subsequent deformation or change in the orifice must think of a plan of removing the nozzle that changing with new one, so that is how the different process characteristic go the other important issues I told you is also known as the nozzle tip distance.

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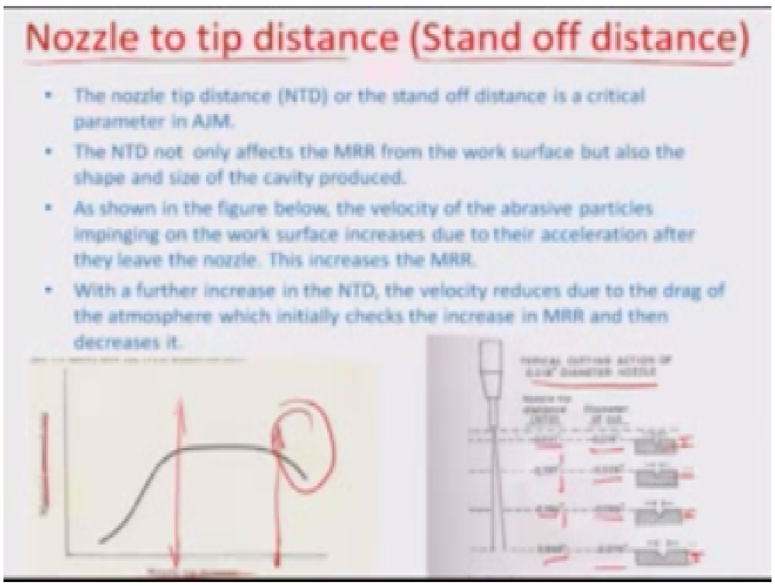

Or what we commonly known as standoff distance and in fact this changes point a bit of the geometry of the cut that is eventually getting formulates in terms of this spread and the depth which would be caused because of such a throw of material and also there is an optimum best nozzle tip distance over which there is actually a maximum material removal rate, so you can think of it in this manner that supposing the nozzle is too close to the work piece and the distance allowing the abrasive to be thrown out of the jet while getting accelerated is very small.

So you already know that you know by the Newton laws v^{-2} becomes equal to it is actually almost proportion to the acceleration and also to the distance, so if you allowing the distance to be more or distance of traverse of the particles to be more obviously the velocity that it would finally end up and the kinetic energy would be much higher now if the nozzle where to close and the abrasive grain would not find.

So much distance to be moved before this strike or colloid on to the surface obviously their moment would be slower now supposing keep on increasing the nozzle distance then this factor increases you know because the momentum is higher and higher, but then there is also an additional factor of drag which comes because of atmosphere obviously the processes done in normal open atmosphere.

And they are going to be air molecules in the path of the abrasive and there is also going to be a cross collision affect which happens normally because these are all you know if you look at the velocity profile it is coming out of a pipe so it is more like a pipe flow while the central regions are of the particles which are in the central regions of the pipe have much more velocity in comparison to that at the sides.

So typically this profile looks something like a Gaussian with the maximum velocity at the center and you know telling velocity at both ends and so you can think of a that in such a casse when the abrasive comes out of the nozzle and it has top traverse for a such distance that is going to be number 1 track atmospheric track which slows down the abrasive and also there is going to be cross grain collisions okay.

So because of all that there is a tendency that the momentum again starts at new c beyond a certain nozzle temp distance, now this would not affect upto some region where thereis a cancellation affect that the on when the momentum is increasing another it is reducing because of the track but then beyond the point where the drag becomes dominant you know obviously the momentum is going to reduce.

So therefore if I wanted to look at the way that the nozzle tip changes the material removal rate so for the first few you know units of length the material removal increases and then there is almost a cancellation effect because of this increase in subsequently the drag factor and then drag becomes predominant beyond which the MMR again goes down, so typically it also affects in terms of the profile.

So you think of a that this is a case where they are showing nozzle at distance of let us say 0.031 inches which results in a diameter of a cut which is 0.018 inches and of course the depth is more prominent here okay. But as you change the nozzle tip distance to 0.197, 0.394, 0.590 so increasing the nozzle tip so obviously there is a beam spread so your diameter reduces from increases from 0.018 to 0.025, 0,059, 0.079 inches respectively and if you look at the along the depth at which the penetration is taking place here, the depth also reducing with the nozzle tip distance.

So obviously it will be more broader and shallow if we talk about increased entities and therefore that control of accuracy of the exact cut size actually chances as the nozzle tip distance is increased. So that is a very, very important phenomena that happens in case of grain throw machining kind of cases.

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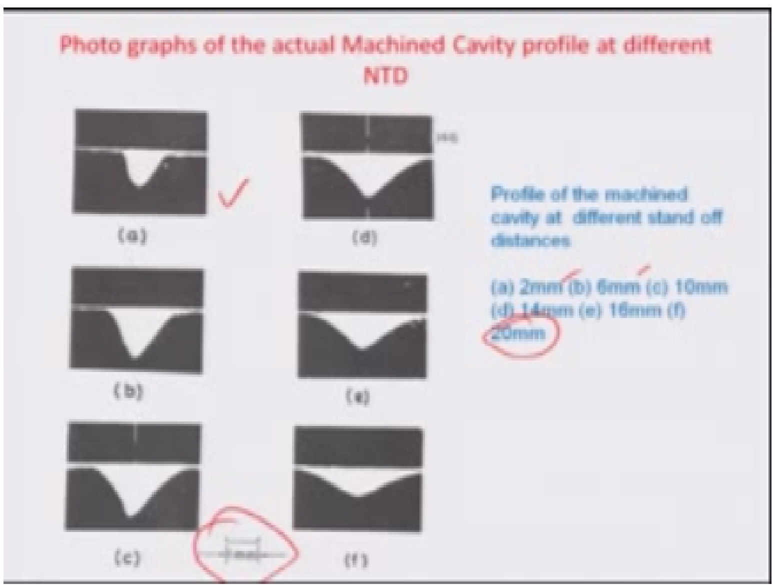

These are actual cavities in several cases build by build in experiment where a scale of this is about 1mm and it is corresponding to a nozzle tip distance 2mm, 6mm all the way above 20mm. So there are different cases where it shows how shallow and wide the cavity becomes as the entity is increased from 2mm to 20mm.

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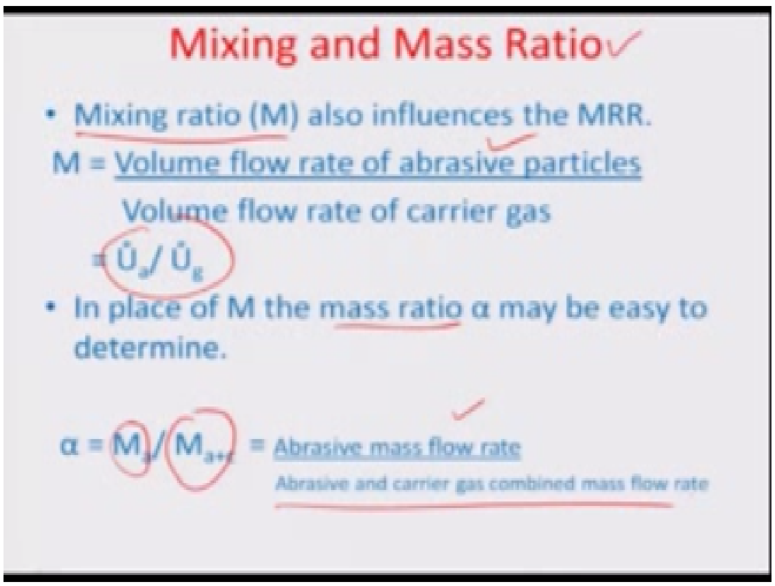

The two important parameters in case of how the gas is flown and how the abrasive is loaded are one mixing ratio another is the mass ratio, so by definition mixing ratio M can be determined by the volume flow rate of the abrasives per unit the volume flow rate of the carrier gas so you can call it as $\dot{U}_a/\dot{U}_g$ and the mass ratio on the other hand the α can be determined as a mass of the abrasive by the total mass of the abrasive plus the carrier gas which flows out the nozzle.

So in other words you can actually if you wanted to put in weights instead of the total mass so obviously these are function of times you can have the abrasive mass flow rate per unit the abrasive plus carrier gas combined mass flow rate in this particular case. So let us actually investigate one or two problems where we can see if you can calculate the mixing ratio of the mass ratio given some parameters in a process and arrive at some ball pack values where it is more important to understand what is the level at which should operate in terms of mixing ratio and the mass ratio.

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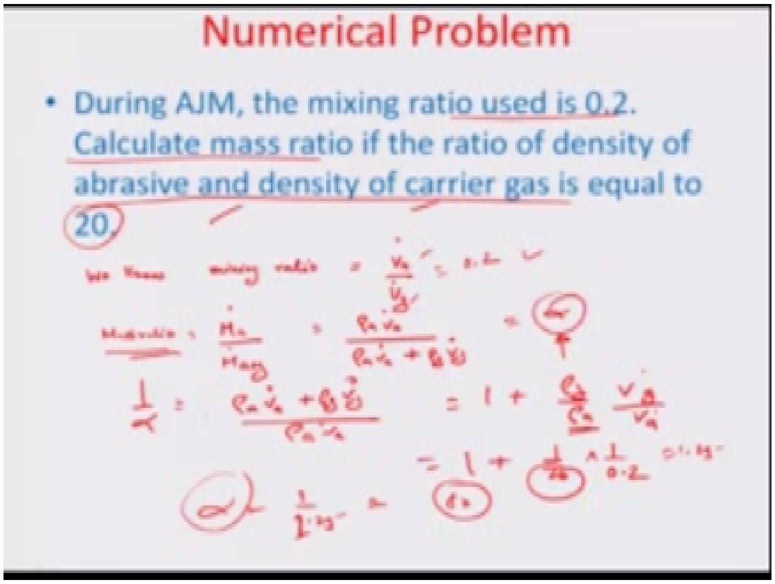

So let us actually do a numerical problem now where we are talking AJM machine with mixing ratio which is about 0.2 and we want to calculate what is the mass ratio if the ratio of the density is of abrasive and density of carrier gas is given to be about 20. So we know the mixing ratio equals $\dot{v}_a/\dot{v}_g$ and the mass ratio is $\dot{M}_a/\ \dot{M}_a+\dot{M}_g$ so $\rho_a\dot{v}_a/\rho_a\dot{v}_a+\rho_g\dot{v}_g=\alpha$ so α is basically the mass ratio here the rate of flow of abrasives by rate of flow of abrasive plus the gas.

So $1/\alpha$ becomes equal to $\rho_a\dot{v}_a+\rho_g\dot{v}_g/\rho_a\dot{v}_a$ which is $1+\rho_g/\rho_a\ \dot{v}_g/\dot{v}_a$ and that becomes equal to 1+1/20 times of 0.2mm where the layer to the abrasive to the carrier gas density is given to be 20, so obviously ρ_g/ρ_a would be 1/20 and similarly the volume flow rate of the gas to the abrasive is just the inverse of 0.2 which is actually the mixing ratio, so this becomes equal to 1.25 and other words α becomes equal to 1/1.25 which is actually equal to 80.

So given the density ratios of the abrasive and the carrier gas so given the mixing ratio and the abrasive you know abrasive to carrier gas density ratio we can calculate easily the α or the mass ratio for any process.

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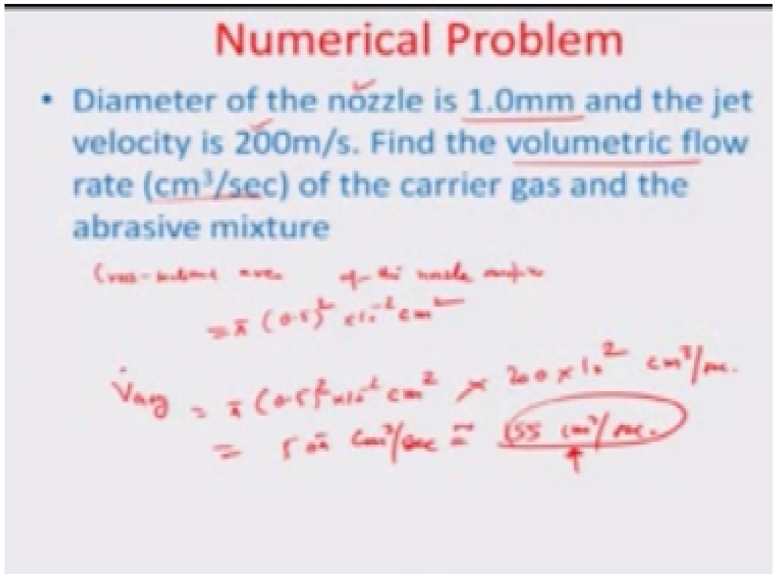

Let us look into another problem we have diameter of nozzle which is about 1m and the jet velocity of 200m/s and we want to estimate what is volumetric flow rate and cm^3/s of the carrier gas of the abrasive mixture we assume this nozzle to be circular because of the diameter factor that is there so the cross sectional area here of the nozzle RFS given by πr^2

And so the volume of the air plus abrasive gas abrasive the volume flow rate will be actually given by this cross section area which is in cm^2 times of the velocity in cm^2 again and so many cm^3/s is a volume of the impressive and the gas this becomes we go to 55cmm^3/s is actually=about close to 155cm/second approximately. So that is how you know the volumetric flow rate of this particular nozzle can be calculated.

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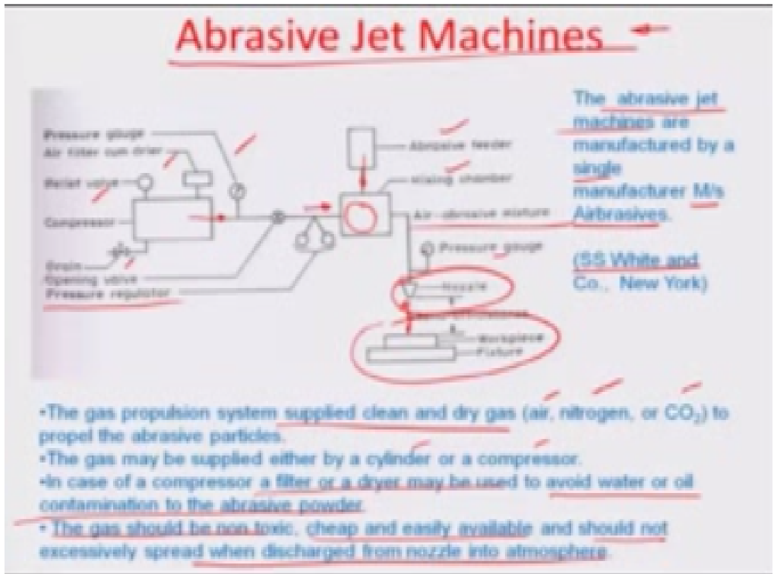

Now we try to look at the constitution of the machine which helps in doing AJM, so basically the various parts of the machine probably you realize this is the nozzle this is the work piece fixture which there piece can be held and the distance between the two also known as the stand of distance nozzle.

So beyond the nozzle there are many different parts of this particular machine for example there is a abrasive fitter the feeder there is a mixing chamber one side there is a air and flow which is regulated pressure wise by opening and closing set of valves which comes directly in the rout of the compressor. So the compressor feed compressed here in to this particular circuit through the valve on this mixing chamber.

Obviously the compressive would have a really valve they would have a air filter come drier which maintains the air quality which is being compressed there is a pressure gage to indicate what is the pressure ate where is the compressor is operating there is obviously the relive valve given to the compressor to train off what excess whatever excess pressures are felt within the compressor chamber.

And so typically the air abrasive mixture happen here because of the hoping effect or hoping process the abrasive fetter hops the abrasive grains in to the ambient air. And the air abrasive mixture is again pass through the nozzle there is a pressure way is add just in the close vicinity of the nozzle to have a look at what is kind of ambient pressure that is being injected through to nozzle on to the work piece.

So typically majority of this abrasive may jet machines are manufacture by a single manufacture called air abrasives and it is typically from a SS white and Co. at New York, the gas propulsion systems supplied clean and dry gas typically different gasses like air nitrogen and see or two can be utilized for mixing abrasives and to prepare the abrasives.

So it can supplied either by cylinder or compressive typically compressor is preferred when its repeated use case and case of a compressor a filter and drier may be used because obviously it is dynamic way to compress whatever KDL medium like to set in to carry the impressive and it is also to avoid the water royal contamination of the abrasive power. Gas should be non toxic cheep is evaluable should not excessively be spread when discharge from the nozzle in to that atmosphere so on and so forth.

So that is how abrasive jet machines are carried out. Now let us look at another mechanical process of substantial inters which is known as ultrasonic machining or the USM process.

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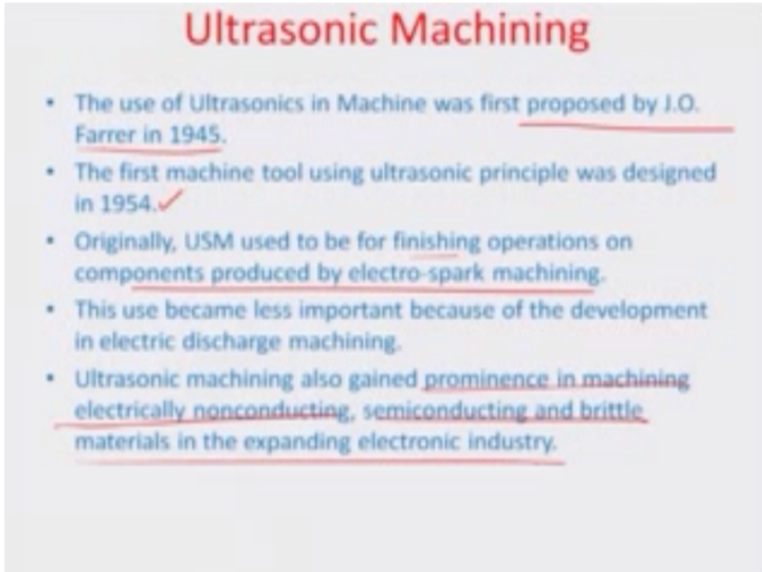

So the process was first proposed by this guy J.O. Farrer in 1945 and the first machine tool are using this USM principle or ultrasonic principle was designed about 9 years later in 1954 and originally it was used for finishing process particularly for those components which should be otherwise used by electro-spark machining or electro discharge machining.

But it came very important development and a almost independent process which did not have any more finishing requirements but actually beyond finishing requirements more into machining okay so now today ultrasonic machining can be used for fabrication of micro structures particularly if you want to make a very small high result hole in a silicon vapor the best way to do that is through your seam people have made bulk macro machine the piece of sensors which would otherwise monitor pressure on a silicon membrane by using very accurately using the USM process.

So it gained to lot of prominent in machining electrical and non-conducting semi conducting and brittle materials particularly in expanding electronic industry and let us look at some of the basics of USM particularly what really USM is how different from abrasive machining and again is the mechanics of material you will say different let us look at how the basic removal process of material takes place in USM.

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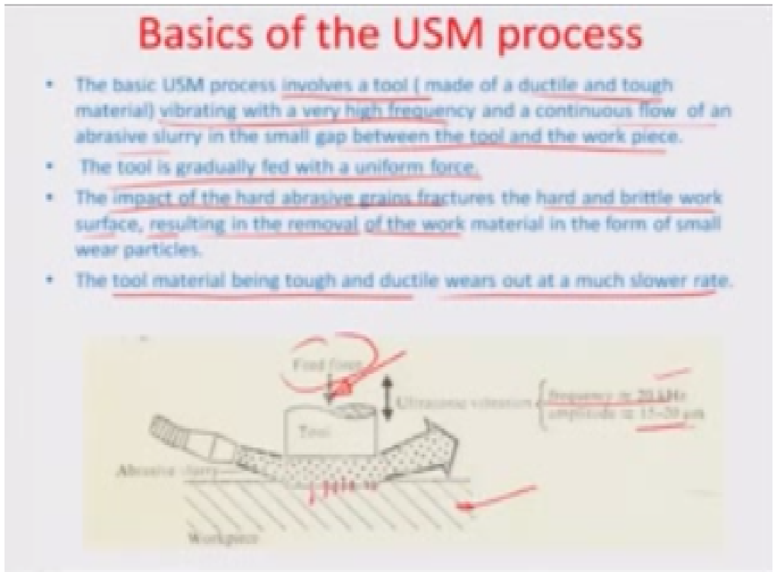

So it is basically involves tools which is otherwise ductile and tough you can see this tool right here ductile and tough tool which has a speed force and there is a slurry which is injected in to the web zone at certain pressure so the idea is the tool moves against of the slurry to the work piece so the ploughing the individual abrasive grains into the work piece.

And the mechanics so again is that is involved through brittle fracture so the material that is being machine here is mostly brittle glass silicon or the ceramics so on so forth so therefore impact of sharp abrasive grain because of tool lead would be much more in comparison to what otherwise AJM process do by just a great through actual is also case where there is a few grains which are thrown into the work piece.

But their material removal of the contribution to their material removal as well as actually evaluate later is in significant in comparison to the MRR because of the actual direct hampering and ploughing effect so here you have a active hampering of again causing a fracture and so MRR rates material removal rates are much, much higher in this case and comparison to simple abrasive inject machining process.

So the tool lead vibrates with a high frequency as a continuous flow of abrasive slurry small gap maintain between the tool and work piece and obviously the tool is gradually fed with a uniform force creates impact of the hard abrasive fractures the hard and brittle work surface and this is majority is the major mechanism of removal of the work materials.

So basically removes the small particles small ware particles and they carried away very easily with the steam that carries the slurry so the medium which has a slurry in fact is also the cable medium for the fracture pieces of the work piece which is generated because of the machining action so tool in the cases normally tough and the ductile it wears out much slower in the comparison to the work piece.

One of the reason were work piece gets removed because of the tough and ductile material abrasive obviously is going to much harder so it create a impact both f the tool side as well as work piece site and so we will have to put all these things in to the model when we try to build up the mathematical model for the material removal as in the particular case.

And the frequency which are typical used in this cases are size about 20kh amplitude of the motions is very small, typically about 15 to 20 microns, which creates the impression in the work piece, so let us look at some of the you know geometric approximation which are involved in polughing action resulting in the numeral rate and for this the best reason or the best theory which has been purposed so far is by Mc. Shaw.

The Shaw theory as certain assumptions which are involved in order to geometrically model the situation, so that you could actually look at things from a perspective of material properties like hardness ultimate strength etc. on one hand and the geometry of grain and the relative motion between the tool and the work piece, so it is the complex would say mechanical problem when we talk about USM model of the estimation of the material rate.

So let us look at the Shaw theory, so some of the assumptions which the Shaw theory takes into the count.

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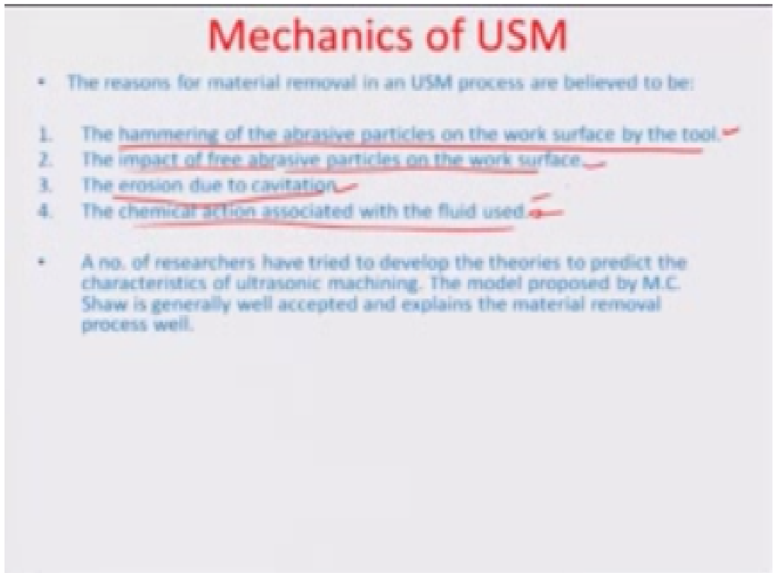

The hammering of the abrasive particles on the work surface is typically done by the tool, the impact of the free abrasive particles create the material remover mostly on the work surface. There is off course some removal because of cavitations effect. Obviously tool is vibrating at almost 10kh probably horizontal magnitude about 20kh in that particular range. So tool is supposed to move much faster in comparison to the relaxation property on the medium and the medium always lacks behind the tool, which may be resulting in some kind of gaps and some kind of bubbles.

And these bubbles are responsible for mostly carrying away or sometimes even creating additional impact creating additional or sometime even creating additional impact effects on the work surface. And so the erosion of the material mostly you can say even if the fracture is developed in the materialistic semi fractured can be propagated through this cavitations mechanism because of the highly vibrating and so also there is the chemical actions fluid used.
And whether can be a material made because of the USM process.
So I think I will close this module now but in the next module I am going to work on this short theory with the assumptions that have been made here as a potential causes for material remover in USM and then look at geometrically how the material removal rate can be modeled, so as if now thank you so much bye.

<u>Acknowledgement</u>

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