Advanced Machining Processes
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Module - 03
Lecture - 08
Magnetorheological Finishing

Welcome to the course on advance machining processes. We are going to discuss on magnetorheological finishing process and magnetorheological abrasive flow finishing process. Last class we have discussed on magnetorheological finishing process, different component of MRF process and also we have discussed different component of magnetorheological abrasive flow finishing process.

Now today we shall discuss about different process parameters, effects of different process parameters on magnetorheological abrasive flow finishing process okay. So different process parameters already we have discussed. So finishing pressure, extrusion pressure is the one of the most important parameter for magnetorheological abrasive flow finishing process. Then finishing cycle then applied magnetic field okay.

So these 3 are actually machining parameters you can change from outside. So these 3 parameters are most important parameters for magnetorheological abrasive flow finishing. Other than this parameters are different parameters are concentration of CIP particles and size of carbonyl iron particles and then concentration of abrasive particles and size of abrasive particles or mesh size of abrasive particles and concentration of base media.

So base media in our case we are considering paraffin oil okay. So as our experimental setup in MRAFF process as our experimental setup it is made of cast iron okay. So there is a corrosion problem that is why you cannot make water based water based media. So that is why we have made oil based media okay. So in that oil based media we have used we can use mineral oil so we have chosen paraffin oil as the base medium and we have added grease so grease is added there inside this base media so 40% it is 80% in volume percentage is the paraffin oil and 20% by volume grease is added.

So grease is added actually to increase the viscosity of this media. So it is it acts as a thickening agent in case of MRAFF polishing media. So this grease Fe3 grease it acts as a thickening agent so whenever this iron particles its density is higher than this paraffin oil so that is why it resist the sedimentation problem in case of MRF process okay.

So with this we are going to start the parametric analysis on in case of MRAFF process. So these are the different parameters already we have discussed in last class okay.

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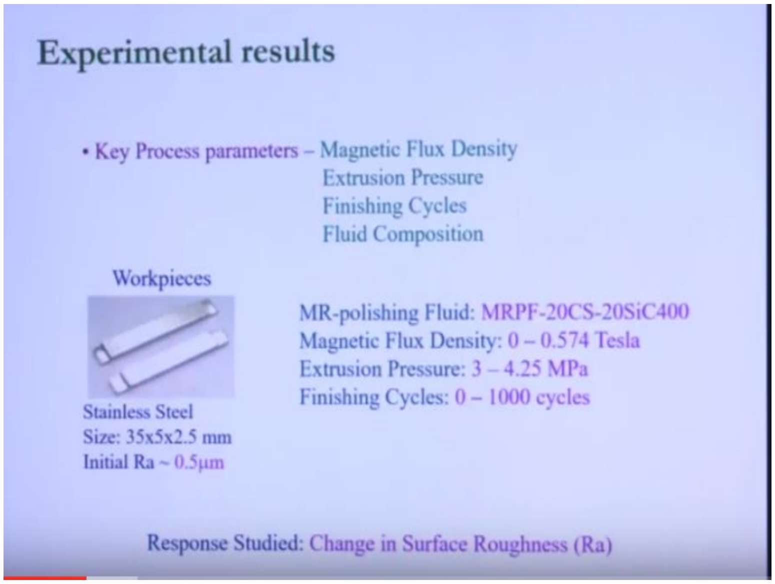

So we have considered this kind of workpiece, this length of this this kind of flat workpiece we are considering. So length of this workpiece is 35 mm and width is 5 mm and thickness of this workpiece is 2.5 mm. So these workpiece are made of stainless steel so these workpieces are initially pregrinded. So initial workpiece surface roughness is 0.49 to 0.5 micron so around 0.5 micron that initial workpiece surface roughness. So these are pregrinded workpiece, stainless steel workpiece okay.

So these workpieces are kept at the at the internal surface I have shown earlier. At the internal surface there are some small slots are there. In that slots this workpieces are flat workpieces are kept. So it is kept inside a cylindrical workpiece where small small slots are there okay. So we have considered this, this is the MR fluid we have considered. So it is given this kind of name MRPF means magnetorheological polishing fluid with 20% of CS means CS is the carbon nanoparticles with different grids are there different grids are there.

So this is one of the grid, CS grid. It has 8 micron abrasive diameter. So we have considered 20% by volume this CS grid carbon nanoparticles then 20% by volume silicon carbide abrasive particles with 400 mesh size and remaining 60% is the base material. So in that base material also 80% by weight is the paraffin oil and 20% by weight is the Fe3 grease.

So magnetic flux density, so it has a we have a certain limit of magnetic flux density using our electromagnet. So this electromagnet can generate from 0 to 0.574 tesla magnetic field. So maximum magnetic field available from this electromagnet is 0.574 tesla. So this magnetic field actually measured at the surface of this core material.

Extrusion pressure we have considered from 3 to 4.25 MPa or you can say that 30 - 42.5 bar pressure okay, so if you consider in bar okay. So finishing cycle we have considered 0 -100 cycles 0 - 100. So these are the main parameters we are considering with this, this is the range here. Now response we have to study. So what is the response? So as this is a nano finishing process we have to consider what is the change in surface roughness.

So initial we have measured the initial surface roughness so after polishing we have to measure again surface roughness that is the final surface roughness. This change in the final initial minus final surface roughness will give the will give our output. So it is written DLRA. So change in surface roughness is DLRA. So that is the response we have studied in our experimental in in this experimental study. So first we are going to show so what is the effect of magnetic field flux density okay on changing surface roughness.

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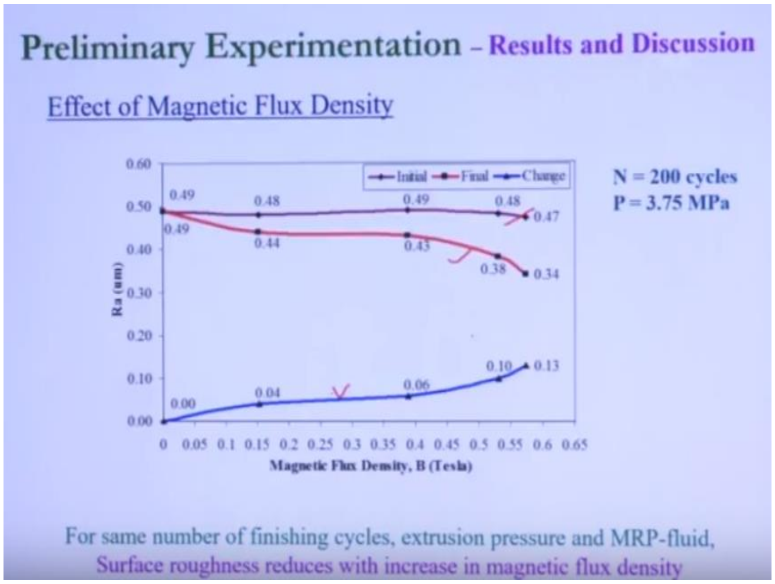

So you can see here so you can see here this is the initial surface roughness okay so 0.49, 0.48, 0.49, and 0.48 again 0.47 okay so this is the initial final initial surface roughness of the workpieces and experiments are conducted at different magnetic field. So here you can see at 0 magnetic field, then 0.15 tesla magnetic field, then 0.4 tesla magnetic field and then 0.55 tesla magnetic field and then 0.57 tesla magnetic field.

So at different at 5 magnetic field this preliminary experiments are carried out and at that time other parameters are kept constant so finishing cycle we have considered at 200 cycles and pressure considered as 37.5 bar pressure okay so for at different magnetic field different workpieces are considered. So all the initial surface roughness of the workpieces are considered at the same level. So here almost near to 0.50 micron okay. So this red colour line this is the final surface roughness profile okay.

Now you can see at 0 magnetic field there is no change in surface finish okay. So we shall we shall discuss all these things in the next slide, why we did not get any surface finish at 0 magnetic field but when we are increasing the magnetic field here you can see this change in surface roughness here this blue colour line you can see this change in surface roughness. When you are increasing the magnetic field from 0 to 0.5, 0.15, then 0.4 then 0.55, then 0.57 with the increase in the magnetic field keeping other parameters constant you can see this change in surface roughness increases okay.

So we can see that if we increase the magnetic field, surface roughness improves. So why it improves? Because when you are applying we are when we are increasing magnetic field this CIP particles they are forming strong chains okay so at 0 magnetic field there is no chains available. So there is no formation of chains. So this is this is also verified with microscopic image of this polishing media okay.

So we have seen that without any magnetic field or zero magnetic field there is no formation of chains. So now when we are increasing the increasing the magnetic field you can see with the increase in the magnetic field this chain structure actually is stronger, becomes stronger and stronger. So initially this chains are actually columnar structure. Then all these chains will form a bigger columnar structure okay so initially single chains will be formed and then all these single chains will form a columnar structure and they will become stronger and stronger okay.

So this dipole movement also increases with the increase in the magnetic field. So this CIP chains are CIP dipole movement of all the individual iron particles also increases that is why it forms a stronger chain. So when this abrasive particles are held in between this stronger chain, so these abrasive particles, active abrasive particles will polish in a with a better efficiency because they are getting more bonding strength by due to the increase in the magnetic field. This abrasive particles will get more bonding strength because these abrasive particles are held in between these chains, they will get more bonding strength okay.

So that is why with the increase in the magnetic field this surface finish improves or changing surface roughness increases. So we can say that for the same number of finishing cycles extrusion pressure and MRP fluid composition surface roughness reduces with the increase in the magnetic flux density. Now we are going to discuss what is the explanation.

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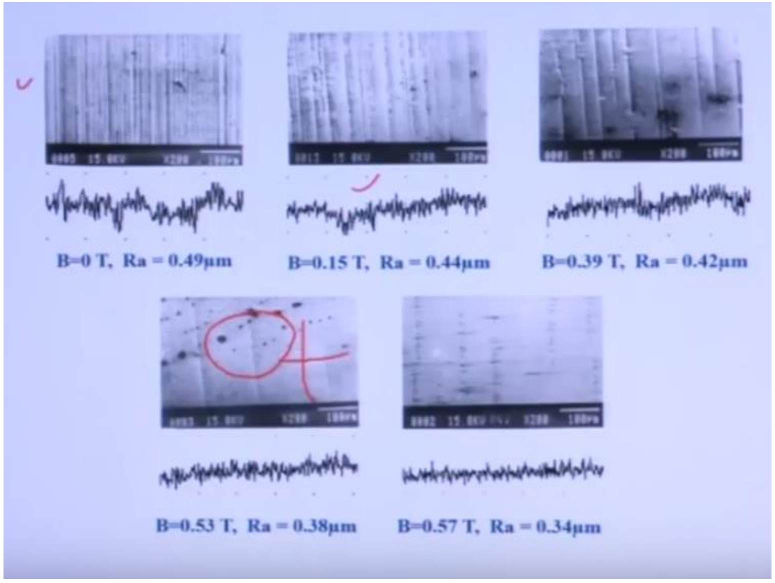

So now we can see here this is scanning electron microscope photograph of workpieces at different magnetic field. So you can see here at 0 tesla magnetic field initial surface roughness is 0.49 micron at 0 tesla magnetic field this initial surface roughness is 0.49 so you can see here in this figure so many scratch so many abrasive marks are there because all these samples are prepared by grinding operation so in grinding operation these abrasive particles make a scratch marks. So these marks are you can see lots of peaks and valleys are available in this workpiece okay. So these peaks and valleys are available.

Now we are increasing to 0 tesla to 0.15 tesla magnetic field. So when we are increasing to 0.15 tesla magnetic field you can see the surface finish improves to 0.44 micron okay. So why it happens? You can see here this whatever in initial workpiece surface whatever this scratch marks dense scratch marks are there are in peaks and valleys are there these valleys are actually these valleys are now separated. So in between 2 scratch marks 2 valleys actually this distance actually increasing here.

So now you can see better polishing is obtained in this figure. Now when you are applying higher magnetic field at 0.39 tesla magnetic field now this lines, these lines actually valleys okay so they now more separated here. So in between 2 valleys whatever these lines are there in between 2 valleys this distance actually increases okay.

So initially at 0.15 tesla these valleys are actually not so much separated but here you can see here at 0.39 tesla magnetic field these valleys are too much separated here okay. So now you can see these peaks and valleys are almost removed here. Now you can at 0.53 tesla magnetic field you can see these valleys are now too much separated.

Now here you can see here exactly at this point you can see these abrasive marks are there. These abrasive marks are due to the MRAFF process. So these MRAFF process this in MRAFF process this workpiece lathe this grinding lathe are this workpieces are kept in such a way that this grinding lathe (()) (13:36) along this direction this grinding wheel is moving. This grinding lathe and the this MRAFF lathe they are perpendicular to each other.

This in this direction this lathe marks are due to the MRAFF process and in this direction this lathe marks are due to the grinding operation. So these 2 lathes lathe marks are perpendicular to each other. That is why polishing happens so fast. So you can see here this valleys are now too much separated okay. So now at 0.57 tesla you can see almost it is vanished, these valleys are almost vanished although little bit of valleys are available here okay.

So you can see with the increase in the magnetic field how this surface finish actually improves. So all these photographs are taken at the same magnification at electron scanning electron microscope. All these things are taken at 200 X magnification. Now coming to the explanation why it happens with the magnetic field why this surface finish improves. So you can see here at this first figure so all these 3 figures are given at 0 tesla magnetic field means you are not applying any magnetic field in this case.

Now you know this this abrasive particles are surrounded by this CIP chains okay. So these CIP chains are forming strong CIP chains are forming okay with the application of magnetic field and when an abrasive particles are held in between this CIP chains there actually they actually give bonding strength to this abrasive particles. So more the means stronger the CIP chains stronger will be the bonding strength to the abrasive particles. So now at 0 tesla magnetic field there is no chains are available. No bonding strength to the abrasive particles.

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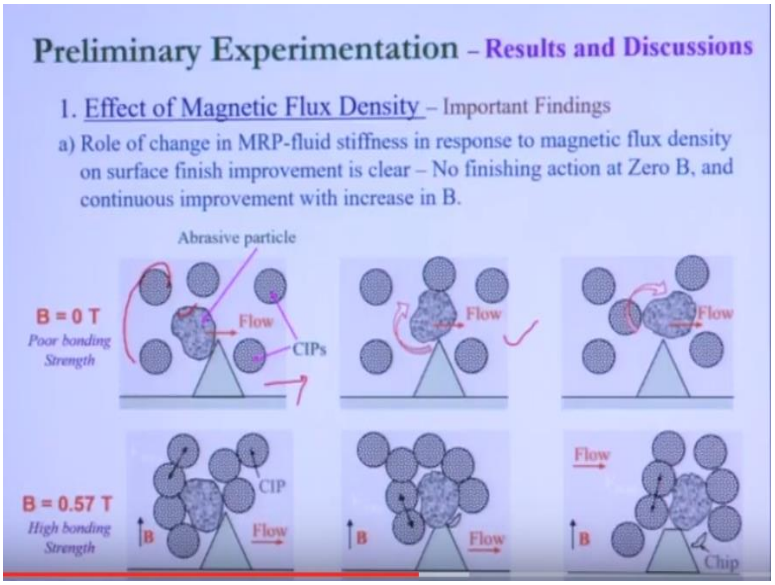

Here you can see these abrasive particles it is actually loosely held. It is so it is not held by this CIP particles, surrounding CIP particles. So it is not held by the surrounding CIP particles okay. So now this flow in this direction this fluid is moving in this direction okay. So when there is a surface peaks are there when there is a surface peak is there okay so in that case when some abrasive particles comes into contact with the surface peaks because there is no bonding strength to this abrasive particle so these abrasive particles will try to rotate here okay.

So to as the flow is there so this abrasive particle will try to rotate here it is shown in the second picture okay. Now in third picture you can see these abrasive particle crosses the surface peaks without cutting the roughness peak without cutting anything from the roughness peak. So it is it is just rotate and then it crosses the roughness peak.

So like that because of there is no bonding strength to the abrasive particles by surrounding CIP chains there is no cutting possible without application of magnetic field. Now the second row it shows that magnetic field is 0.5 tesla magnetic field. So here high magnetic field is available here. So now you can see this CIP chains they are forming chains. So because of this dipole movement there is a strong chains are forming in between the CIP particles.

Now when some abrasive particles are comes into contact or it comes in between the CIP chains they are actually held in between these chains okay. So they are held in between these chains. Now there is a flow is there. So you are flowing this media now. So when this abrasive particle comes into contact with the some roughness peaks okay so at that time it removes the surface undulations from the work from the it removes the surface undulation from the workpiece surface. Now second picture you can see it removes the small peaks from the roughness from small it removes small chains from the roughness peak here. So here in the third picture you can see it is completely removed.

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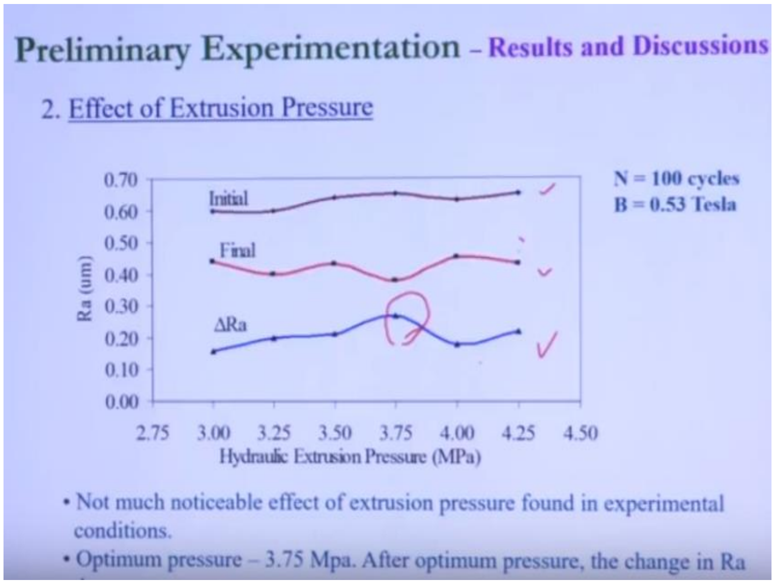

Now effect of extrusion pressure. So this is the initial surface roughness then this is the final surface roughness plot and then this is the change in surface roughness plot. From this figure you can see so from this red figure this second one you can see here there is no change in surface roughness, final surface roughness profile except at 37.5 bar pressure or 3.75 mega pascal pressure okay.

So there is no significant change in surface roughness with the application of pressure in case of MRAFF process. But you can see here at 37.5 bar pressure this surface finish actually improves and when it goes to a at 40 bar pressure then surface finish again there is a increase in the surface roughness okay.

So with the increase in the pressure there is no significant change in surface roughness from experimental from experiments. So all the experiments are carried out at 100 finishing cycles at 0.53 tesla magnetic field. So optimum pressure it is means at optimum pressure here it is the change in surface roughness you can see. So maximum change in surface roughness available at 37.5 bar pressure that is why all the MRAFF experiments are carried out at 37.5 bar pressure.

So after optimum pressure you can see again this change in surface roughness decreases.

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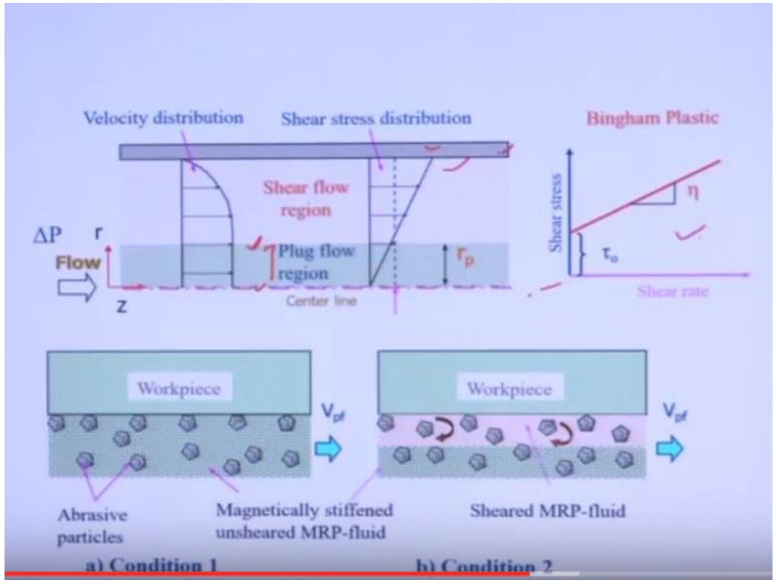

So you can see here we can we can give the reason so we can see from here this is the wall here cylindrical wall you consider cylindrical wall, so we are considering we are showing the one half of the one half of the cylindrical cross section. So this is the central line okay. So this is the wall okay. So MR fluid is flowing through this channel, cylindrical channel okay.

Now first one is the shear velocity distribution. So you can see here velocity, there is a change in velocity profile up to this point. Then after that there is no change in velocity profile. So here from here to here there is no change in velocity profile. So velocity is constant at this point. So from here velocity is constant. So these constant velocity is called the solid coat region, called plug flow region because here this because with the application of magnetic field this MR fluid behaves like a solid kind of thing.

So we can see here at this here from here to here this there is no change no shear of the fluid. So MR fluid is flowing like a solid coat region. It is flowing like a solid without breaking okay. So why it is happening because if you plot the shear stress here shear stress is actually it is maximum at the wall and it is going to it is coming to 0 at the center okay. Shear stress is maximum at the wall it is coming to 0 to at the center here okay.

So shear stress will be high here at the wall okay. So this is the plot for the Bingham plastic fluid. So for this Bingham plastic fluid you can see here. So it is a non-Newtonian fluid, this MR fluid with the application of magnetic field can be considered as a Bingham plastic fluid okay. So here this there is a shear stress tau 0. This is called yield stress, yield stress of this fluid when applied pressure is greater, applied shear stress is greater than this yield stress of this fluid then only fluid flows otherwise there is no flow of fluid. So when applied shear stress is greater than yield stress of this fluid then only fluid flows, otherwise there is no flow of fluid okay.

So there is a slope of this curve. So this slope of this curve is called eta or plastic viscosity okay. So when your applied pressure is greater than your yield stress of this fluid then only this MR fluid flows. After flowing it takes a straight line path. So at that time the slope of this curve will give the plastic viscosity okay. So here coming to this earlier picture this radius of this solid coat region is rp here okay.

So in this zone this applied shear stress is greater than yield stress of this fluid. So that is why this fluid is flowing but in the solid coat region this applied shear stress is less than yield stress of this fluid so that is why this fluid does not flow and this in this region okay. So there are 2 methods of machining. One is called so first one is the condition 1 second one is the condition 2.

In first condition this total solid coat actually moving through the cylindrical fixture okay, total solid coat region of this MR fluid is moving through the cylindrical fixture. Now as the fluid in condition 1, as the fluid is not sheared this abrasive particles will be held with higher bonding force. So as the fluid is not sheared this abrasive particles will be held with higher bonding force okay. But in case in the second case you can see this fluid is sheared here.

So at this zone this fluid is sheared here so there is no this bonding between the CIP chains now it is reduces okay. So unless the fluid is not sheared this fluid will not flow through this cylindrical fixture. For this fluid to flow there it should be sheared, this MR fluid should be sheared okay.

So here this is the sheared MR fluid here this is the unsheared MR fluid at the center. So at the center your shear stress is less 0 and at the wall shear stress is maximum that is why fluid actually sheared at the wall only first it sheared at the wall okay. So here you can see these abrasive particles in the sheared zone it does not have that much bonding force that is why this abrasive particles can rotate here, it will rotate okay. So if it is not able to cut then it will rotate there in that in condition 2 okay.

So if we increase the pressure then what will happen? Your sheared zone will be or yielded zone will be more and solid coat region or unyielded zone will be less okay. So if we do not if we if we apply more pressure then your sheared zone will be will be more and unsheared or solid coat region will be less okay. So with the increasing pressure it happens. So as the sheared zone increases in that zone actually your bonding strength is not strong, bonding strength to the abrasive particle is not strong so that is why your surface finish reduces at higher extrusion pressure.

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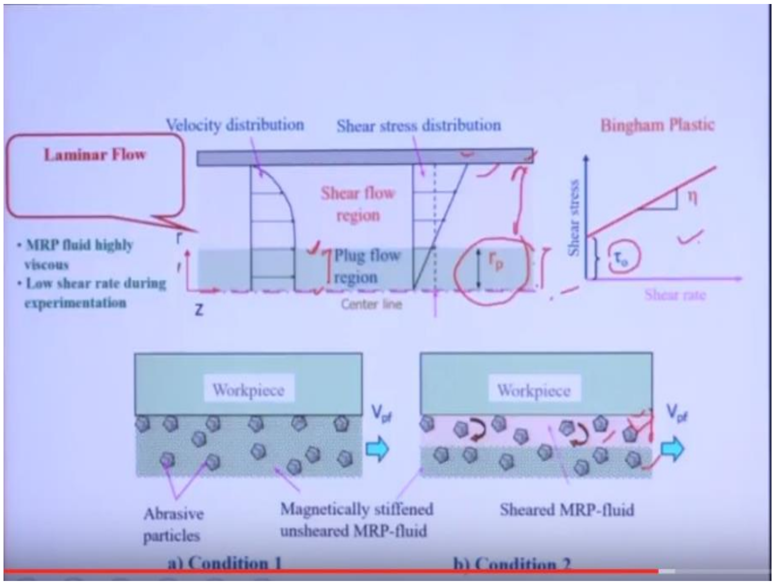

So MR fluid can be considered as a laminar flow. So as this fluid is highly viscous fluid okay and low shear rate during the experimentation. So it has a very it is applied at low shear rate so that is why MR fluid can be considered as laminar flow okay.

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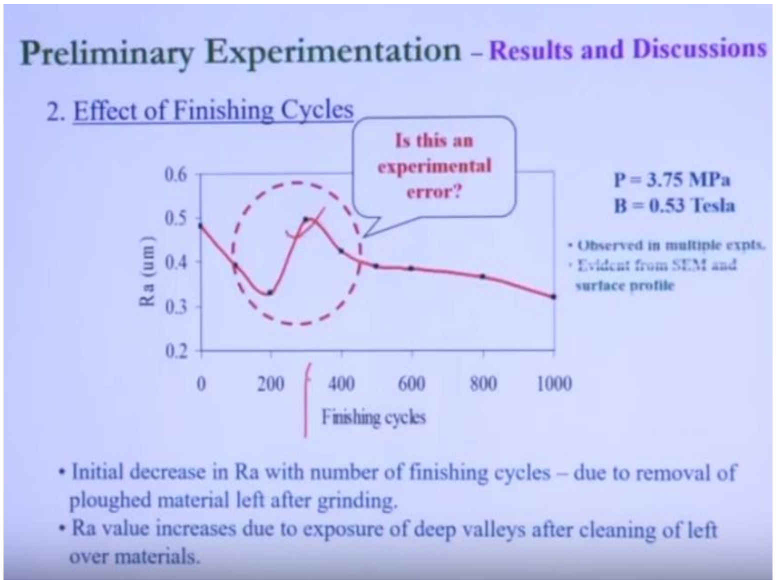

So another experimental parameter is finishing cycle. So now finishing experiments are carried out at 37.5 bar pressure or 3.75 Mpa pressure and with a magnetic field of 0.53 tesla magnetic field okay. So this finishing experiments are continuous conducted at 3.75 mega pascal pressure and 0.53 tesla magnetic field. So whatever the final surface roughness obtained from the previous experiment is considered as the initial surface roughness for the next experiment. So like that only this in this case like that only it happens.

But in our earlier case all the experiments are carried out at certain means on a new workpiece, new pregrinded workpiece but here initial experiment means previous experiment whatever final value we got so that is considered as the initial for the next experiments. So now again we should tell that one template is actually made to measure the to measure the surface roughness at different points on the on at different points okay.

So one template is measured actually to measure the surface roughness at different points on the workpiece and average value is actually taken for for giving the surface roughness abrasive surface roughness okay. So this abrasive surface roughness will give the value of surface roughness from the entire workpiece surface okay. So now with the increasing the finishing cycle from 100 - 200 cycle you can see your surface final surface roughness reduces in this case. Final surface roughness reduces but when you are again increasing means when you are increasing from 200 – 300, 300 finishing cycle so in that case you can see here again final surface roughness increases.

So what is the reason here? Why at the initial few cycles surface roughness improves? Why after that surface roughness deteriorates because initially whatever fluid material are there because this workpieces are actually grinded workpiece so whatever fluid material or loosely hit material that materials also removed by the abrasive particles. So these sometimes this this loosely hit material actually it is deposited on the workpiece surface.

So there is a chance that because of this ploughed materials are there it is little bit removed and it is filled in the workpiece surface whatever valleys are there it is filled in the valleys okay. So that is why initially few cycles you can see your final surface roughness actually improves but after few finishing cycle whatever the original valleys are there fixed valleys are there that exposes okay.

So due to that with the increase in the finishing cycle okay your surface roughness actually again deteriorates then slowly actually it is slowly it is improving okay. So here again this final surface roughness will increase okay because of the leftover materials because of the cleaning of the leftover materials okay. So during that time again with the increase in the finishing cycle your surface finish improves okay. So Ra value increases due to the exposure of deep valleys after cleaning of the leftover materials and initial decrease in the Ra value with the number of finishing cycles due to the removal of ploughed material leftover left after grinding.

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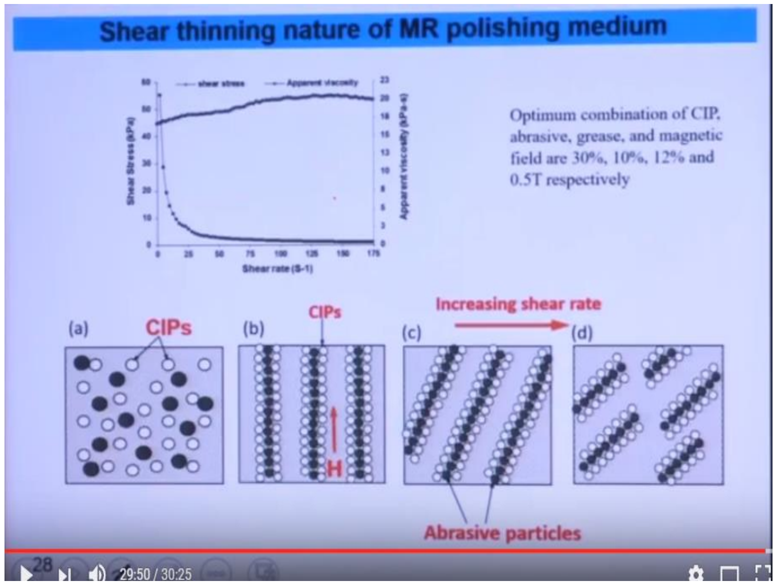

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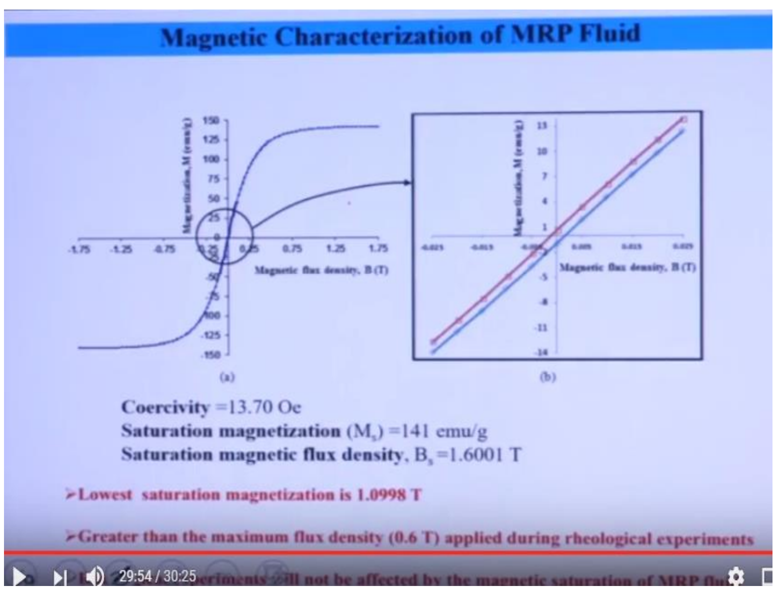

Now magnetic characteristics of MR fluid so we shall discuss all these thing in our next slides.