Advanced Machining Processes
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Lecture No 15

In the last lecture we discussed about the variation of the current in smooth direct current supply for the electromagnet and pulse direct current supply to the electromagnet and we found that before really the current reaches to the 0 value, the on time or on pulse started and it never attain the 0 value then we also measure the forces with the help of dynamo meter and we found that during pulse DC power supply there was a substantial increase in the normal forces that are acting on the workpiece compared to the smooth DC power supply.

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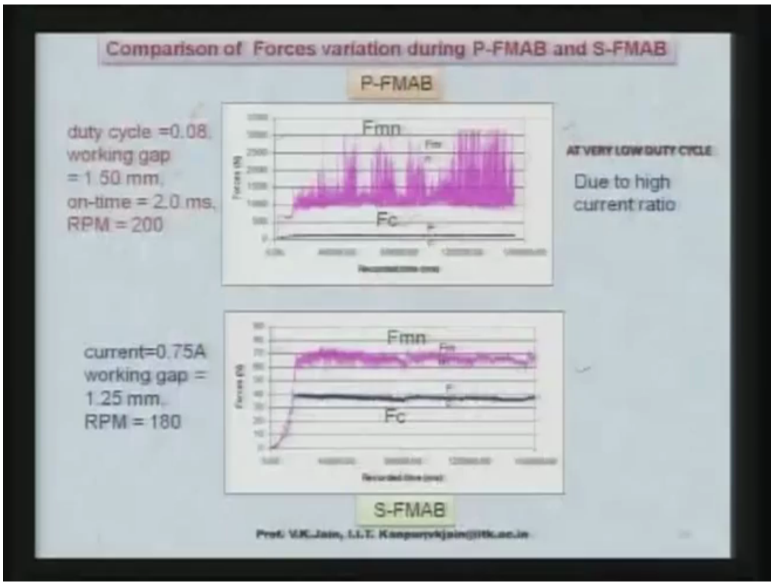

As you can see in this particular figure that with the 0.08 that is lowest duty cycle that we could use in our pulse generator, the highest normal force that you are able to achieve is around 3000 newton while in case of smooth DC power supply it is around 70 to 75 newton so there is a very large increase in the force normal forces and this normal force is responsible for the penetration of the abrasive particle inside the workpiece surface. So if penetration is very large then what will happen that the cutting force may not be large enough to remove whole of the material in the form of the chip, so there are other phenomenon and there are other problems also, if the normal force is very large, penetration is very large, it may lead to the defect the workpiece being finished. So let us see what are the problems we can expect?

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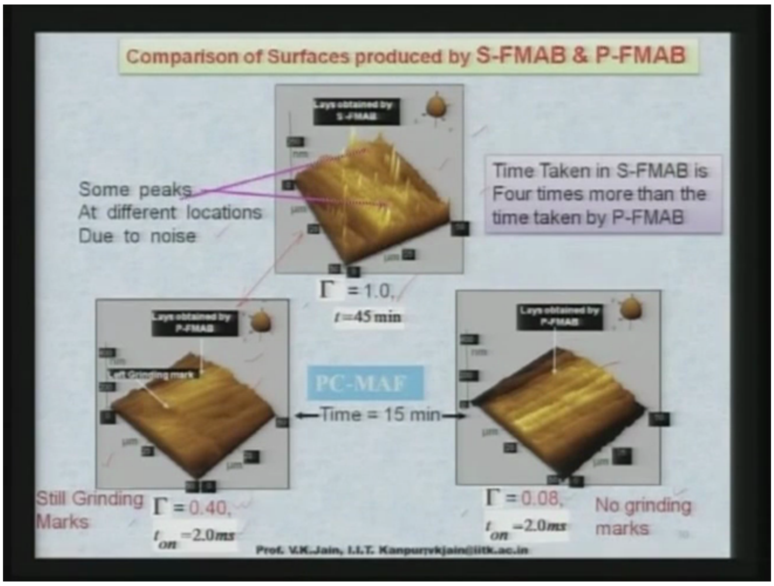

If we see here these figure shows you the lay obtain by static flexible magnetic abrasive brush that is when you are using smooth DC power supply and if you see on the left side this is the figure which shows the smoother finished surface obtain by the pulse DC power supply. Now here the duty cycle is 0.40 as you can see here but still some grinding lay or marks are left here which you can clearly see. When we use a smaller duty cycle that is 0.08 we got a better surface roughness value and better texture of the surface there were no grinding marks as you can clearly see over here, the marks are only that made by the magnetic abrasive finishing process and the time taken in case of pulsating flexible magnetic abrasive brush is much lower than the time taken by static flexible magnetic abrasive brush.

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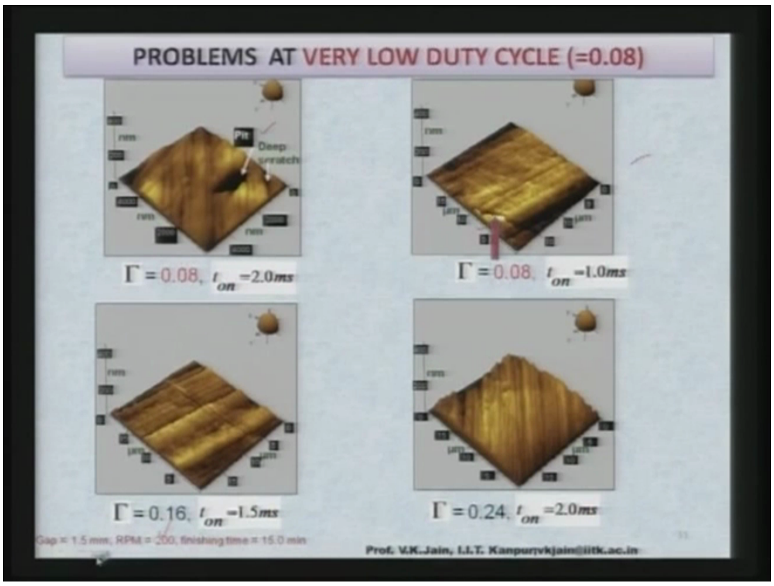

But as I mentioned a minute back that force is very large in case of very low duty cycle and due to the very large normal force the penetration of the abrasive particle is very deep and as a result of that it may result sometimes the defect in the finished surface as you can clearly see here that pit has been formed and this pit has been formed because of very deep penetration of abrasive particle due to very large normal force acting on the workpiece through the abrasive particle.

So these kind of the defects are not acceptable on the finished component, other kind of defects you see on the right side the workpiece, finished workpiece has been has a very micro-nano crack as you can see over here through the arrow shown over here that some micro-nano crack has been formed on the finished workpiece although the surface roughness value is very good but these kind of defects may lead to the rejection of the finished component. If you perform the finishing operation at high duty cycle just like say 0.16 as the duty cycle then those kind of defects are not visible on the finished component if you go still higher, the surface roughness value may slightly increase about those defects may be overcome as you can see when it is performed at 0.24 as the duty cycle, so the gap in these machine finishing process is was maintained as 1.5 millimetre and revolutions per minute was 200 and finishing time is 15 minutes.

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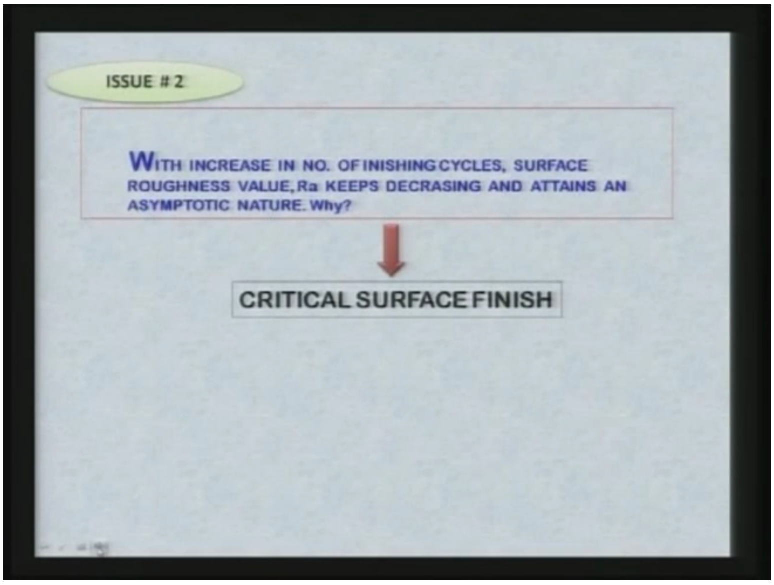

Second issue which is important in case of magnetic abrasive finishing is with increase in number of finishing cycles, surface roughness value Ra keeps decreasing and attains an asymptotic nature. The question arises and as a lay man or in general way if you keep increasing finishing time it is Ra value should keep decreasing but after a certain number of finishing cycle its Ra value becomes more or less unchangeable or constant or it attains an asymptotic nature and that surface roughness value is named as critical surface finish that you can obtain for the given finishing conditions and the workpiece.

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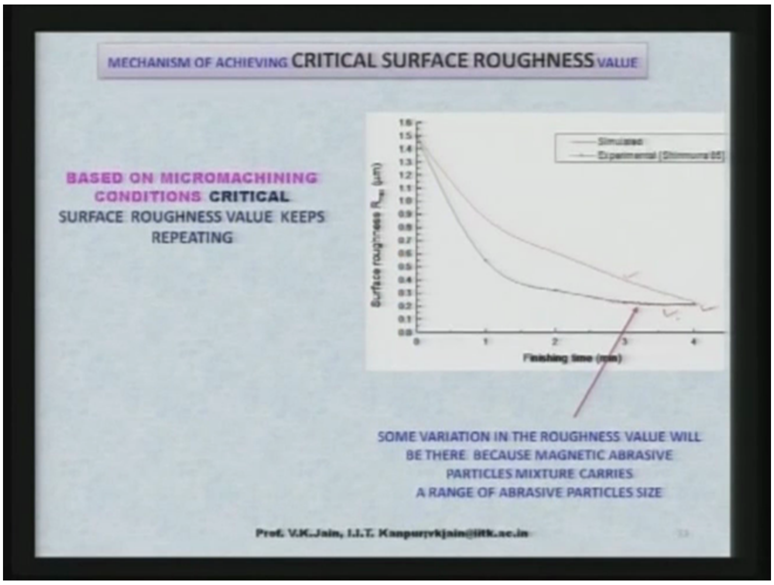

As you can see here that based on micro-machining condition critical surface roughness value keeps repeating. Now here also this is a simulated one and these are the experimental ones. Now what will happen that they are more or less constant or no change there but still slide variation you will find when you observe these value because unless you have a highly homogeneous flexible magnetic abrasive brush, you will not exactly the same value, so slide variation is there but this becomes more or less a constant value and that surface roughness value is known as critical surface roughness value.

Some variation in the roughness value will be there because magnetic abrasive particles mixture carries a range of abrasive particles size also. Now suppose there is a certain mesh size was diameter of the abrasive particle should be to micron but this will not all the particles will not have the same to micron is the diameter as it will be varying in certain range and because of that variation in certain range there you find that there is a variation in the critical surface roughness value that you are achieving for the given finishing conditions.

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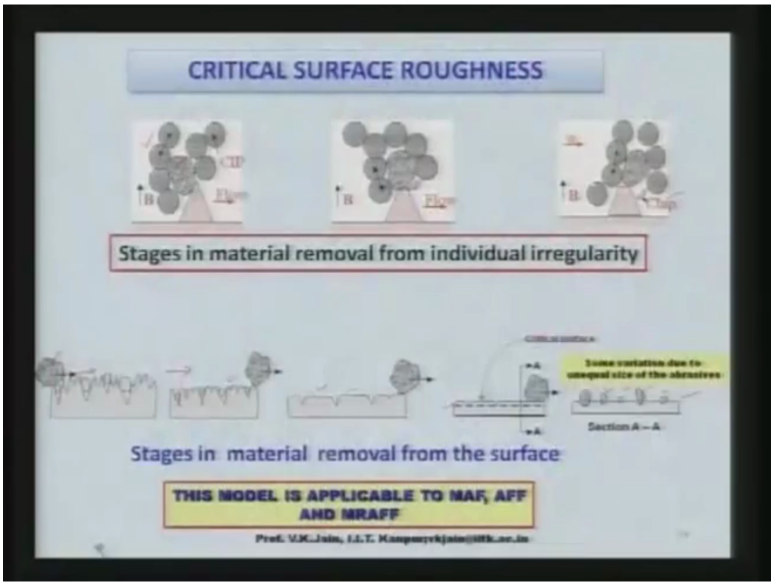

Now how the mechanism is working? Let us try to understand this as we have seen that you have the abrasive particles and ferromagnetic particles in the case when you are not using the standard ferromagnetic abrasive particles, how it is working? So you can see here that this is the abrasive particles and these are the ferromagnetic particles and these ferromagnetic particles will align along the magnetic lines of force and they will form a chain or they will form the chains.

Now in between the chains abrasive particles is entangled over here as you can see here and when this set of abrasive particles and ferromagnetic particles comes and strikes the workpiece surface peaks over here then if the cutting force is more than the resistance offered by the workpiece surface then it will shear off this peak as you can see here in the form of the micro or nano chip depending upon what is the normal force value and this chip microchip gets separated out as the whole chain of the ferromagnetic particles and abrasive particles keeps moving in the axial direction, so or tangential direction rather, so you get the material removed in the form of the micro nano chips.

Actually in this way it works and stages in material remover from individual irregularities in 3 stages we have tried to explain this mechanism. Now let us see the same thing but in a different way stages in material removal from the surface as you can see this is the abrasive particles which you can stimulate with this particular abrasive particles and there are certain abrasive particles whose diameter is smaller than the width of the valleys, so what will happen that some of them will get set over there which are unless it will be will not be able to remove the material and this is the bigger size particle, so as the axial force is acting in this particular direction it will move and remove the peaks and it will shear of those peaks and you will get this kind of the situation by the time it reaches to the end of the workpiece.

Now if you again there will be another abrasive particles coming behind this and that also will keep shearing off the peaks and finally you will get this kind of the surface. Now after this you attain this particular surface what will happen that peaks have been reduced to the extent that their depth or penetration of the abrasive particles is larger than the depth of these peaks and valleys as a result of that as this process continues…and that fixed Ra value of the finished surface which is known as critical surface roughness value.

Now I also mentioned in the earlier slide that the critical surface roughness value will keeps slightly changing from cycle to cycle because the size of the abrasive particles is not constant unless the size is constant this Ra critical value we keep on changing as you can see in the last figure over here that there are the abrasive particles of different sizes and they will create the scratches or the depth of penetration will be different in each case depending upon what is the force acting on the individual abrasive particle. That is why the critical surface roughness value keeps slightly changing on either side of that particular Ra value. This model is applicable to magnetic abrasive finishing, abrasive flow finishing and magnetorheological abrasive flow finishing also because all the 3 are working more or less on the same principles.

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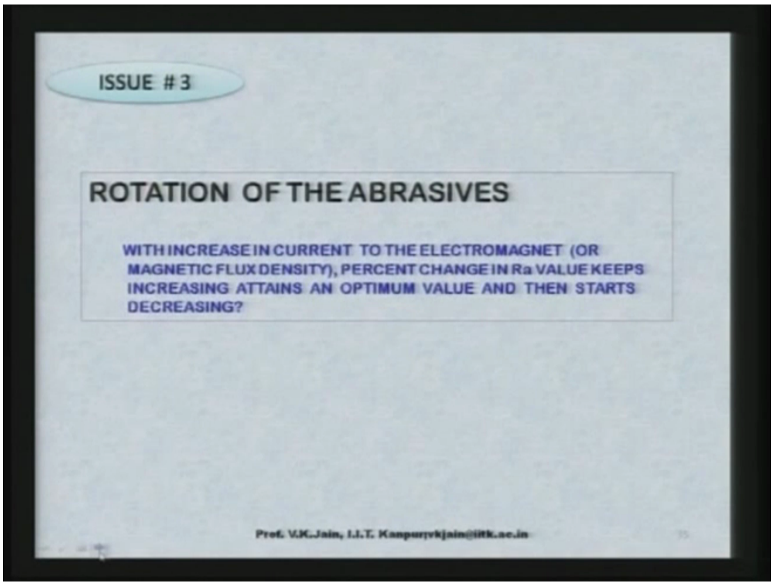

3rd issue related to magnetic abrasive finishing which is applicable to other of processes which I just mentioned like abrasive flow finishing and magnetorheological abrasive flow finishing are rotation of the abrasive particle with increase in current to the electromagnet or magnetic flux density percent change in Ra value keeps increasing. It attains an optimum value and then starts decreasing that we have seen already one figure related to this.

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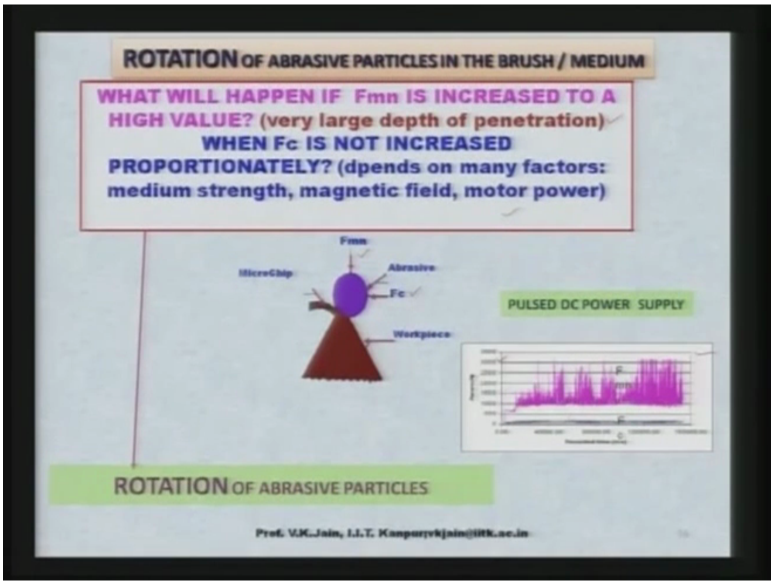

Now what will happen if normal magnetic force F mn is increased to a higher value? As I mentioned earlier we have already seen the observations made during the magnetic, pulse rating magnetic abrasive finishing that normal force increased to 3000 Newton from 70 to 75 Newton in case of a smooth DC power supply. So with such a large value of normal force till depth of penetration is going to be very large so when cutting force is not increased proportionately what happens actually in MAF that you are getting the cutting force from the electric motor and you are not changing the ratings or any other parameter, so that the cutting force also changes.

Now due to the very large depth of penetration due to the high normal magnetic force, if cutting forces does not increased proportionately then the resistance offered by the workpiece material will be much higher than the cutting force being applied through the rotation of the flexible magnetic abrasive brush and this rotation is attain through an electric motor. So it depends on many factors such as medium strength magnetic field, motor power, et cetera.

Now if this does not happen that means cutting force does not increase proportionately and what will happen to the abrasive particle? 2 possibilities are there, either that abrasive particle remains implanted in the workpiece or changes its depth of penetration such that the cutting force becomes larger than the resistance being offered by the workpiece material and this is exactly what happens during MAF, we have tried to show it through the observation, experimental observation on the finished component as well as computation or applications of finite element method.

That we have already discussed that this is the normal force which is coming due to the magnetic field and this is the cutting force which is being applied due to the rotation or the flexible magnetic restive brush and that power comes from the electric motor. These variation in the forces we have already seen I have told you that during pulse rating flexible magnetic abrasive brush you get as high as 3000 Newton as the force that is normal force acting on the workpiece surface and you can clearly see there is hardly any increase or there is no increase as long is cutting force FC is concerned that is very clear from this diagram also.

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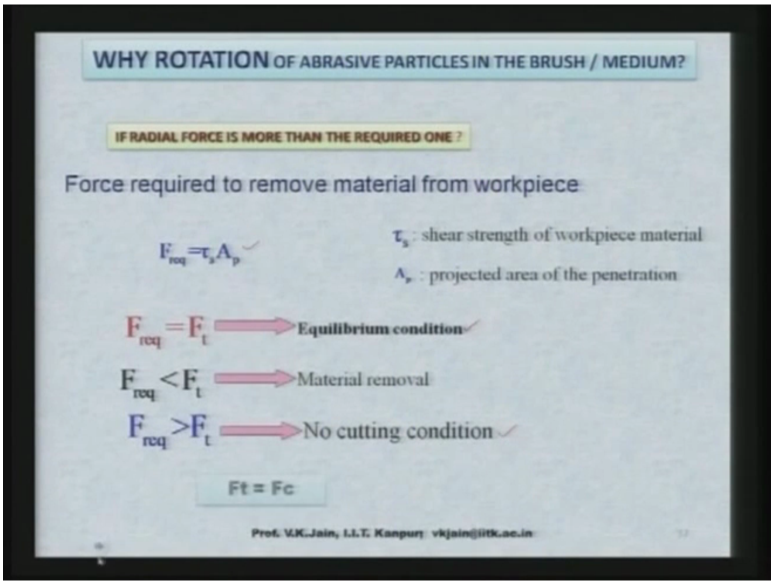

Now so 3 conditions adjusted over there I will show you, now why rotation of abrasive particles in the brush or the medium takes place? If radial force is more than the required one what will happen? Force required to remove material from workpiece will be equal to tou s multiplied by A p where tou s is shear strength of the workpiece material and A p is the projected area of the penetration we have seen in the earlier slide that material is being removed in the form of the microchips, so whatever is the penetration that projected area A p that particular abrasive particle and the workpiece common (())(16:37) area that is known as A p and tou is the shear strength of the workpiece material.

Now if required force is equal to the cutting force of tangential force which is acting on the abrasive particles then this condition is known as equilibrium condition that means neither cutting is taking place nor abrasive particles is moving and with just at the beginning of the moving. If required force is smaller than the cutting force that is acting on the abrasive particles and what will happen the abrasive particle will move for the and it will remove the material in the form of the microchips on nano chip. If required force is greater than the force acting on the abrasive particle then there will be no cutting condition that means abrasive particle will sit there inside the workpiece and this is the condition which we are discussing about the rotation of this particular abrasive particle under this condition.

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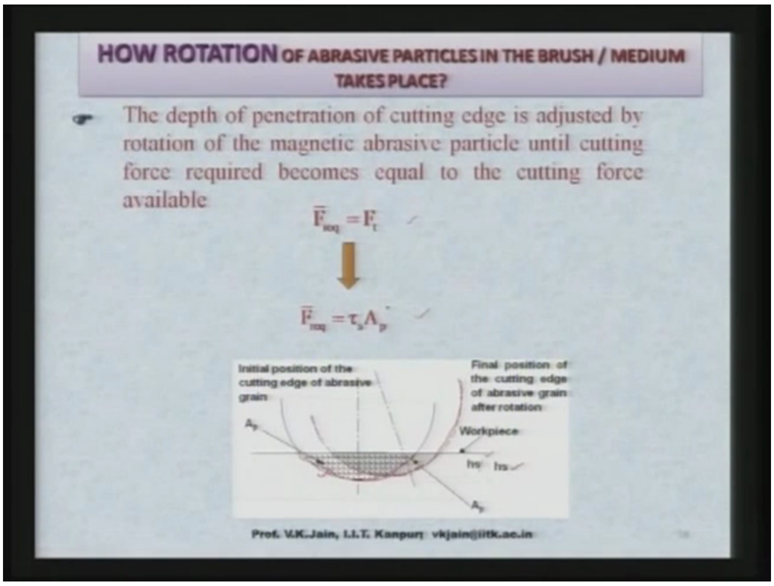

Now how rotation of abrasive particles in the brush or medium takes place let us understand this. The depth of penetration of cutting-edge is adjusted by rotation of the magnetic abrasive particle it is the case of the centred magnetic abrasive particle it can be just the abrasive particles in case of in case you are using the homogeneous mixture of the abrasive particles and ferromagnetic particle, so until cutting force required becomes equal to the cutting force available or cutting force acting on the abrasive particles.

So that is the equilibrium condition and this force can be calculated what is the force needed under equilibrium condition. This is exactly what happens let us try to understand this, now this is the condition as you can see here A p and this conditions is shown over here. Now here the cutting force require is much larger than the cutting force F c or F t acting on the abrasive particles.

So what will happen that this abrasive particle will try to rotate in such a fashion that in place of this hs is the depth of penetration it comes lower and becomes equal to hs dash that means it rotates and it attains the position like this where hs dash is now the new depth of penetration and if hs dash is the new depth of penetration which is smaller than the hs then the axial force or the cutting force require will definitely be smaller to remove the material in the form of the chip and this hs dash gets adjusted till the abrasive particle is capable to move further. So this is how it attains the condition when very large force is acting, normal force is acting but still it rotates and attains the condition that it can remove the material in the form of the microchips and whole of this analysis has been carried out using finite element method by Doctor S.C. Jaiswal of IIT Kanpur.

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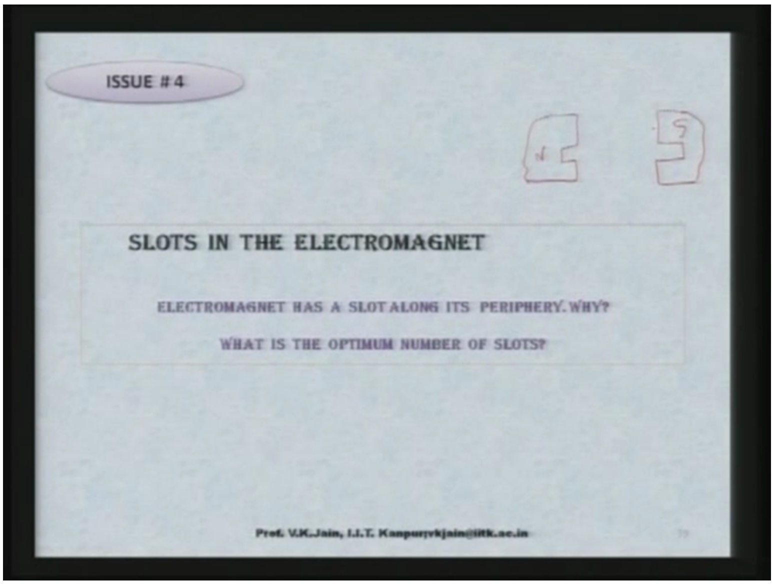

4th issue is again an important issue, we have seen that while finishing cylindrical workpieces there was a slot in the electromagnet something like this suppose this is the pole and there was a slot in the electromagnet and say this is the North pole same way there was a slot, 1 slot in the side of the South pole. Now the question arises why these slots are there and if we have one slot and why not to have 2 slots, 3 slots or 4 slots if a slot is advantageous. So let us see electromagnet has a slot along the its periphery, why? And what is the optimum number of slots, we have try to analyse it using finite element method and some of the results are presented over here.

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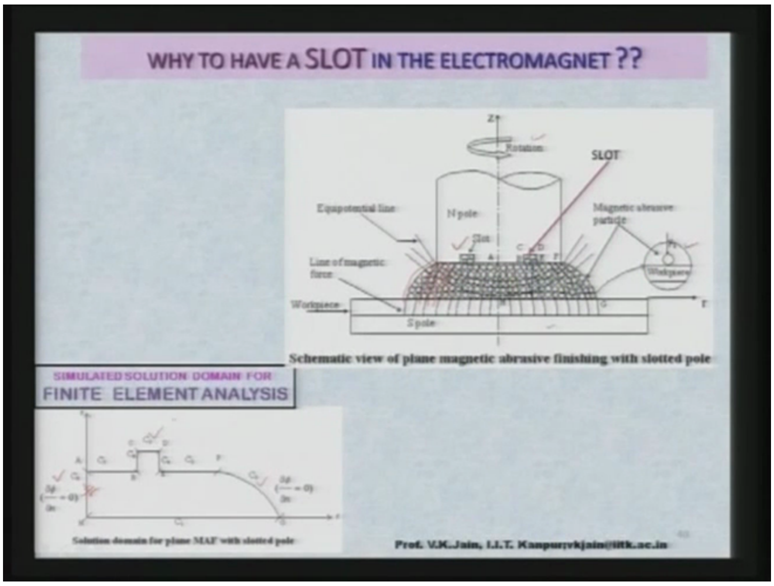

You can see the magnet here this is the magnet and which is having this is cylindrical magnet and which is having the slot over here and here is the South pole. Now this slot has been made deliberately take advantage of the slot in the magnetic abrasive finishing, this is how the abrasive particle is acting on the workpiece and these are the magnetic lines of force along with these ferromagnetic abrasive particles are aligned and this electromagnet rotates help of the electric motor.

Now while analysing it with the help of the finite element method we have made a particular domain and we have assumed that along C2 del phi over del n is equal to 0 condition exists same way here also on the and this is the central line of the magnet and also again we have assumed del phi over del n is equal to 0 and this is the condition of the slot all this has been analysed.

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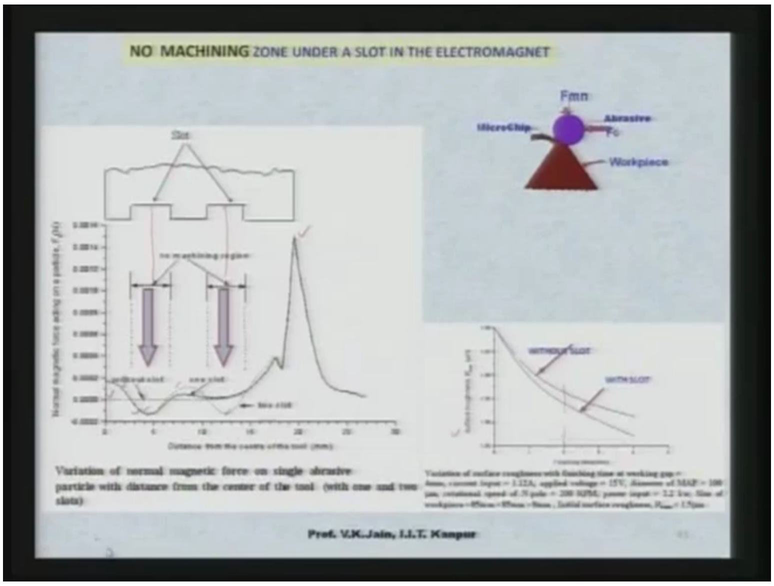

We have found these results, now these are the slots in the magnet, now here if you see the results carefully wherever there are the negative forces acting over here and these negative forces are acting just under the slot if you projected here forces are negative that simply means that just under the slot there is no machining, so that area is known as no machining zone but if you see other areas here if you see this more or less horizontal lines this tells you the magnet without any slot and the lines which are shown above this that is having either one slot or 2 slots.

So we can see that in certain area the force acting on the workpiece is higher than the case when there is no slot in certain areas the force acting on the workpiece is negative force that means no machining is taking place. Now because the flexible magnetic abrasive brush is rotating it is covering the whole area and the workpiece is also moving in x and y direction. So really speaking this will not affect too much as the negative force are concerned because at that particular time no machining will take place but rest of the places the forces are higher than the case of no slot condition and these forces are responsible or increasing the finishing rate and that is why we found that with each slot in the magnet finishing rate is higher compared to the case when there is a no slot and also we can see there is a curve which is showing for 2 slots and there is a curve for one slot.

In 2 slots cases the forces are slightly higher than the case of one slot negative force as well as positive force, so we also conclude that there is some advantage but not substantial difference is there in case of an slot and 2 slots, so at the most you can go for the 2 slots if you increase the slots for 4 slots, you do not get any substantial advantage. So at the most you can have 2 slots but generally one slot only is used to enhance the performance of the magnetic abrasive finishing and this is the highest force at you are otherwise also going to get at the edges of the electromagnet and this contributes a lot as long as finishing is concerned. Now you can see the this particular figure where you can see surface roughness Ra value obtain in a certain period of time and that period of time without slot the Ra value is higher and the slot the Ra value is over, so that means it is giving better performance or you can say indirectly that finishing rate is higher in case of magnetic has a slot compared to the case where magnet has no slots that is very clear from this curve.

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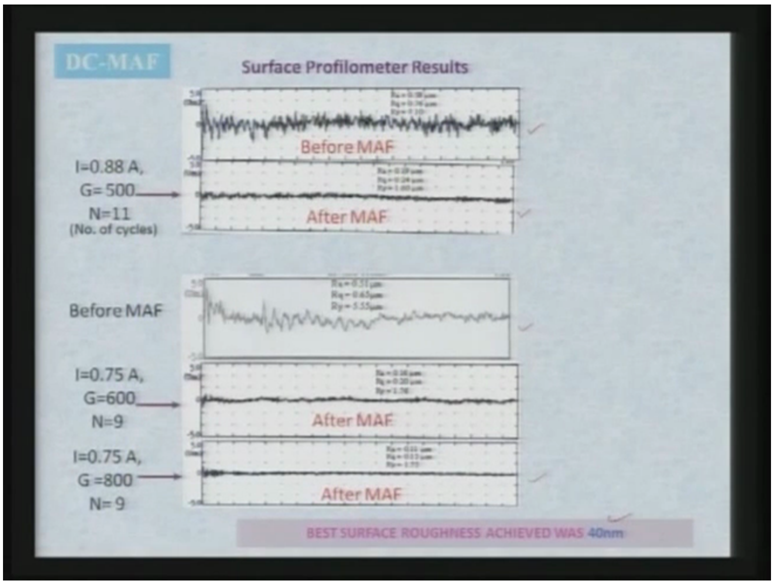

And let us try to see what is happening with TC MAF surface profilometer results are given here this is the surface which was obtain before finishing and this is a surface which is obtain after finishing and you can clearly see that the finish before finishing the surface roughness value was 0.58 micron and after finishing the surface roughness value came down to 0.19 micron, Rq is also there that has also decreased and Ry also has decreased from 7.10 to 1.60 micro-meters, so there is substantial improvement in the surface finish or surface roughness value.

Now another case we started with the 0.51 micron as the initial surface roughness value and in different cycles it came down to 0.11 micron as the final surface roughness value which is substantial improvement, improvement by a factor of 4 after a certain number of cycle. However, the best surface of this value obtained at IIT Kanpur for the given set of configuration was 40 nanometres.

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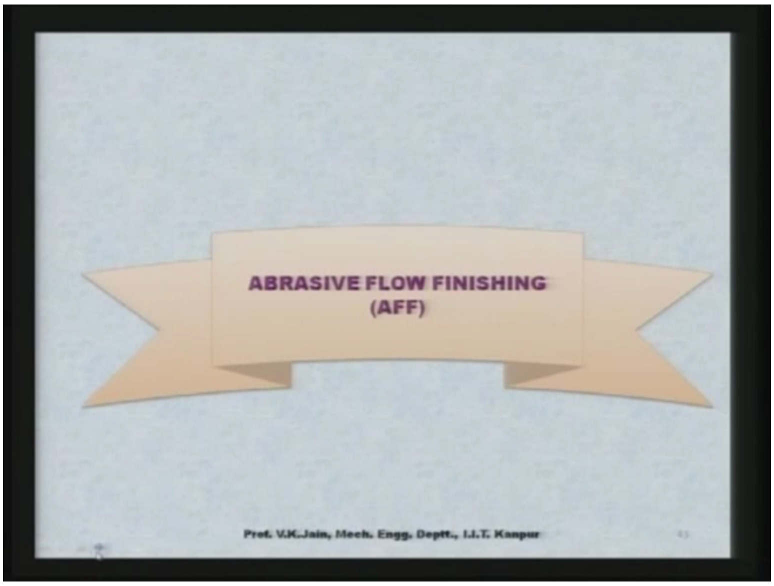

Now there is another process, very versatile process for finishing purposes because this magnetic abrasive finishing which we have seen in the last class and in this class as well as big limitation you cannot finish very nicely the components which are 3 dimensional in nature and which have complex configuration or geometry. In those cases this process is not very suitable, let us see a new process that is known as abrasive flow finishing process.

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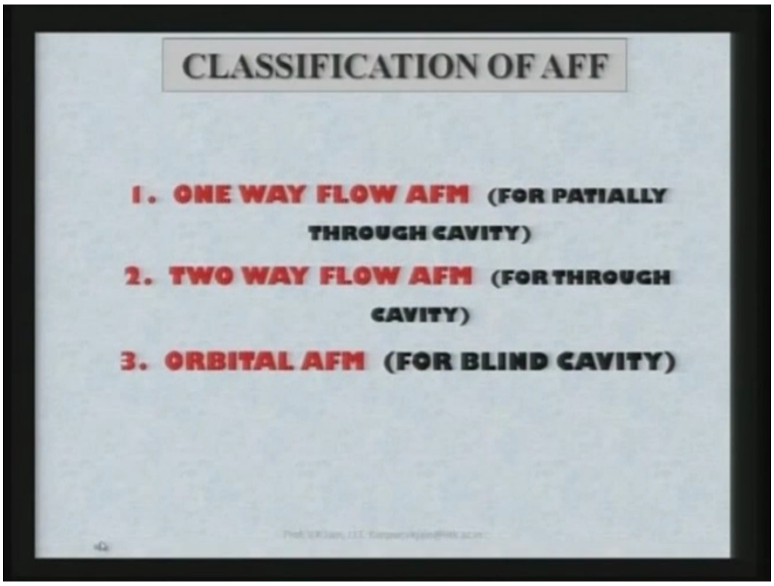

This work on this particular area was started by the extruded home company of USA. There are different models of this particular process as you can see here there are 3 types of the abrasive flow finishing process one is one-way flow abrasive flow finishing process which is applicable for partially through cavity and there is two-way flow abrasive flow machining process it is for through cavity and the 3rd one is orbital abrasive flow machining process which is for blind cavity. I will show you all are 3 types of a setup and it will make you very clear that what are the limitations of all these 3 types of the finishing configuration?

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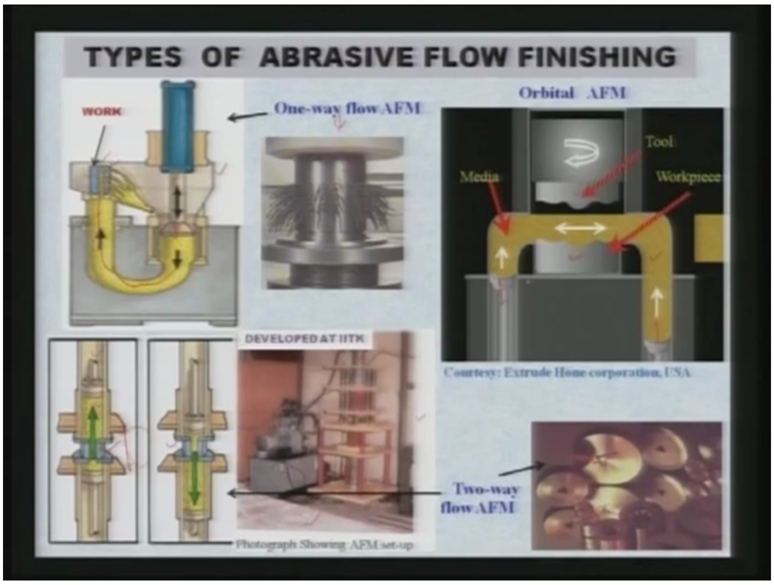

Now this is the one-way abrasive flow finishing process, now you can clearly see the workpiece is shown over here and it has certain cavity and this yellow color is the medium, now here if you see this is the piston cylinder arrangement is there, piston is here, this piston is pushing the medium that medium moves like this comes over here, this is the workpiece and in the workpiece there are certain cavity and through these cavities the medium is flowing.

Now this medium consist of viscoelastic material, abrasive particle, very fine abrasive particle and some other additives like mineral oil. Now when this medium passes through these fine cavities then abrasive particle comes in contact with the peaks of these cavities and as we have discussed earlier in case of the working principle of abrasive flow finishing normal force acts over the axial force also our cutting force also acts over there and due to the penetration and cutting force it keeps shearing off the peaks of the workpiece surface and you get a better surface roughness value and when this medium comes out it is collected and again sent to the same passage where it is getting pushed and this completes the circuit of the flow of the medium and this way you are able to control the surface roughness value of these kind of the components but minded here this is one-way flow, flow direction is only in one-way and cavity are not the through cavity.

Now see take this example very interesting example this is a cylindrical part which has hundreds of very fine holes less than 1 millimetre diameter and you can see this medium is coming out of this, now what is happening? Medium is being supplied from here through proper tooling arrangement and this coming out of these holes and collected and then again is applied from the top or from ballroom also.

So what happens that when these abrasive particles come in contact with those peaks of the surface they are sheared off and you get a match better surface finish in the miniatures holes and there are thousands or hundreds of number, you cannot finish by any other process except abrasive flow finishing or magnetorheological abrasive flow finishing process because MAF also cannot be applied because those are the solid particles and they cannot easily pass and you cannot apply to forces the way it is possible with the nature of this type of medium and in the 2nd one here is the two-way, this is the two-way flow abrasive flow finishing process as I mentioned earlier also says the workpiece and this is the upper cylinder and this is the piston and this is the medium this (())(31:44) mixed with abrasive particles as additives.

Now when this medium is moving up and down it comes in contact with the peaks on the workpiece surface and abrasive particle shear off the peace of the workpiece surface and you get better surface finish. The best surface finish (())(32:01) equipments have obtained is around 50 nanometre, now this is the experimental setup which was developed at IIT Kanpur here you can see this is the hydraulic bottom cylinder, hydraulic upper cylinder, this is the medium upper cylinder and this is the medium bottom cylinder and here is the workpiece and rest of the configuration is shown over here.

Now this is very good for the workpiece is which have the through cavity like this shown over here you can see these are the different dyes and punches used different applications and these are the through dyes, so they are they can be finished easily buy two-way AFM configuration but when you have the workpiece is like this which are the blind cavity, how will finish? You cannot use one-way, you cannot use two-ways also, so the extrude hone developed an orbital AFM process.

In this process you see very interesting one that you have the one cylinder and piston on the left side, another cylinder, piston on the right side and this is the medium and this is the workpiece just inverse image of the workpiece here is the tool and when this tool comes down it comes in contact with the medium it pushes downward then the medium comes in contact with the cavity of the workpiece which is quite irregular and when this tool rotates and medium also gets mixed up and medium is being pushed from here as well as here, so that medium there is a relative motion between the medium and the workpiece surface as a result of that those abrasive particles finish the blind cavity of the workpiece and you can get away good surface finish with this.

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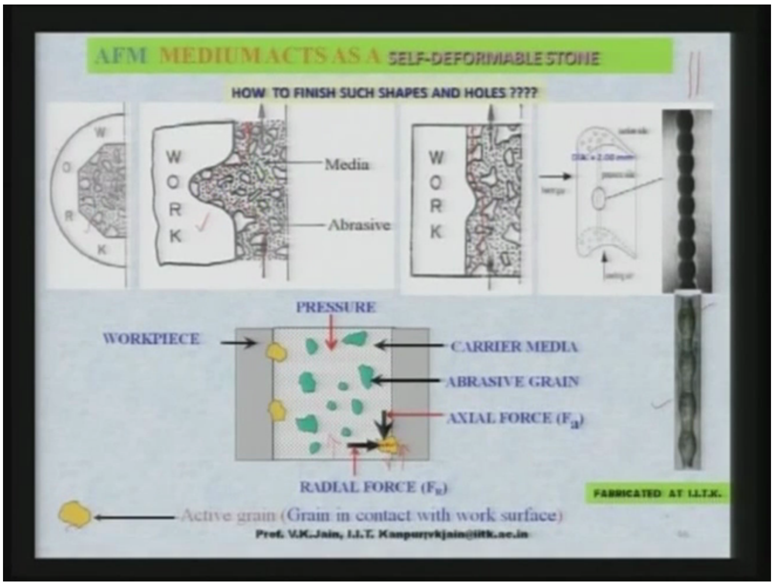

Now let us see medium in abrasive flow finishing process or abrasive flow machining process, the medium in AFM process acts as a self-deformable stone, how to finish different kind of the shape which are shown in this particular slide is really a problem. Here you can see the octagonal hole shape which you cannot finish by normal finishing processes even with MAF you cannot apply that one here.

This is the abrasive flow finishing process where you have viscoelastic medium mixed with abrasive particles, viscoelastic material, additives, et cetera that it will pass through very fine cavities or very fine fissures like this over here and when this abrasive particle comes in contact with the surface then it shears off the peaks of the surface and you give it gives a very good surface finish. If there is a concave shape like this and this particular process can easily finish it as you can see the medium is going like this, it is moving like this and it will be able to finish the cavities as well as plane surfaces or cylindrical surfaces.

Then there can be the convex surface, this particular process can easily finish these convex surfaces as the medium is going like this only surface and like this and abrasive particles are coming in contact with the convex surfaces and the going to shear off the peaks or irregularities of the convex surfaces. Now here is very interesting example which I have shown, now in all these cases the working principle remains the same as you can see here, here is the abrasive particle which is being pushed forward say in this particular direction and at that time 2 forces are acting one is the normal force which is responsible for penetration of this abrasive article into the workpiece and there is the axial force it is moving this abrasive particles the in this direction or in this direction.

Then this abrasive particle will remove the material in the form of the microchips, now since this is the flexible medium it can go into the fine cavities and finish them just like the holes we have seen earlier slide, hundreds of holes can be finished at one go and the diameter of the holes may be smaller than 1 millimetre. Here is another very complex shape, these are the cooling holes the turbine blade, nowadays present day requirement of designers of the turbine blades is the tabulated cooling holes rather than the straight sided cooling holes like this which we have made earlier.

So the question arises how to finish these cooling holes because if these cooling holes have very high surface finish that is very low surface roughness value then cooling will not be very effective, if they have very rough surface then losses will be very high, so the control surface roughness value of these cooling holes is required and AFM or AFF is the only process which can give you control surface roughness value of such features. Now these cooling holes in the super alloy have been made and fabricated at IIT Kanpur as you can see this is the actual photograph of a cut piece of the super alloy which is used for making the turbine blade.

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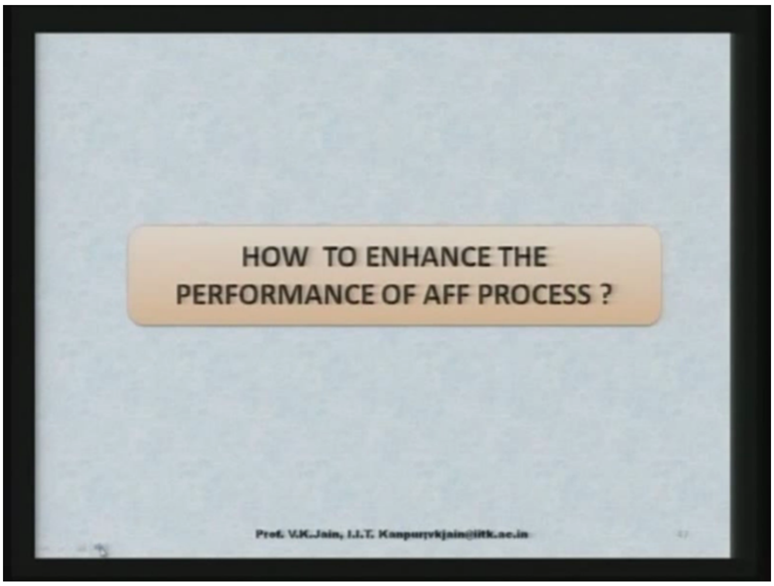

Now the question arises we have seen 3 different types of the configuration of the abrasive flow finishing process, now question arises can we enhance the finishing rate using AFF process because enhancement of the finishing rate means higher productivity and this is always desirable by any industrialist.

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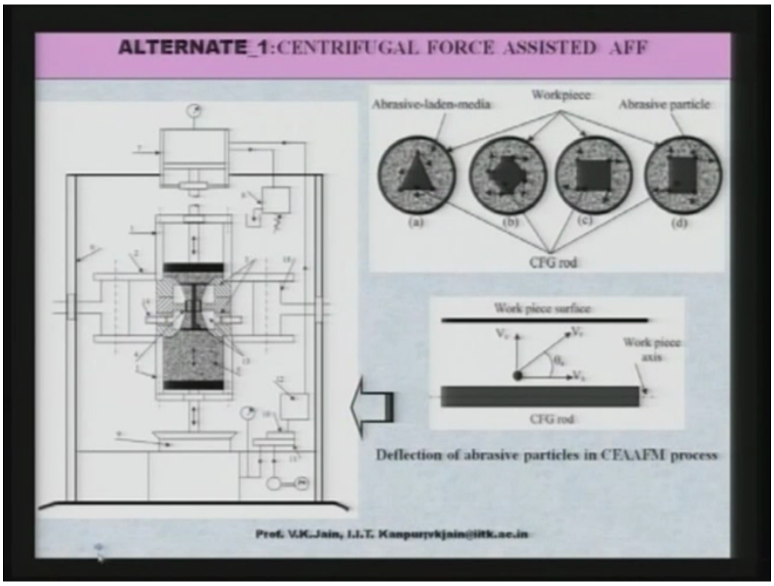

Let us see people have been making lot of efforts for enhancement of the finishing rate using different configuration of the setup, some of the researchers have used centrifugal force (()) (38:45) abrasive flow finishing process where AFF process was modified and the central part in case of cylindrical workpiece, they used a rod and this rod could have different shapes as shown over here and because of the rotation of this rod they assumed that centrifugal force is acting on the abrasive particle and because of this centrifugal force the abrasive particle will penetrate deeper inside the workpiece and if it penetrates deeper inside the workpiece and cutting force is large enough to remove that amount of material from the workpiece then the finishing rate will definitely increase.

Now these are the 4 different shapes they have attempted with and they claim that the finishing rate improved when they used these kind of the rods as compared to the case when there was no finishing rod and they have gave some analysis also and they have tried to prove that higher force is acting and because of higher force penetration is also higher and they did not give any analysis related to the cutting force.

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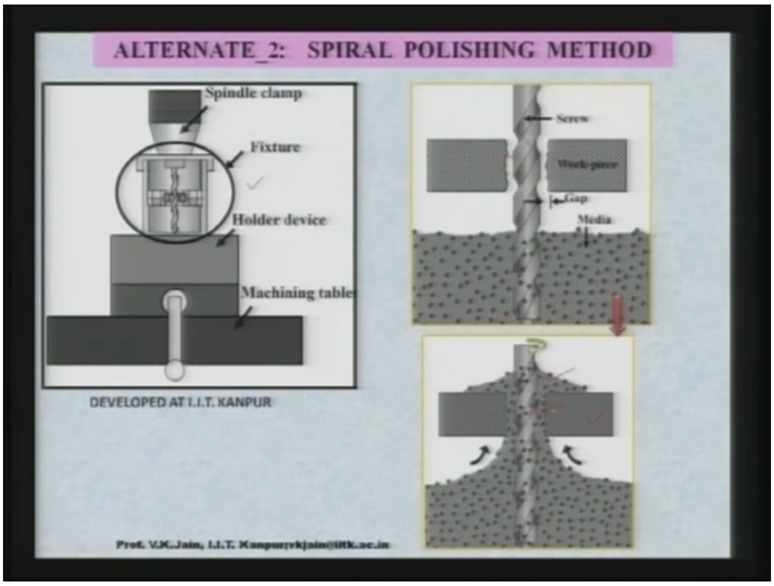

Other attempt was also made where they have used spiral polishing method in this particular spiral polishing method as you can see that they have used a screw passing through the cylindrical workpiece and this screw is rotated as you can see in this particular figure and medium is flowing up and down as in earlier cases as a result of that the finishing rate improved to some extent, definitely it is going to improve because the area through which the medium is passing has decrease and with the same force if you pass the medium through the restricted area then definitely the radial force acting on the abrasive particle is going to be higher as compared to the gap when there was a no screw and because of this higher radial force and if cutting force is large enough then the finishing rate will definitely improve and this is what they have found that finishing rate has improved in case of spiral polishing medium method and the situation when the medium is passing through this is the workpiece and this is the medium and this is the rotating screw and definitely this becomes the restricted area, so the larger radial force is acting on the abrasive particle and that force is transferred to the workpiece for higher penetration.

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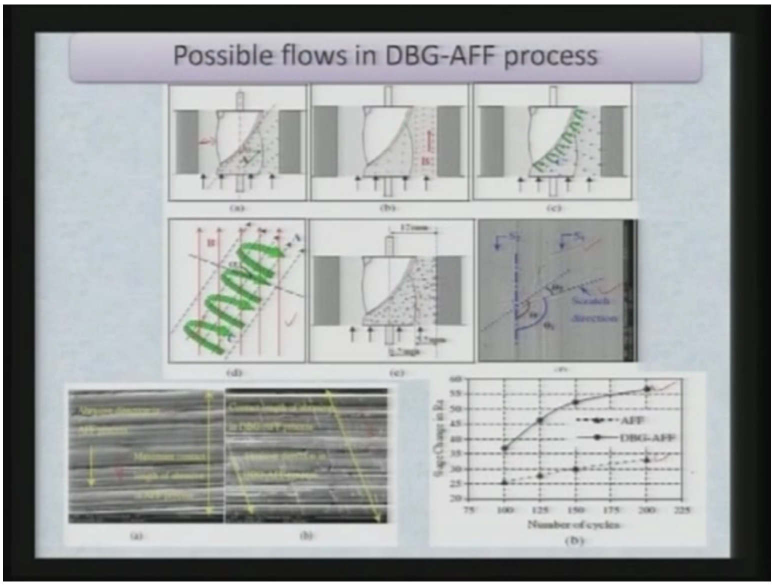

Then there was a drill bit guided abrasive flow finishing in place of screw, some of the researchers have used the drill bit and they rotated that drill bit and same logic holds true here also that this space available for the flow of the medium decreased and because of the decreased area or volume of this space, the radial force that is going to act on the abrasive particle and getting transferred on the workpiece surface is higher than the case there is no such drill bit as a result of larger radial force the penetration is larger and if larger the penetration is there, cutting force is large enough, then definitely finishing rate is going to improve.

Now they have try to show it analytically that finishing rate will improve, they have (()) (42:26) it and they have (())(42:28) the motion of the abrasive particle in case when there is no drill bit and this is spiral motion in case then there is a drill bit in the space within the cylindrical workpiece and they have shown through experimental observation that the scratches form or the material removed is not in axial direction rather than it is also in radial direction that is what is shown over here there is S1 and S2 and they are making certain angle that is the scratch direction they have shown over here.

Then they have given the photographs in both the cases here you can see scratches are in this direction also which are not in the axial direction rather than in the radial direction and in AFF process the moment of the abrasive particle is going to be in this particular direction not in the incline direction like this and they have shown that in abrasive flow finishing process the percent change in Ra value is lower than a drill bit guided abrasive flow finishing process for the same number of cycle.

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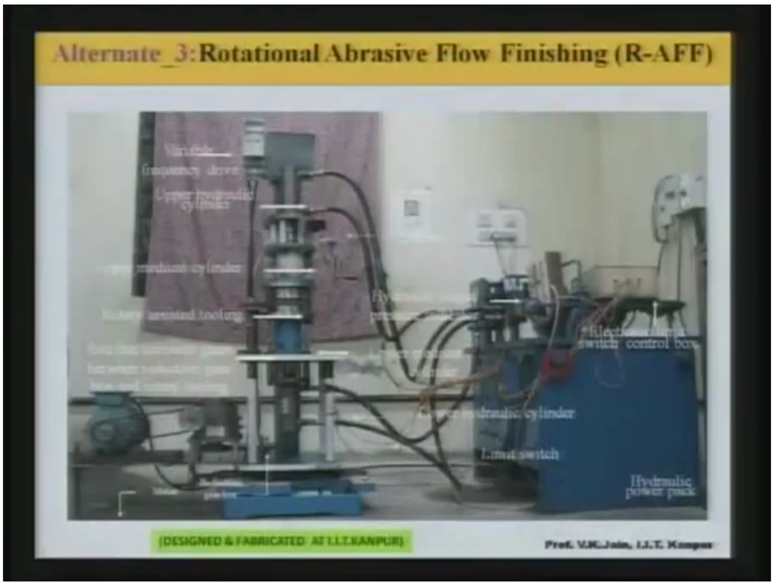

Experimental setup which has been developed at IIT Kanpur is shown over here various elements are shown over here as you can see here there is a hydraulic cylinder, lower medium cylinder, workpiece is there, hydraulic upper cylinder, upper medium cylinder and then the workpiece is rotated with the help of a certain mechanism that has been fabricated at IIT Kanpur and you can see because of the rotation of the workpiece the spiral motion is obtained for the abrasive particles with respect to the workpiece and because of that spiral motion as I will show you in the following slides you get higher finishing rate.

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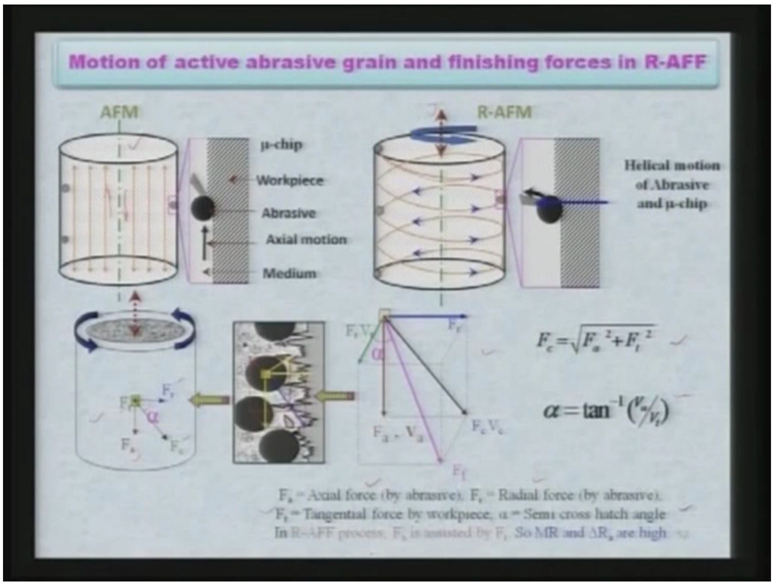

This is the analysis that is motion of active abrasive grain and finishing force in rotary AFF, this name has been given this particular process because here workpiece is being rotated.

Now in case of normal AFF process, the abrasive particle is moving either in direction or in this direction that is in the axial direction. Now there is a certain length which is being covered by an abrasive particle when it is moving in the axial direction or normal AFF process and when rotary motion is given to the workpiece then in place of moving in the axial direction like this, the abrasive particle is moving in a spiral motion as shown over here you can see that it is following spiral motion.

When it is following the spiral motion then the total length of interaction between the abrasive particle and the workpiece increases substantially as compared to the normal AFF process and if length of interaction of abrasive particle and workpiece increases then number of the peaks that an abrasive particle is going to shear off will definitely increase substantially and if that number of peaks shear off in one single stroke is increased then definitely the finishing rate is going to be higher and 2nd thing since larger radial force is acting, so penetration also will be slightly larger.

Now here is shown over here what are the different kinds of the forces that are acting, this is the radial force, this is the axial force and this is the tangential force and this is the resultant force is acting over there in case of normal AFF process and this is the force diagram for rotary AFF process, various forces are shown over here and it has shown it has been shown in different research paper that the performance of rotary AFF is better than the normal AFF process. Now you can obtain the cutting force from F a square plus F t square under the root and alpha that is the x angle at which this finishing force is acting and this is given by V a over V t tan inverse V a over V t where F a is the axial force, F t F r is the radial force, F t is the tangential force, alpha is the semi-cross hatch angle and R-AFF process that is rotary abrasive flow finishing process.

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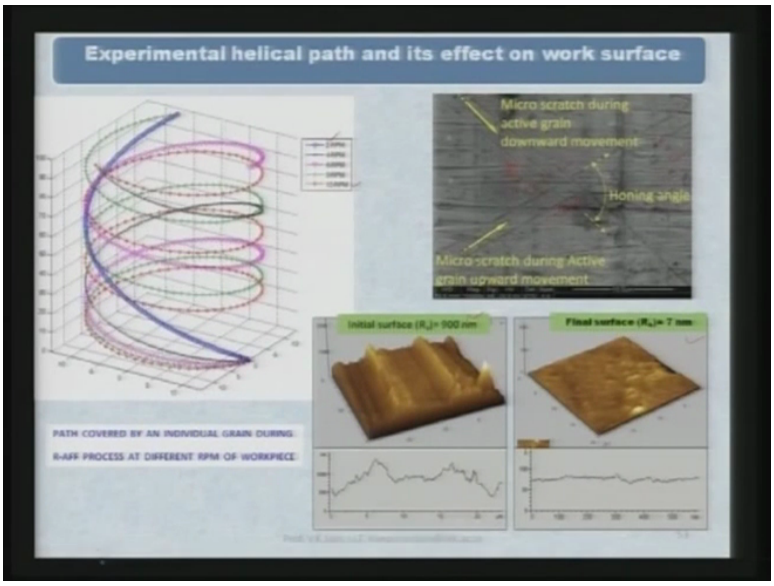

This shows you the motion of the abrasive particle along the periphery inner periphery of the workpiece at different RPM. Now you can say if it is 2 RPM probably it will not be able to over the whole surface of the workpiece it will start from the one end and somewhere in between it will exit the workpiece surface, so depending upon the RPM many rotations it is making within the workpiece surface before exiting from the other end they are shown over here and they have found that in case of rotary AFF process honing kind of scratches are optically and as you can clearly see it is in one direction and this is in another direction.

So you get micro-scratches during active grain upward movement in this direction and micro-scratches during active grain downward moment in this particular direction and they are at a particular angle that they he has mentioned as honing angle. You can clearly see the surface roughness initials surface roughness with which the workpiece rough raw workpiece was taken was 900 micrometres and final surface roughness on the component that they have obtained is around 7 nanometre but the surface roughness value is obtained in a very small area, what is going to be the scenario in the whole surface which has been finished and then one can take the average to find out the average final surface roughness value, same way one can take average initials surface roughness value.

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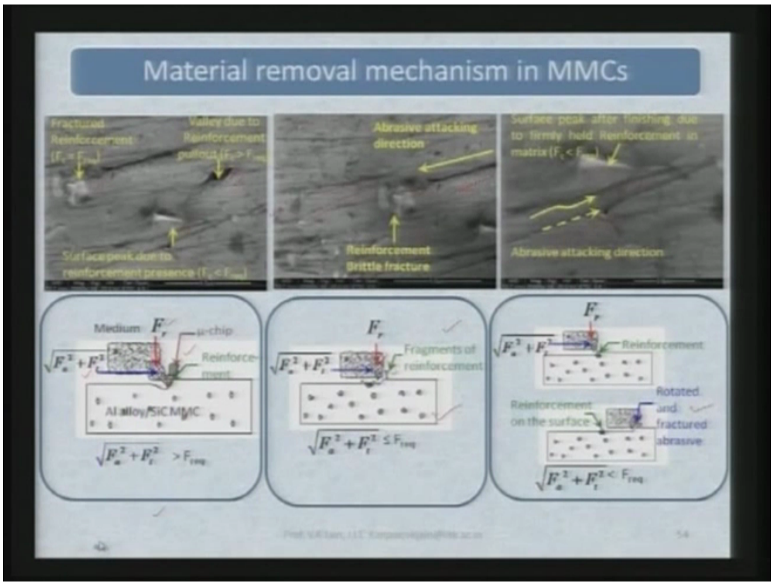

As I mentioned that the various mechanism work in case of abrasive flow finishing of metals and alloys or non-metals also but in some cases when you are using the metal matrix composites where you are using solid particles of abrasive and rest of the matrix material. In that case finishing mechanism are different from the mechanism that is followed in case of uniform metals or uniform materials. Now you can see here in this particular case that this is the metal matrix composite of aluminium alloy and silicon Carbide abrasive particles, fractured reinforcement is taking place over here then the abrasive of the medium acts on this and this reinforcement particle is held very strongly, then what will happen that instead of being pulled out it will get fractured as soon over there.

Now in this particular case valley due to the reinforcement pull out, if the reinforcement is projecting outward substantially then the larger force will be acting on the reinforcement and it will be pulled out and it will form the cavity something like this. Now surface peak due to the reinforcement pressure and this is getting the shining one because abrasive particle has moved up and some material has been removed from it and the same model same phenomena has been modelled as shown over here that you get the microchips and here is the tangential force that is acting and because of this radial force the it penetrates abrasive particle penetrates and this is the reinforcement which is coming out because the force acting or cutting force acting is large enough to remove the reinforcement from the matrix material.

Abrasive attacking direction and reinforcement brittle fracture you can see here abrasive is attacking in this particular direction and there is some fracture over here and then this abrasive particle changes the direction because it is not able to pull out the whole of the abrasive. Same thing has been modelled over here this is the fragment of the reinforcement and this is the abrasive particle in the medium and this is the metal matrix composite. Surface peak after finishing due to firmly held reinforcement in matrix material you can see here that this is this is the firmly held abrasive particles in the matrix material, so slightly change the abrasive particle in the medium changes its direction and without trying to pull it out it moves, it changes its directions and goes away and the same thing as being tried to show here this particular model for explaining this particular phenomena. Thank you.