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Today I am going to talk about another nano finishing process that is known as magnetorheological finishing MRF. Current status of related finishing technologies, now here MRF process is described in terms of 2 very interesting figure, now on the right side if you see you have 2 magnets indicated by N and S North pole and South pole and there is a lens which is to be finished. Now there is a circular channel in which you have a MR polishing fluid which is shown here by the blue color and you can see that this channel is continuously rotating in which the MR fluid is there and here is the lens which can rotate at its own axis

and it can be tilted on either sides to cover the whole surface of the lens for finishing purposes.

Now when this MRF polishing fluid comes under the influence of magnetic field, it gets stiffened and once is get stiffened the abrasive particles which are part of MR fluid, they come and finish the lens, now if you see on the right side here is the MR fluid and arrow indicates the direction of moment of MR fluid which consist of abrasive particles also. Now the white layer here shown is that of abrasive particles mixed in the MR fluid because iron particles or ferromagnetic particles which are there in the MR fluid, they will get attracted towards the bottom of this channel that where magnetic field gradient is very high compared to at the top surface, so most of the abrasive particle will come on the top surface and they will interact with the surface of the lens which is to be finished or named as work piece also here.

Now because once these abrasive particles come in contact with the lens then 2 types of forces are again acting as I mentioned earlier one is the normal force which is responsible for the penetration of the abrasive particle into the lens. Now when I say normal force this is the normal to the surface of the lens and there is axial force of tangential force which is responsible for removal of the material from the lens. Now since irregularities of the lens can be represented as the peaks of triangle shape, so depending upon the depth of the penetration and axial force or the cutting force applied due to the rotation of this channel where MR fluid is there, that will remove the material in the form of the Micro or nano chips whether it is microchip or nano chip will depend upon the abrasive size.

The force that is acting on the abrasive particle and that is transferred to lens or the work piece and available tangential force for removal of the material in the form of the micro or nano chips. Now this was developed initially by at the University of Rochester USA and they developed a machine, that machine is known as QED machine which is very expensive it may cost more than it cost about 2 to 3 crores of rupees and it is very effective in finishing the objects like hemispherical like or semi-spherical lenses, et cetera. Key features of this process are very high precision finishing of lenses spherical, flat or aspherical lenses are there.

Surface finish that has been obtained is lowest one is 8 angstrom that is 0.8 nanometre Ra value and processes deterministic because you are with the help of electromagnet there are shown here by N and S, you can control the magnetic field or in other words you can control

the normal force that is acting on the abrasive particle to penetrate the work piece that is why it becomes more of the deterministic in nature as compared to the abrasive flow finishing process where that determinant is not there in the process that is why this MRF process and abrasive flow finishing process both were combined and we developed a process called magnetorheological abrasive flow finishing process. There are certain limitations of this particular process first is the shaped limitation, only certain shapes can be finished by this particular process solve the configuration of the setup. Standard MR polishing fluid is ineffective for polishing hard materials.

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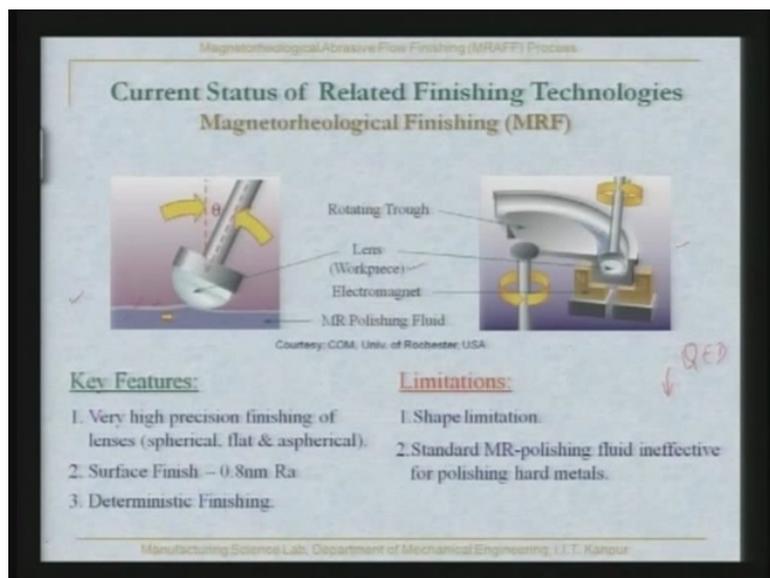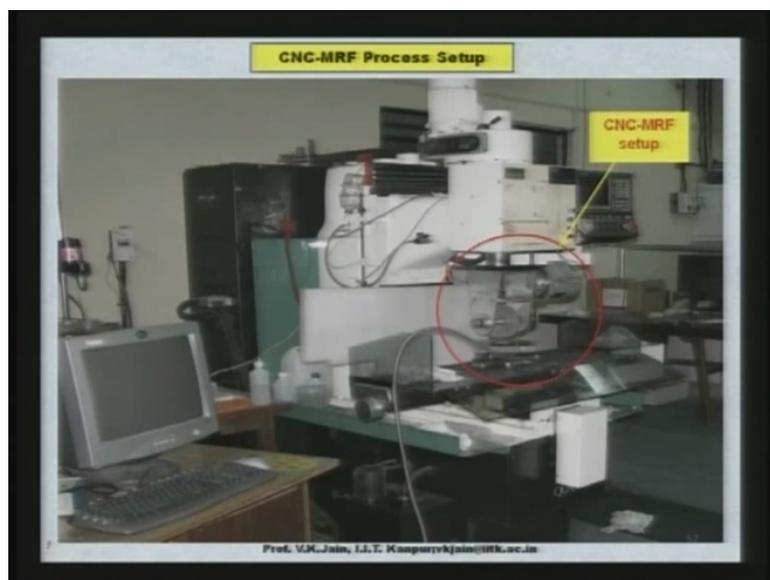
Now a setup has been developed at IIT Kanpur and that is CNC Computer Numerical Control magnetorheological finishing process setup, you can see this particular area within the circle

where we have attached an attachment which consist of rotating wheels made up of prospects material inside this there are magnets which can see here and here is the place for the workpiece to be placed that can be metallic it can be non-metallic and this wheel rotates which is having a layer of the MR polishing fluid in the form of the ribbon which is shown here by the arrow and once it is rotates and you feed the work is inside the rotating wheel a same situation arises which was shown in the earlier slide that means the extrusion of the lenses start taking place as you can see over here that those abrasive particles is in contact with the lens and extrusion of the fluid is taking place as a result of that this finishing of the lens takes place in the same way. Here finishing of the work piece that you place here flat workpiece in this particular case will take place and we mainly finish the silicon wafers over here.

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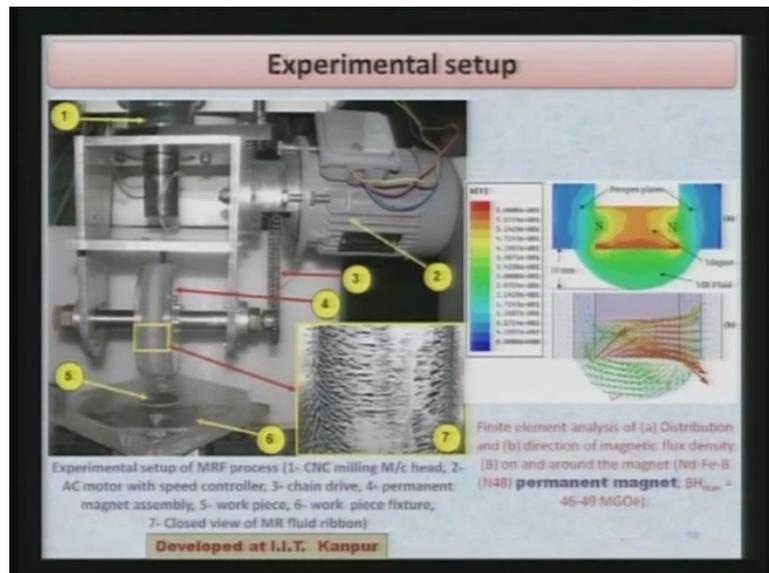
You can see the enlarge view of this particular one 5 is the workpiece and this is the enlarge view of the ribbon is over here and you can see the effect of the magnetic field which is forming the change of the iron particle in between the chain you will see if you further enlarge this you will find that abrasive particles are entangled between their chain or even in some cases within the chain and when these abrasive particles in contact the workpiece over here designated as 5 interaction takes place in material removed in the form of micro-nano chip you can see in this setup CNC milling machine is there and 2 is the AC motor with speed control over here and 3 is the chain drive that you can see and 4th is the permanent magnet assembly which is on the rotating wheel 5 it is the workpiece and 6 is the workpiece fixture and 7 close view of the ribbon as you can see here.

Now this shows the finite elements analysis of distribution and direction of magnetic flux density on and around the magnet permanent magnet are used you can see over here and you can clearly see the area where very large magnetic field is there and comparatively small magnetic field is there and this analysis had been quite useful in developing this particular process.

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Mechanism of material removal

- CI particles form a chain-like columnar structure, with the application of magnetic field and they are aligned along the lines of magnetic force.
- The magnetic force between iron particles provides bonding strength to it.
- When these chains have relative motion with respect to the workpiece surface the asperities on the surface are abraded due to shearing / plastic deformation at the tips.

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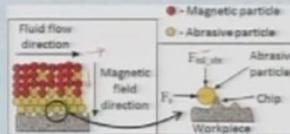
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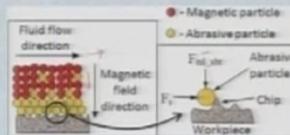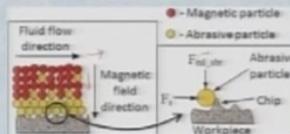
Fluid flow direction

Magnetic field direction

● – Magnetic particle
◯ – Abrasive particle

F_{n}

Abrasive particle

F_{s}

Chip

Workpiece

MRF

Source: www.qedmrf.com

Now mechanism of material remover in case of magnetorheological finishing process is important to understand, we have the CIP that is carbonyl iron particles for a chain like columnar structure with the application of magnetic field and these CIP and abrasive particles they get rather CIP gets aligned along the lines of magnetic force and the abrasive particles get entangled within the chain or between the chain. The magnetic force between iron particles provides bonding strength to it. Now you can see here these yellow blue colours are the abrasive particles and they are these purple colours are abrasive particles and others are the iron particles.

An aggressive particles are coming at the top which are interacting with the lens as you can see here, so abrasive particles are responsible for the removal of the material from the lens. Now when these chain have relative motions with respect to the workpiece, here workpiece is the lens shown in this blue color workpiece surface the asperities on the surface are abraded due to shearing or plastic deformation at the tips.

Now this is this figure clearly, more clearly shows mechanism of material removal as you can see here is a magnetic field action is shown with this arrow and this is the fluid flow direction and these are the abrasive particles yellow color over here because of this normal force is abrasive particles is penetrating inside the workpiece surface and there is a shearing force which is responsible for removal of the material in the form of the microchips on nano chips depending upon the death of penetration.

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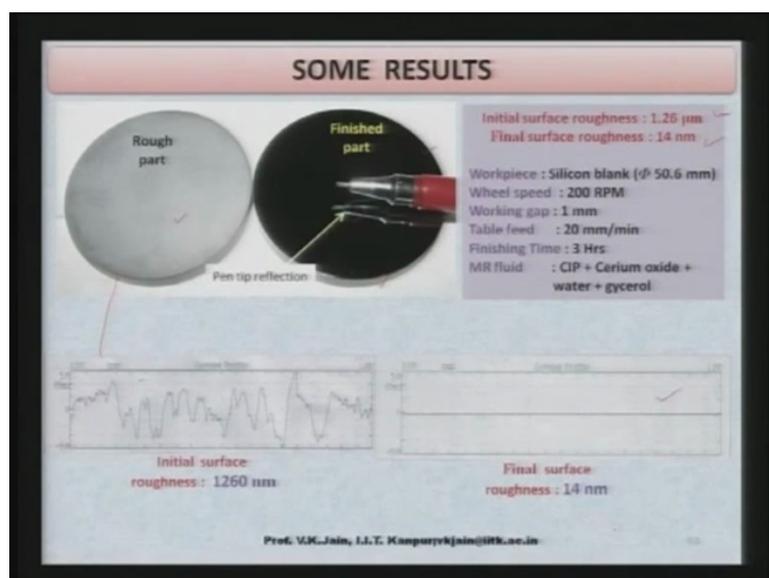
Now I will show you some of the results that we have obtain using this particular process, you can clearly see this is the rough part or initial part which was taken for finishing purposes. This is the finished part and you can see the reflection of this pen tip reflection over here, shown our here, so that simply means this is a mirror finish that has been achieved during this process. Initial surface roughness was 1260 nanometre and final surface roughness that achieved was 14 nanometre, so there is substantial improvement say around hundred times reduction in the surface roughness value.

Workpiece wise silicon blank 50.6 millimetre diameter, wheel speed was 200 RPM, working gap was 1 millimetre and table speed to cover the whole surface was 20 millimetres per minute and total finishing time is quite large that is 3 hours and MR fluid consist of CIP carbonyl iron particles, cerium oxide as the abrasive particles, soft abrasive particles, water and glycerol were the other fluid that were used over there and this is the this is surf analyser plot for the rough surface or initial surface and you can see that 1260 nanometre is the initial surface and quite large peaks and valleys are visible in this portable surface.

After finishing again we took the surf analyser plot for this particular finished workpiece and you can clearly see the difference in the left side figure anoraks figure. Right side figure is more or less just a straight line giving the surface roughness, average surface roughness as 14 nanometre. So this clearly indicates that this process is very effective for finishing silicon type of the workpiece here water is used which chemically reacts with the silicon develops or produces a top surface which is removed by the abrasive particles as well as to some extent by the iron particles because it becomes quite soft after chemical reaction.

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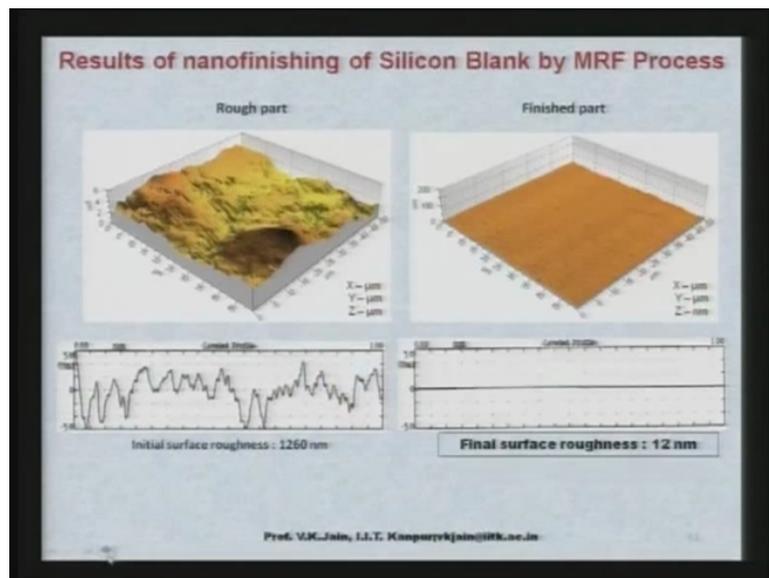
Now this is the atomic force micrograph of the initial rough surface for which the surface roughness value reported in the earlier slide was 1260 nanometre and this is I have already shown you and this is the finished surface of the same blank after finishing by MRF process and in this particular case surface finish obtain was 14 or 12 nanometre as you can see in this case it was 12 nanometres.

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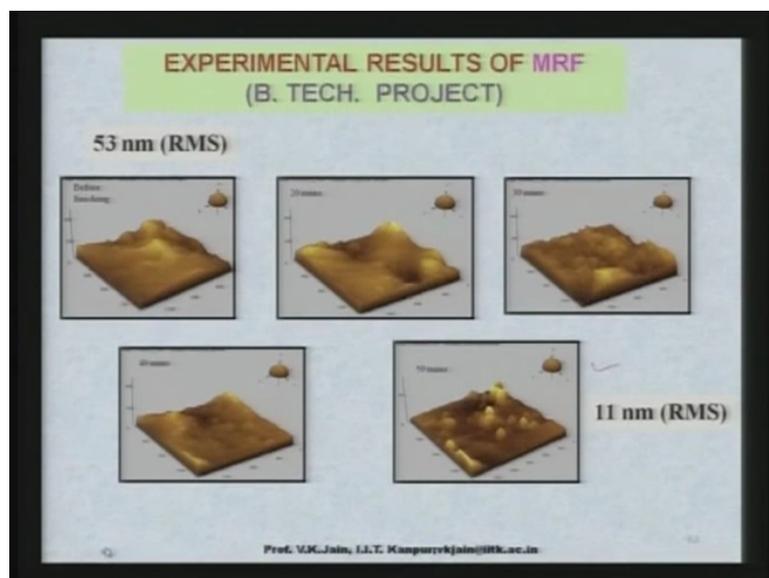
Now at IIT Kanpur B Tech. Student developed a similar kind of a setup and they conducted the experiments and they took the lenses which are used for wearing on the faces or faces in the initials surface roughness that we obtain was 53 nanometre and they finished it for 50 minutes and after 50 minutes they found that the surface roughness of gained by just 11

nanometre. So there can be there was a substantial reduction in the RMS value of the surface finish that was around 5 times in 50 minutes and 11 nanometre is really a very good surface finish provided there are no defects and since here the force is acting on the component are very low which are deterministic, so those kind of the things can be or damage or defects in the finished lens can be minimised.

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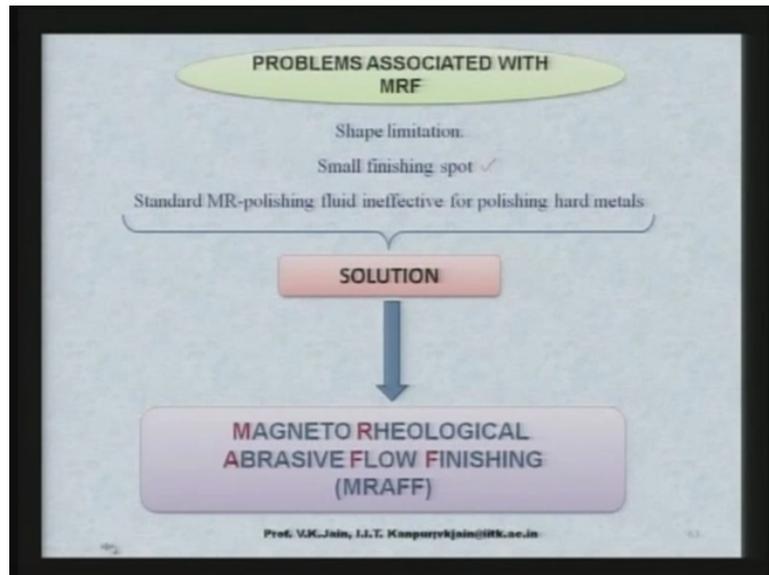
Now there are certain problems associated with magnetorheological finishing process. 1st thing is the shape limitation you have seen that you cannot finish different kind of the shapes complex shapes cannot be finished three-dimensional components cannot be finished. Small finishing spots is formed over there, I have not discussed finishing spot but small area is being finished at a time that is why it takes a lot of time as we have seen I mentioned there that finishing of silicon blank of 50.6 millimetre diameter to 3 hours which is a substantial time because of this particular reason that finishing spot is small.

So the total area covered is very small and it takes longer time for finishing the whole blank. Standard MR polishing fluid are ineffective for polishing hard metals because those records are aggressive particles like cerium oxide are soft, so what we did? We combined the 2 processes MRF process and AFM process and named at as magnetorheological abrasive flow finishing process to overcome the weaknesses of this process as well as the weaknesses of abrasive flow finishing process as I will explain you.

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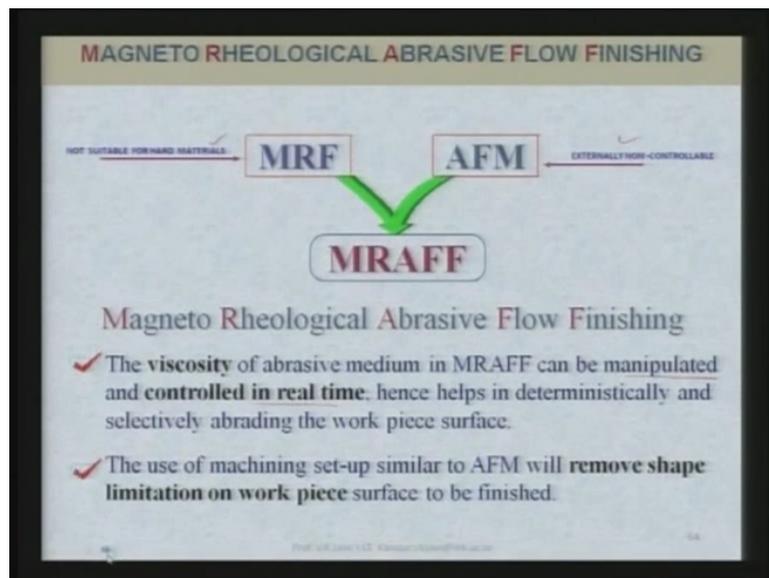
AFM and MRF, MRF is not suitable for hard material, AFM is externally non-controllable, combined these 2 and developed the process as magnetorheological abrasive flow finishing. The viscosity of abrasive medium in MRAFF process can be manipulated and controlled in real-time, hence it helps in deterministically and selectively abrading the workpiece surface. 2 important points are here that you can manipulate it and you can manipulate it in real-time, so you can finish it in a definite desired fashion. The use of machining setup similar to abrasive flow machining will remove the shape limitation on workpiece surface to be finished and this is what we have really done.

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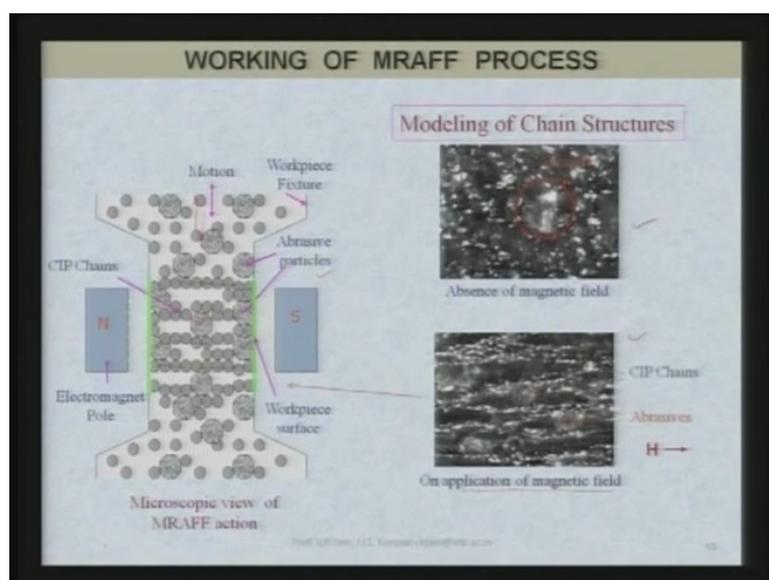
What we did? To understand the mechanics of removal of material during MRAFF process, we took a photograph of the MR polishing fluid in the absence of the magnetic field and you can clearly see the iron particles and abrasive particles are randomly distributed in this particular figure. Now then we took the another figure and here the figure wise taken on the application of the magnetic field that means electromagnet (())(18:40) supplied the current magnetic field came into picture and you can now clearly see the chains are being formed they are quite visible over here, iron particles form the chain and in between iron particles you can clearly see the large size abrasive particles are there.

They have been taken deliberately large size to see in the microscope so that we can understand what is really happening during MRAFF process, so it clearly indicates that iron particles get aligned along the magnetic lines of force and within the chains or between the chains iron particles are entangled. Now when these iron abrasive particles are entangled, when these abrasive particles come in contact with the workpiece surface they abrade the workpiece surface and remove the material in the form of the microchips as you can see in a schematic diagram here, these are forming the chains along the magnetic lines of force and in between the chains you can find the abrasive particles are there when these abrasive particles come in contact with the workpiece surface, they remove the material in the form of micro-or nano chips and this whole medium is moving either in this direction or in this direction depending upon whether the stroke is upward or downward. One cycle is completed when the medium moves up comes back goes down and then returns to the original position that completes the one cycle.

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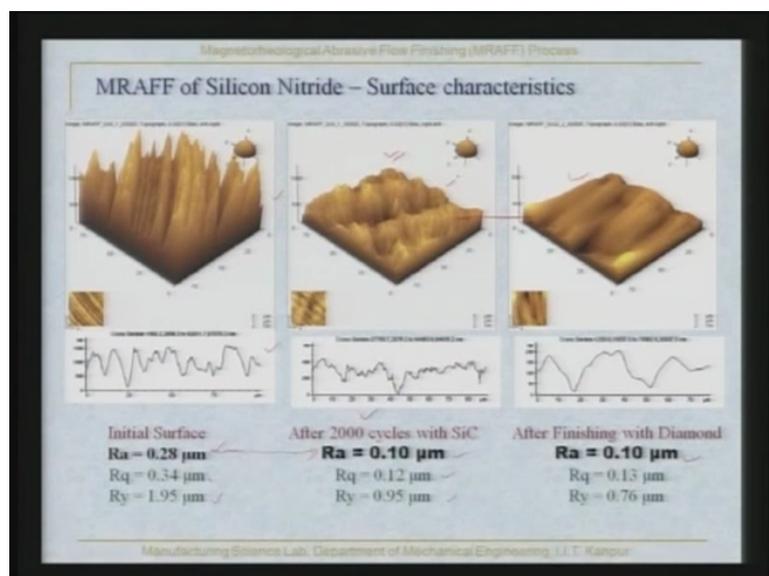
Now then what we did, we took the atomic force micrographs of the initial workpiece surfaces before finishing and we measured its surface roughness, you can see this is atomic force micrograph and this is the surface analyser plot and the initials surface finish was Ra was 0.28 micro-meters, Rq was 0.34 micro-meters and Ry was 1.95 micro-meters. Then after finishing it for 2000 cycles with silicon Carbide as the abrasive particle not the cerium oxide, silicon Carbide as the abrasive particle which is hard then the surface roughness value came down to 0.1 micron, so there was 2.8 times reduction in the surface roughness value and Rq also came down to 0.12 micro-meters and Ry also came down to 0.95 micro-meters that means all the 3 characterisation of the surface finish are improved and you can see the difference.

Now after finishing we are not very happy with the kind of the texture that we obtain on the surface, finished surface. Then what we did? We finished the components same way and same component with the help of the diamond particles of the same size and we did not get improvement as long as Ra value was concerned although Ry reduced to some extend and Rq remain more or less the same but there was significant change in qualitative change in the texture of the surface as you can see at the extreme right and in the middle the Ra remains the same but surface texture, qualitatively surface finish has changed substantially. So that tells clearly that there is a difference in the surface texture when you are using different kind of abrasive particles.

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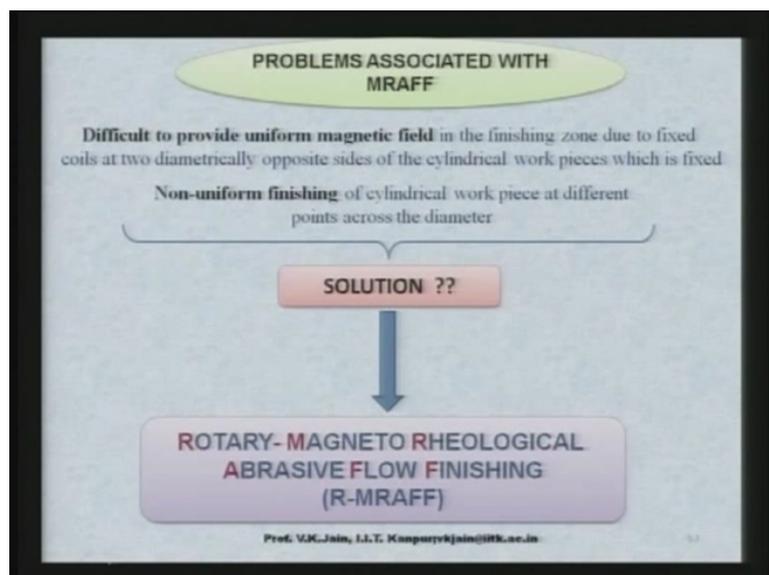
Problems associated with MRAFF process, magnetorheological abrasive flow finishing process, it is difficult to provide uniform magnetic field in the finishing zone due to fixed

coils at 2 diametrically opposite side of the cylindrical workpiece which is fixed secondly non-uniform finishing of cylindrical workpiece at different points across the dye meter. Since magnetic field is different at different points, that is why non-uniform finishing takes place of the cylindrical workpiece, so to overcome this problems we modified this particular process, we thought what should be the solution, so what we did? That we modified this magnetorheological abrasive flow finishing process as Rotary magnetorheological abrasive flow finishing process as I will show you in the following side.

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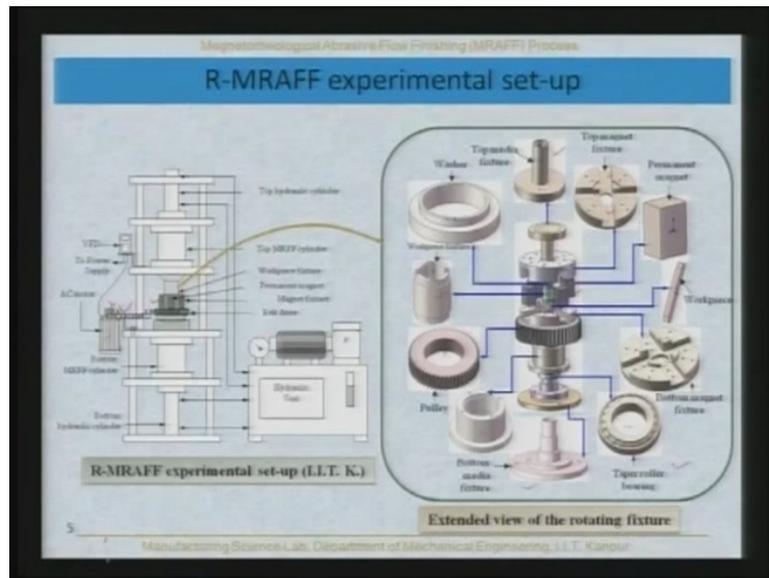
Now you can see here on the left side rest of the setup remains the same as discussed earlier but here is the set of the magnets and these magnets are fixed in a fixture and that fixture is rotated with the help of the AC motor there is a chain drive and this fixture is having the (()) (23:48) which is connected to the chain drive and as depending upon the RPM of this spindle of the model you will be able to rotate it the magnet and that makes a lot of difference in the finishing characteristics. Now the enlarged view what we developed was like this, these are the 4 magnets and this is the type of the workpiece and rest of all just the fixture to hold the magnet, you can hold the 4 magnets over in these 4 slots as given here top and bottom, you can hold it and then this whole fixture is rotated.

So extended view of the rotating the fixture taper roller bearing were used which that bottom medium fixture and this is the top medium fixture and rest of the things are just for getting an appropriate RPM or rotational speed of the magnet. So here make one point very clear that we are rotating the magnet not the medium but since the magnet is rotating, so media also will be rotating and that rotating medium will come in contact with the workpiece which is

stationary which is not rotating, so the moment of an abrasive particle which are earlier moving in axial direction will be spiral directional movement of the abrasive particle which will make lot of difference and that spiral movement of the abrasive particle can be stimulated with honing operation where abrasive particles is rotating in the axial direction as well as circular direction, so it is very similar and similar kind of the crosshatch pattern is also obtain after R-MRAFF process.

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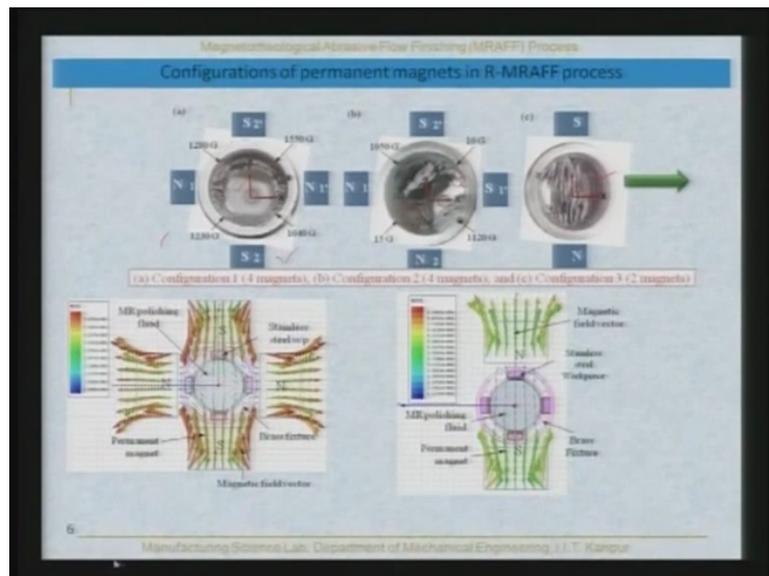
Now there are various ways of putting the permanent magnet in the R-MRAFF process, one configuration is shown over here you can have south - south poles opposite to each other and north - north poles opposite to each other. Now you can see the distribution of the…this is the chains or the brush being formed by the MR fluid. Now here you are putting South North and North South over here and you can see the non-uniformity of the brush being formed because here there is nothing and here also nothing.

Here in this particular case it is very uniform all around, now when you have only 2 magnets in place of 4 magnets again there is non-uniformity in the brush being formed and so it looks that this is an extreme left configuration is a better configuration as long as uniformity of the brush formation is concerned. If the brush is uniform definitely you will get more uniform surface improvement on the cylindrical internal or external surface. Then we also tried to take the magnetic field distribution and you can see this particular case the field distribution and here are the stainless steel workpiece which is kept here these are the 4 magnets and you can clearly see that in this particular case the field distribution is better than the other case.
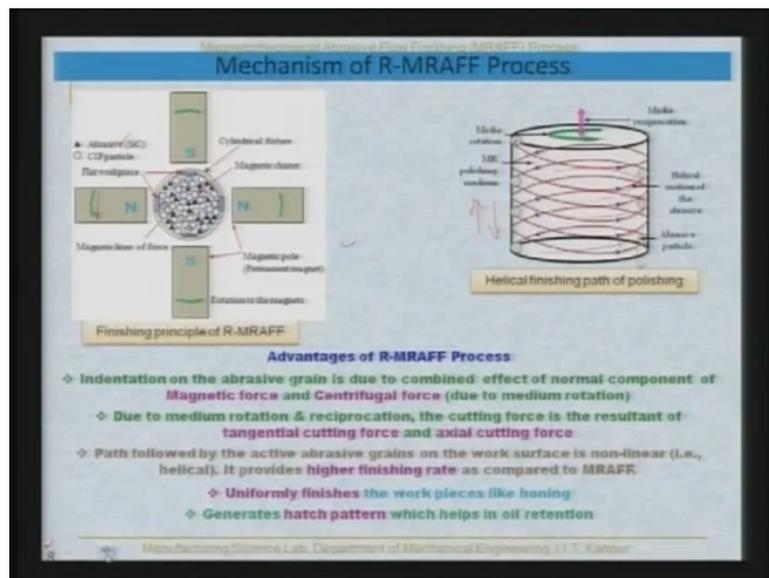
Now so this configuration was adopted which gave the better field distribution and more uniform distribution of the brush being formed, same thing is shown over here and this arrow shows the rotation of the 4 magnets through the fixture in which these 4 magnets are mounted and here this triangular field symbol indicates the silicon Carbide abrasive and circular empty symbol indicates the CIP and when these are rotating then abrasive particle is moving in the axial direction as well as rotational.

So as you can see here that helical finishing path of polishing is opted by an abrasive particle, you can see the path say this is the abrasive particle then it will be moving like this and coming like this and then only coming out over here following the helical path and this helical path when it is following then the total length travel by an abrasive particle before it enters into the work piece and after it comes out of the workpiece zone will be much larger than when it is moving only in the axial direction and if it is its path length travelled increases then interaction also will increase with the peaks of the workpiece surface as a result higher or large number of peaks will be shear by that particular abrasive particles or in other words finishing rate will increase in case of R-MRAFF process as compared to simple MRAFF process and that is the main advantage of giving rotation to the magnets as compared to the stationary magnets in case of MRAFF process.

Advantages of R-MRAFF process are indentation on the abrasive grain is due to combined effect of normal component of magnetic force and centrifugal force due to the rotation or the medium, so these 2 forces are combined together and leading to higher depth of penetration. Compared to the MRAFF process now due to medium rotation and reciprocation the cutting

force is the resultant of tangential cutting force and axial cutting force, so total cutting force also increases. Path followed by the active abrasive grains on the work piece is nonlinear that is helical. It provides higher finishing rate as compared to simple MRAFF process. You get uniformly finishes on the workpiece surface and it is very similar to…but you get in case of honing operation and it generates hatch pattern crosshatch pattern which helps in oil retention in certain type of the workpiece.

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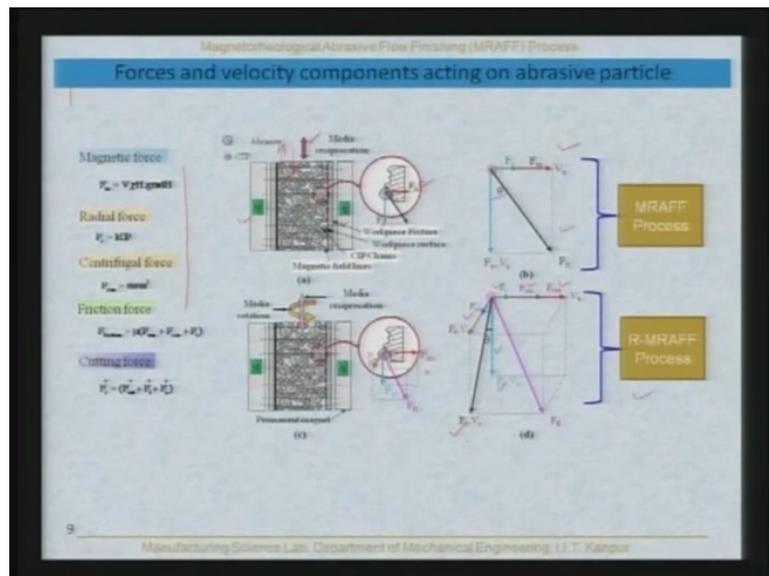
You can clearly see here the force diagram this is for the MRAFF process and simple moment of the fluid is up and down as it is indicated by the arrow over here. This is the North pole and this is the South pole and here the normal force FM is responsible for the penetration and axial force which is the resultant force is responsible for removal of the material in the form of the microchips.

It gives you the velocity diagram as well as the force diagram but when you are providing the rotation to the magnet or in other words rotation to the MR polishing fluid then the force combination changes completely and you can see here there is a radial force, there is a normal magnetic force and there is the centrifugal force all 3 are acting in one particular direction and all of them are responsible for penetration inside the workpiece surface of an abrasive particle and a force normal to this there is the axial force Fa that is acting due to the axial motion of the medium and that motion is provided by the piston and then there is a FT tangential force and F mt the component of the magnetic force in the tangential direction both of them are also contributing and the resultant of these 2 forces Fa and F mt and FT you get

what is known as cutting for Fc and this force is responsible for the removal of the material in the form of micro/nano chips.

Now this cutting force should be greater than the resistance being offered by the workpiece material for the removal of the material otherwise the abrasive particles will remain sitting or implanted inside the workpiece surface. In that case either the rotation of the abrasive particle will take place so that it reduces its depth of penetration and sheers of the material from the workpiece surface or if it is pulled out then it will leave the indentation mark or pit over there and which will be nothing but the defect in the workpiece surface which we really do not want. Now you can determine different forces, magnetic force, you can determine radial force, you can determine centrifugal force and then there is frictional force and there is a work cutting force is the resultant of all the 3, these 3 forces, details are given in the research paper published by Mr Manoj Das.

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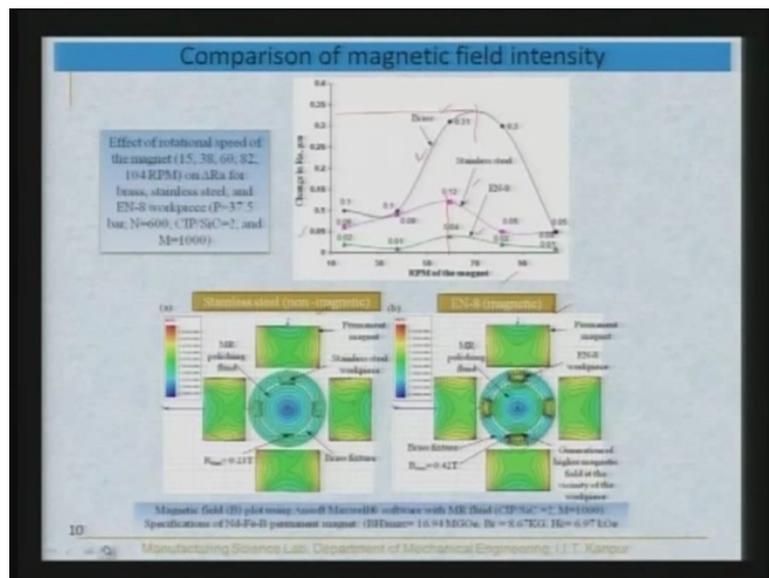
Now the conduct comparison of magnetic field intensity, we conducted the experiment to find out the effect of rotational speed of the magnet at different RPM as you can see the RPM of the magnet and this is the change in Ra and you can see in most of the cases in there is some optimum RPM on which you are getting the maximum change in the change in Ra and this is somewhere in the range of 50 to 70 RPM and here is the work piece stainless steel and there is the EN-8 and then there is a brass, so it is found in this particular case that the change in Ra is maximum in case of non-magnetic material and it is comparatively less in case of magnetic material and it is more in case of softer material compared to the hard material like brass over here it is more compared to the harder material stainless steel.

So in this particular case you can see that in brass you have got substantial change in Ra value while compare to stainless steel which is comparatively hard for the same given time. Then we also try to analyse the magnetic field using fluid software and you can clearly see the concentration of the magnetic field in certain cases is non-magnetic material like this. Here more or less uniformly distributed while in magnetic material it is concentrating in the area of magnetic material that is the workpiece compared to the rest of the portion where it is less, so you will not get uniform finishing and also some of the magnetic particles may get attracted by so large force near the magnetic, magnetic material that finishing rate will reduce substantially.

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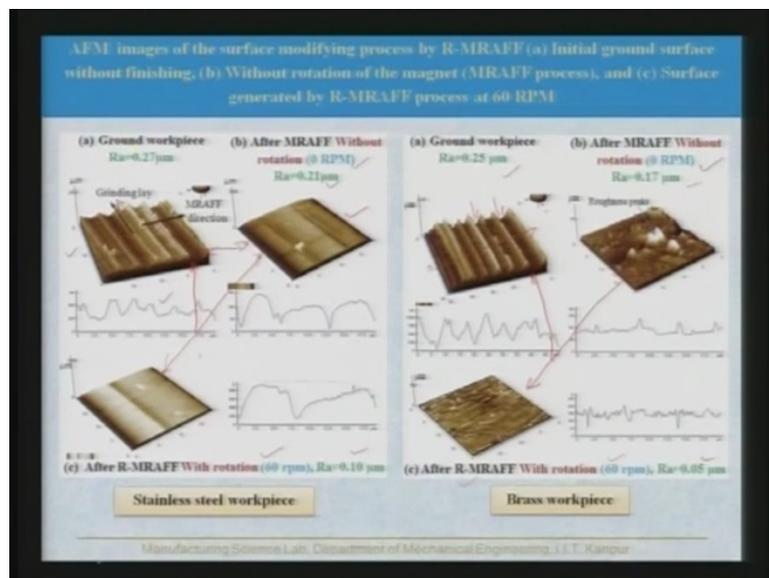
Now let us see some of the atomic force micrograph images of the surface modifying processes by R-MRAFF process. You can see here this is the ground workpiece surface where Ra value was 0.27 micro-meters and this indicates the grinding lay and this is normal to this there was the R-MRAFF direction or R-MRAFF finishing lay. Now…and this is the surfanalyzer graph, after MRAFF process there was no rotations simple MRAFF process this is the kind of surface finish was obtain that was 0.21 micro-meters but you can see the qualitative difference between the 2 although the there is not large difference in the Ra value. Now when rotation was provided say 60 RPM the surface finish reduced to 0.10 micro-meters but there is a difference in the quality of the finished workpiece.

1st thing we had here the grinding mark very close to each other but much wider than the ground surface, so this has improved but in this case it has further improved, some of the grinding marks have disappeared and finishes better it has come down to 0.1 from 0.21 over

here. Now in case of brass, this was the case for stainless steel which is quite hard and in case of brass again we to work piece with 0.25 as the initial Ra value and these are the directions of the or lays of the grinding and MRAFF will be definitely normal to this one and at 0 RPM only simple MRAFF process the surface finish was reduced to 0.17 micro-meters but with rotation and using R-MRAFF process at 60 RPM the surface finish was brought down to 50 nanometre that is 0.05 micro-meters and you can clearly see the difference between this surface and the ground surface, so there is substantial improvement in the surface texture also after using R-MRAFF process on comparatively softer material like brass. So it clearly indicates that there is a qualitative as well as quantitative improvement as long as nano finishing using R-MRAFF process is concerned.

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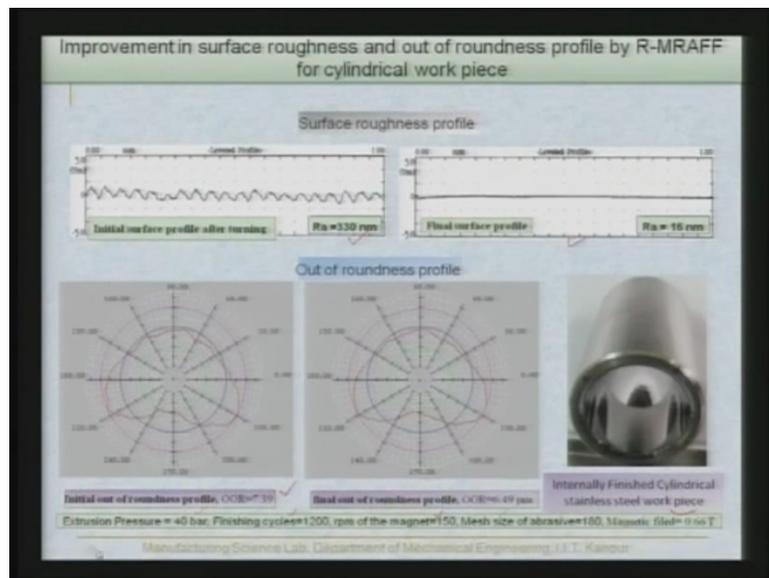
Now surface roughness profile can see this is the initial surface profile after turning operation at 330 nanometre and this is the final surface profile obtained of a cylindrical workpiece as 16 nanometres so you can clearly see the substantial difference between 330 nanometre and 16 nanometres. We also try to find out, out of roundness measurement because it is not only the surface finish of cylindrical workpiece which makes a difference but out of roundness is also equally important and in certain applications it becomes more important.

So we try to measure this and initial out of roundness by 7.39 micro-meters then after finishing we found that it reduced to 6.49, so although there was not substantial improvement there was a difference of 1 micron out of roundness reduction by 1 micron out of roundness but if this process is optimised for improving out of roundness I am confident that this 6.49 will further substantially reduce and internally finished cylindrical surface of stainless steel

workpiece is visible over here you can clearly see the reflections visible over there, so these are the conditions which are given over there, the magnetic field was 0.66 teslas, mesh size was 180 and RPM was 150, finishing cycle were 1200 and the pressure used was 40 bar.

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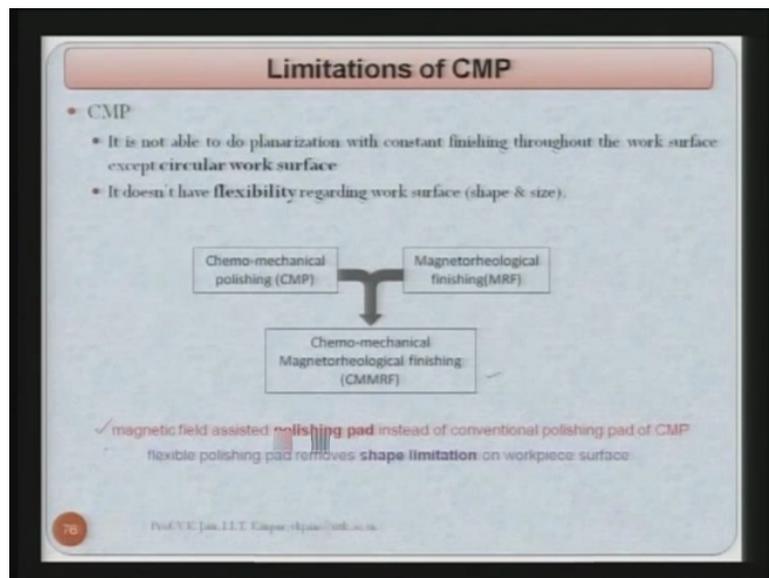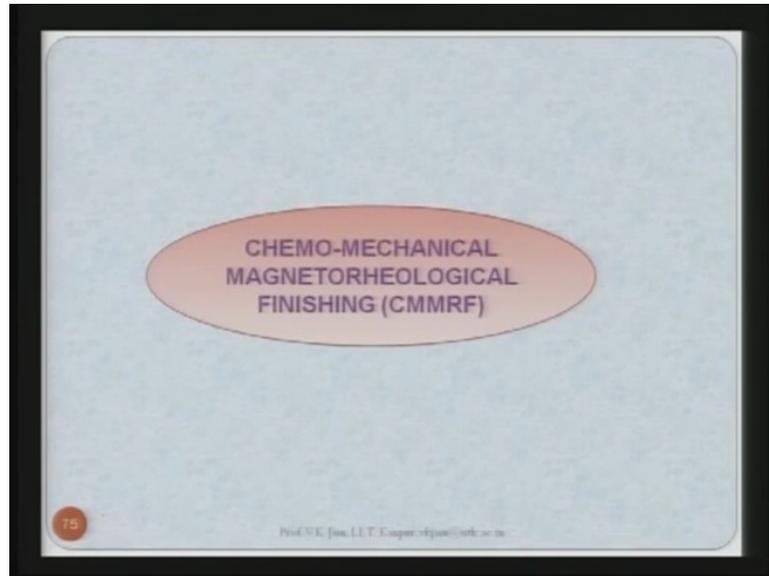
I will quickly go through a Chemo-mechanical magnetorheological finishing process which was developed again at IIT Kanpur it is a very good process for that particular purpose. Let us see some other limitation of Chemo-mechanical polishing process, it is not able to do planarization with constant finishing throughout the work surface except on circular work surfaces. It does not have flexibility regarding work surface that is the shape and size, so what we did that we combined the Chemo-mechanical polishing process with magnetorheological finishing process and develop the process named as Chemo-mechanical magnetorheological

finishing process. Here magnetic field assist polishing pad instead of this conventional polishing pad of Chemo-mechanical polishing. Its flexible polishing pad removes the shape limitation on workpiece surface. 3 because of this magnetic field it becomes deterministic also, you can control the forces.

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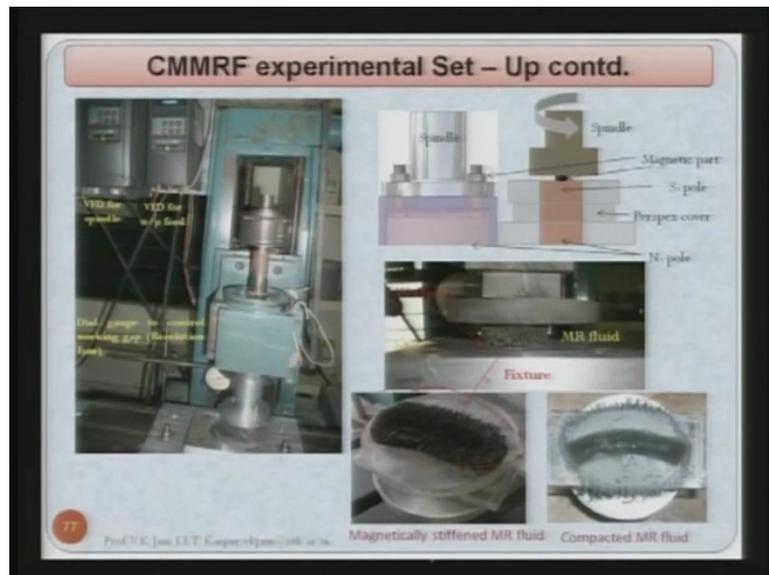
This is the experimental setup which was developed and you can clearly see that these are the VFD variable frequency drives to variable frequency drives and here the (())(42:05) to control the working gap between the top surface of the workpiece and bottom surface of the magnet. Now this you can clearly see here is the workpiece and this is the brush MR polishing fluid which is forming the brush and this is the one which is really responsible for finishing.

Now initially there is a magnet actually which is…this is the top part shown but if you see from the bottom then this top part this particular the visible like this and this is nothing but this particular part, so here before really finishing (())(42:46) this forms the brush as the brush shown over here and when you rotate this magnet than this brush is responsible for removing the peaks from the workpiece surface and sharing of the peaks and improving the surface roughness and when compacted MR fluid that means you have compressed the pad and then when it starts finishing and you can see here MR fluid is her also here also and it is distributed on all these surface.
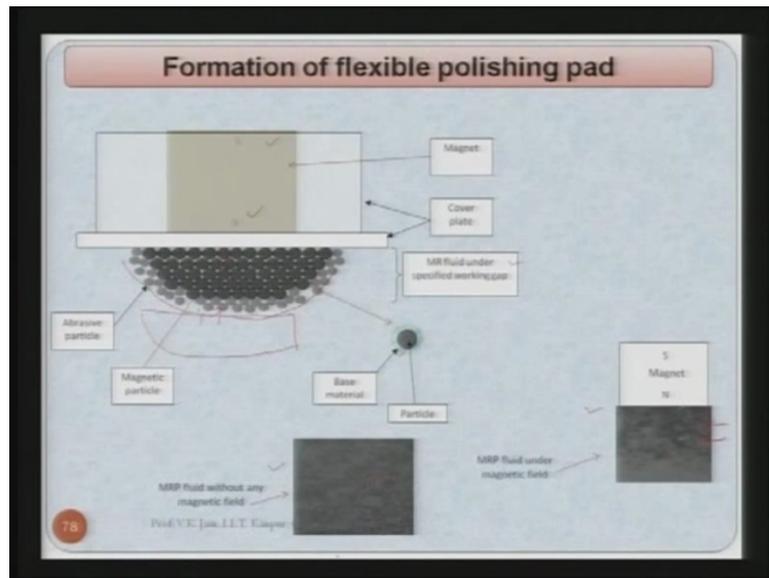
And schematically you can show it here that you have the North pole and South pole of the magnet the iron particles or carbonyl iron particles or iron particles they will get attracted towards the North pole because magnetic field intensity is higher, so all the abrasive particles will be on the outer periphery of this particular brush and here you are going to place the workpiece, so in fact the abrasive particles will be in contact with the workpiece rather than the iron particles and this is shown here this is MR fluid under specified working condition and there is the base material in which you are forming this MR fluid which is shown nearby bluish color and this is the particle that is the iron particle and grey color they show the abrasive particle.

Now you can see here MR polishing fluid without any magnetic field all are randomly distributed and when you apply the magnetic field you can see all iron particles are trying to run or move towards the North pole and rest of the abrasive particles will try to remain on the outer periphery of the brush as you can see clearly over here that these are all iron particles which are moving towards but here they are randomly distributed over the whole surface.

Now mechanism of finishing, the main use of MRP fluid is to chemical reaction with the silicon substrate to soften it. Now chemicals in the MR fluid react with surface materials that is the silicon material, forms chemical compounds that can be removed by abrasive as well as magnetic particles because that soften surface is very soft, so even iron particles to some extent can remove that soften layer and in aqueous solution that is water solution oxide form hydroxides that should be easily removed by magnetic or abrasive particles. Cerium oxide C e O 2 becomes chemically active and so of abrasive to the silicon substrate and it is used for ultra-finishing. The mechanism can be explained in a simple way like this, here you get the chains over there and here are the abrasive particles say in fact this is slightly different, so chains are there.
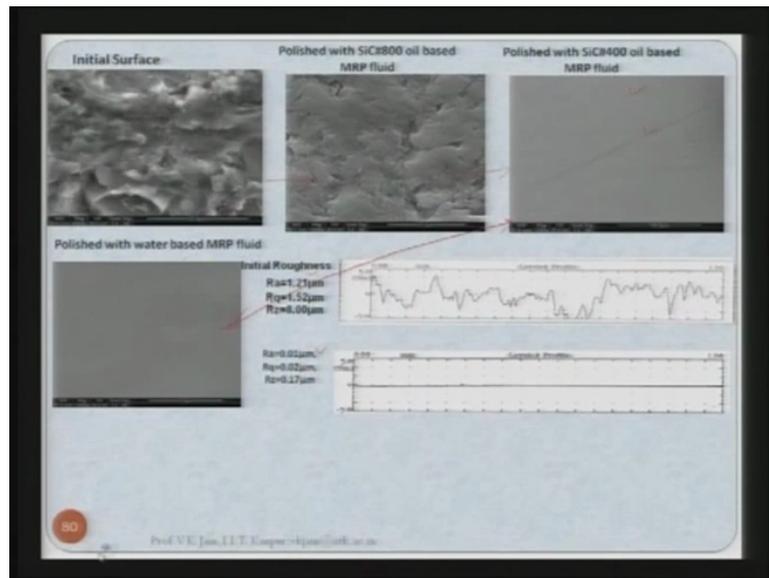
Now this is the initial surface of the workpiece that we took it then we polished it with silicon Carbide 800 mesh size abrasive particles oil-based where oil was the matrix material and then we polished it with silicon Carbide 400 mesh size abrasive particles again oil-based MRP fluid, so you can clearly see the improvement, you can clearly see the improvement in the surface over here and there is further improvement in this particular surface but here you can see some defective marks were there which are really not acceptable when we are talking of nano versus nano finishing then we polished it with the water-based MRP fluid and cerium oxide as the abrasive particles and you can see the difference, qualitative difference in the surface and in this particular surface. So there was a substantial improvement and we conducted this finishing in 4 different stages which are given in the research paper published in the CIRP in the year 2010. Now you can see the initial Ra value was 121 1.21 micron and afterwards we got the surface roughness as 0.01 micro-meter.

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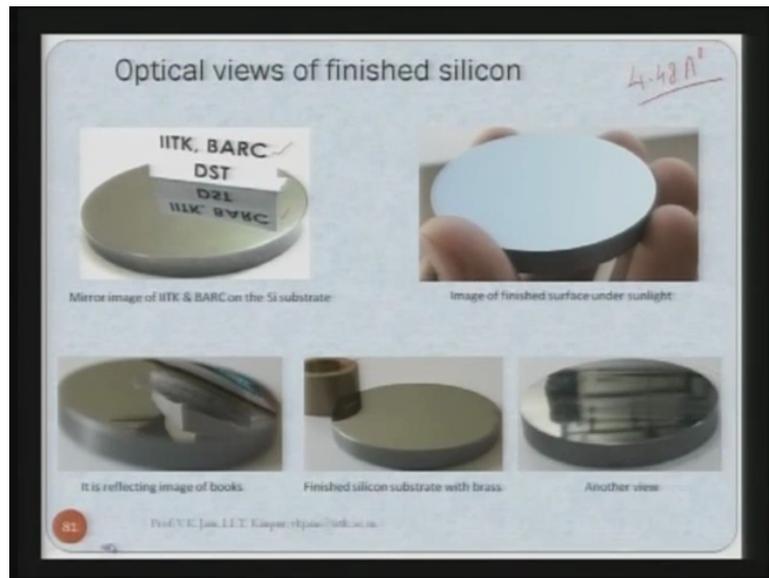
You can see the reflection of the surface reflecting surface, we kept this IITK BARC DST written on a piece of paper and we can clearly, we could clearly see the reflection of these words on the finished surface and it is image of finished surface under sunlight also can be seen how well it is shining. Now there is another some books were kept you can clearly see the reflection of those books or here is a metallic piece and its reflection can be shown over here, so what I am trying to indicate that you get the polished mirror finish on this silicon workpiece using this particular process and we were able to get surface roughness as good as 4.48 angstrom which I even showed it to you in the beginning in the very 1st lecture of this nano finishing, so that was a substantial reduction in the surface roughness Ra value from 1.26 micron that is 1260 nanometre to point approximately 0.5 nanometre.

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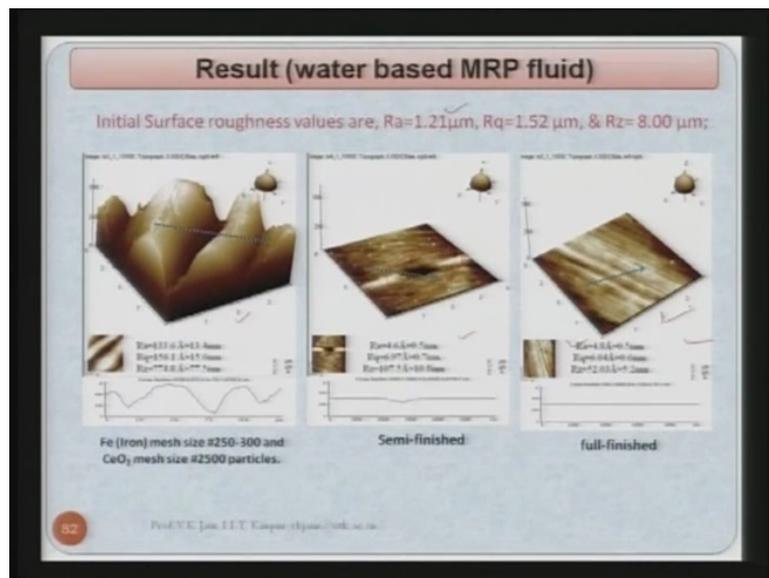
You can see here I have tried to show here at initial surface roughness is 1.21 micro-meters, Rq is this much and final surface finish that we obtained you can see here 4.8 angstrom that is approximately 0.5 nanometre. This is the initial surface this is iron mesh size this much we got it and then we finished it to some extent, semi-finished workpiece was there and then fully finished workpiece there. Now there was some defective in this particular case, so one has to be careful in selecting a magnetic field, if penetration is too much then and the abrasive particle gets pulled out and such kind of defects can be there, so we should avoid taking very high magnetic field otherwise such kind of defects may be there which will lead to the reaction of the workpiece and you can see 0.5 nanometre as the final surface finish it was obtained.
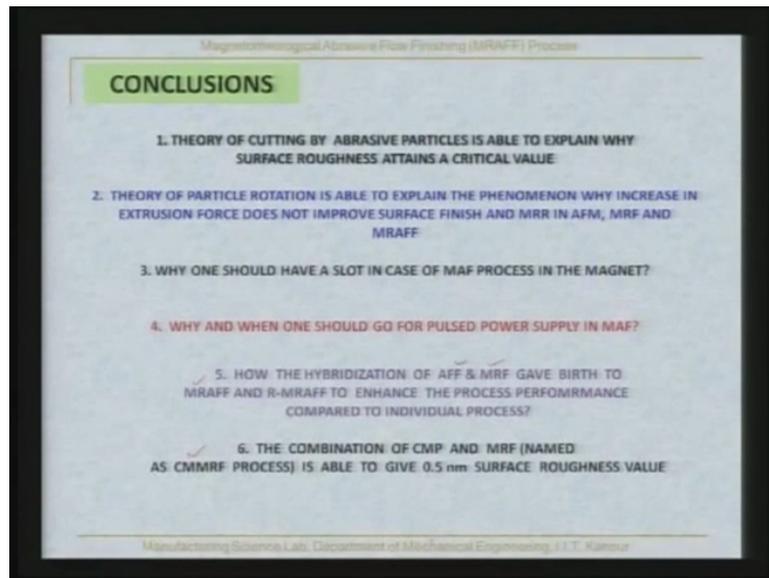
So conclusions from this particular section that is on micro-nano finishing our as follows, theory of cutting by abrasive particles is able to explain, why surface roughness attains a critical value? Especially in case of the processes like magnetorheological finishing, abrasive flow finishing or magnetorheological abrasive flow finishing processes or MAF magnetic abrasive finishing process. Theory of particle rotation is able to explain the phenomenon why increased in extrusion force does not improve surface finish and material removal rate in AFM process, MRF process and MRAFF process.

Why one should have a slot in case of magnetic abrasive finishing process in the magnet, how many slots one should have? And what are the advantages or disadvantages of having a slot and why and then one should go for pulsed power supply in case of magnetic abrasive finishing that was also explained in detail and how the hybridisation of abrasive flow finishing and magnetorheological finishing gave birth to MRAFF and R-MRAFF process to enhance the process performance compared to individual processes that is AFF and MRF process or to some extent you can say even MRAFF process. A combination of Chemo-mechanical polishing CMP and magnetorheological finishing MRF was done and new process called Chemo-mechanical magnetorheological finishing process was developed and it is able to give as good as 0.5 nanometre that is 5 angstrom surface roughness value on silicon wafers.