Advanced machining processes
Prof. Vijay K Jain
Department of Mechanical Engineering
Lecture 29
Magneto Rheological Finishing

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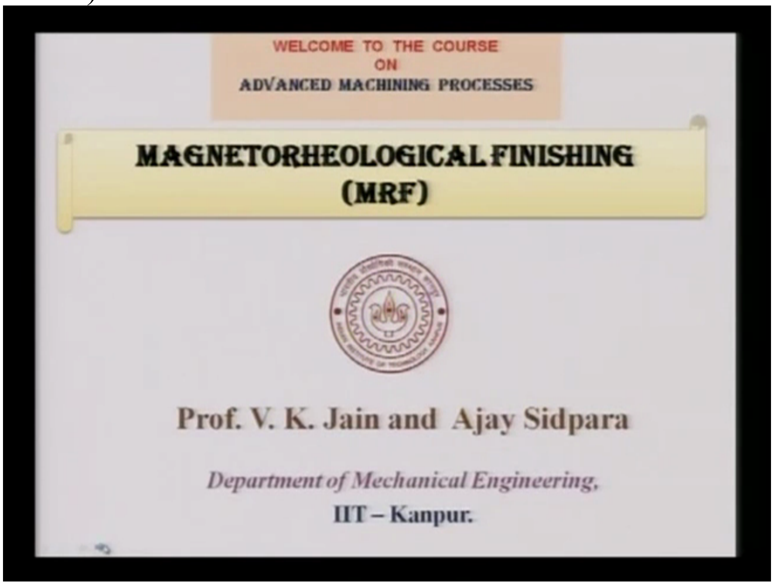

Welcome to the course on advanced machining processes. Today I'm going to discuss magneto rheological finishing; again this is a Nano finishing technique.

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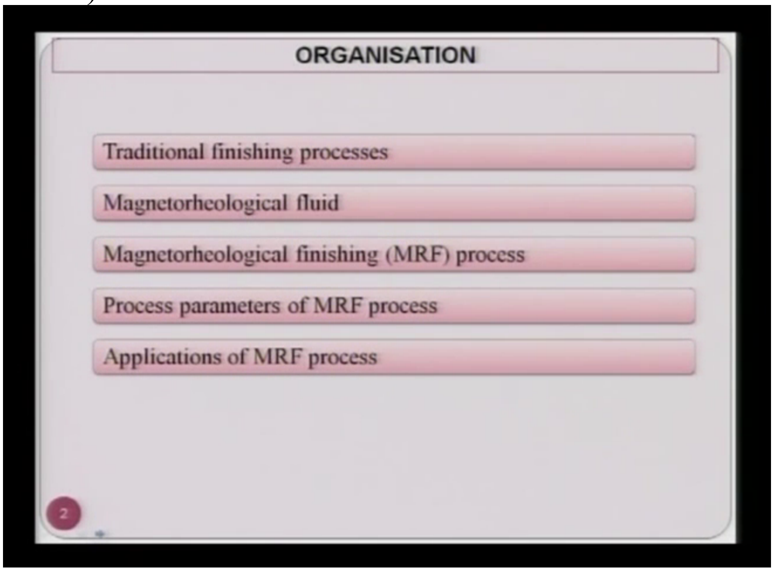

The organization of the talk is as follows, first I am going to discuss traditional finishing processes they magneto rheological fluid which is used in magneto rheological finishing process and then I am going to discuss process parameters of magneto rheological finishing process and finally the applications of magneto rheological finishing.

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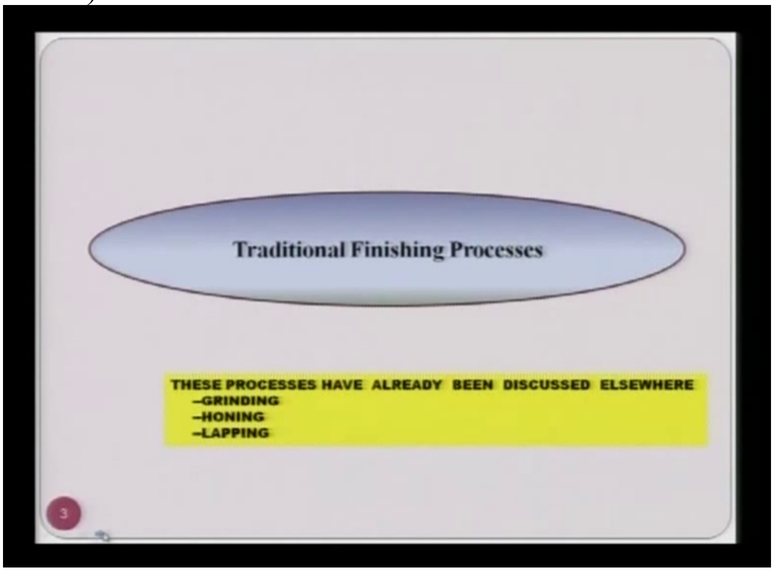

Now traditional finishing processes, most of them we already know that these processes have been discussed in the other sections of this particular course on advanced machining processes, I have already discussed the ending process to some extent than honing process and lapping process all these processes have their shape constraint and size constraint also apart from shape and size constraint they cannot give you a nano level finish in the complex shaped or the components which are made of very very hard materials.

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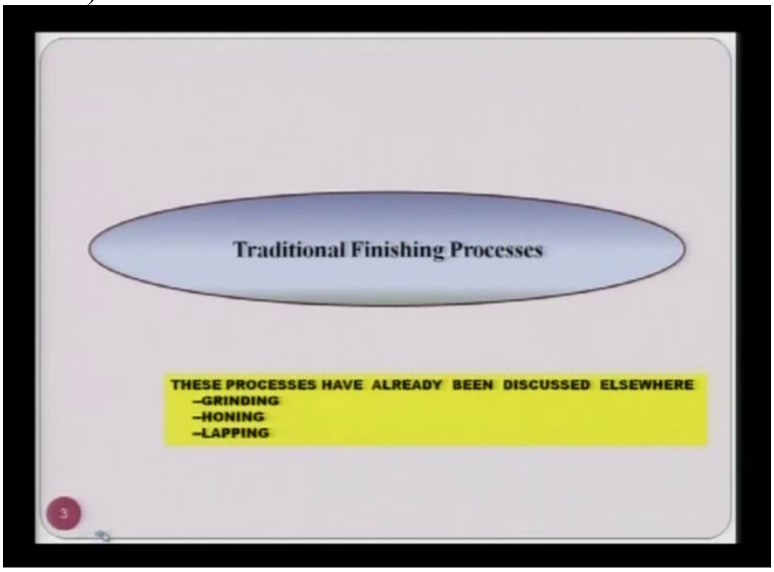

For this purpose we have to go for advanced finishing techniques and magneto rheological finishing is one of the advanced finishing techniques, in the magneto rheological finishing process the medium that is used for finishing purposes is known as magneto rheological fluid or I will be commonly calling it as medium.

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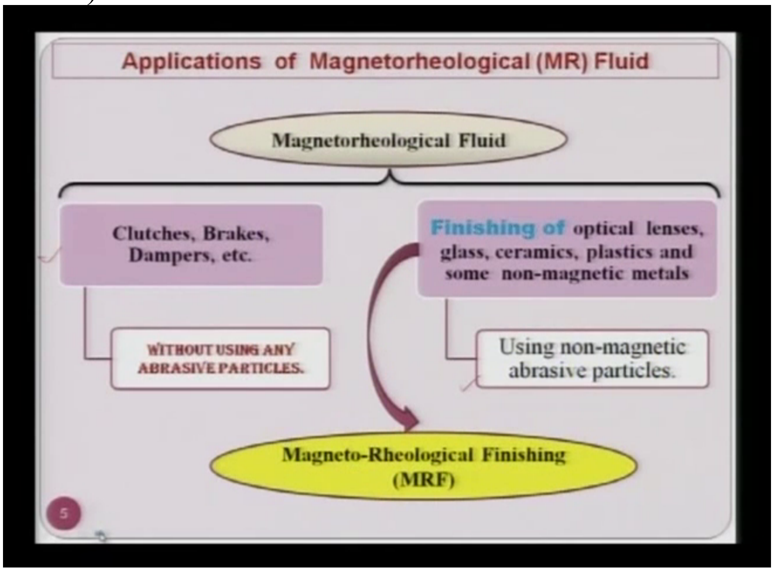

The applications of magneto rheological fluid, the common application initially it was developed for clutches, breaks, dampers etc. Now in all these applications which I have just mentioned no abrasive particles are used. So this is basically to make use of this magneto rheological fluid or known as smart fluid, when you apply the magnetic field across this then this behaves like a semisolid and once you release the magnetic field it behaves as a Newtonian fluid.

On the other hand when this fluid is used for finishing purposes and the difference in the fluid which is used for this clutches etc and the fluid which is used for finishing purposes, in finishing purposes you are using abrasive particles or you are mixing abrasive particles in the MR fluid and finishing of optical lenses, glass, ceramics, plastics and some non-magnetic metals it is commonly used.

Although you can finish magnetic materials also but there are certain limitations under which magnetic materials can be finished. Here you are using non-magnetic abrasive particles for finishing purposes; this is one of the very important parameters abrasive particles which we will discuss later on.

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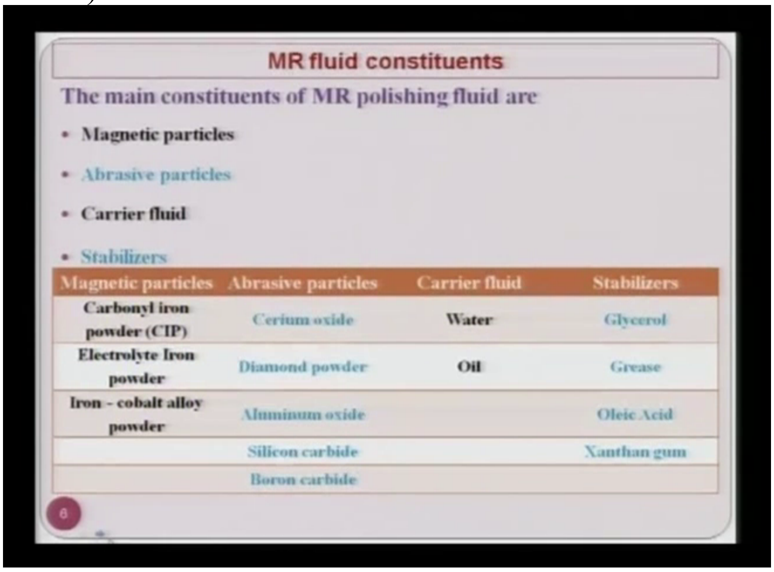

What are the various constituents of MR fluid magneto rheological fluid, the main constituent of MR polishing fluid are as follows magnetic particles then abrasive particles, carrier fluid the magnetic particles are used for forming the chain structure which makes it semisolid when magnetic field is applied. Abrasive particles are basically used for removal of the material from the work piece that functions as a finishing tool and then carrier fluid is the one which carries magnetic particles as well as abrasive particles in the configurations or the features of the work piece that are too if finished then there are stabilisers.

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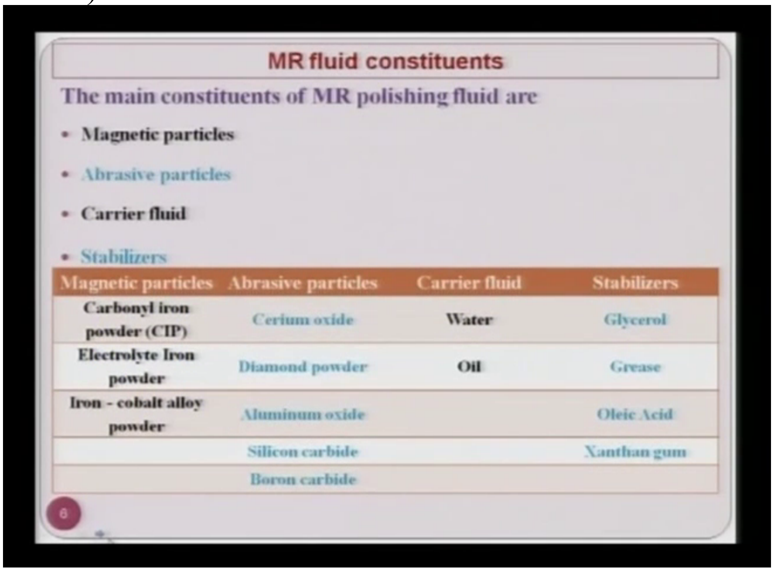

Magnetic particles	Abrasive particles	Carrier fluid	Stabilizers
Carbonyl iron powder (CIP)	Cerium oxide	Water	Glycerol
Electrolyte Iron powder	Diamond powder	Oil	Grease
Iron - cobalt alloy powder	Aluminum oxide		Oleic Acid
	Silicon carbide		Xanthan gum
	Boron carbide		

Now here this table gives you the magnetic particles, what are the various magnetic particles that are used in MR fluid? What are the abrasive particles? What are the carrier fluid and what are stabilisers used? So you can see here, carbonyl iron powder or carbonyl iron particles which is acronymed as CIP then electrolyte iron powder then iron cobalt alloy powder these are the magnetic particles that he had abrasive particles namely cerium oxide, diamond powder, aluminium oxide, silicon Carbide and boron carbide. The selection of abrasive particles will depend upon the type of the work piece material that you want to finish.

Then carrier fluid in many applications specifically ceramic applications or when you want to finish the ceramics single crystal ceramics or other than what are used as carrier fluid? And in some cases you can use oil as the carrier fluid where you cannot use because of certain constraints water as the carrier fluid. Then there are certain stabilisers which are you namely glycerol, Grease, folic acid and Xanthan gum.

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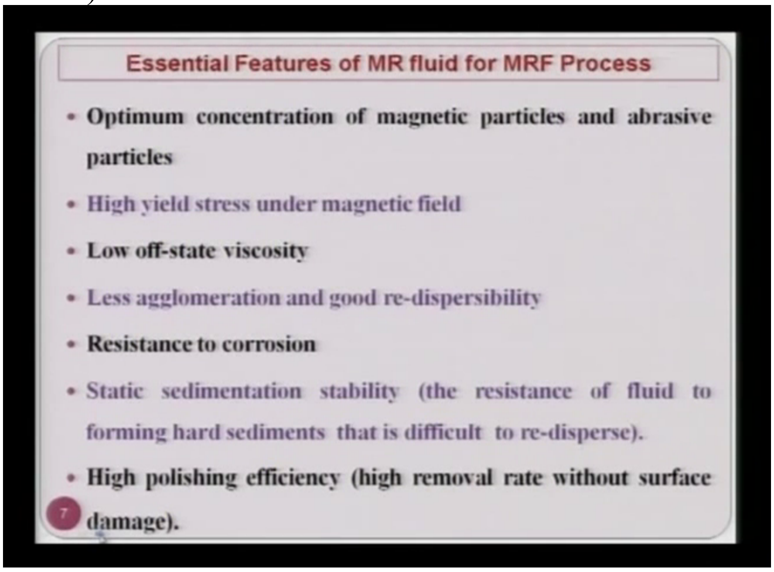

Essential features of MR fluid for magneto rheological finishing process. Optimum concentration of magnetic particles and abrasive particles is an important parameter. High yield stress under magnetic field. The yield stress of the medium should be high when magnetic field is applied it will depend upon the composition of the fluid as well as the strength of the magnetic field.

Low off state viscosity means when there is no magnetic field applied or when the fluid is not under the influence of the magnetic field at that point of time the viscosity of the fluid should be low. One of the reasons for this is, so that it can easily flow in the complicated shapes and that too very fine or very fine features of the component. Another important characteristic that we need to have this MR fluid is less agglomeration and good re-dispersibility.

Agglomeration of the particles or maybe iron particles may be abrasive particle should be minimum and once the magnetic field is removed then the particles maybe iron particles as well as abrasive particles should quickly re-dispersed in the fluid. Resistance to corrosion, it should not be corrosive in nature. Static that sedimentation stability, the resistance of fluid to forming hard segments that is difficult to re-dispersed that is another important characteristic.

And high polishing efficiency that means high removal rate without surface damage is another characteristic which we look for in the MR fluid for MRF process.

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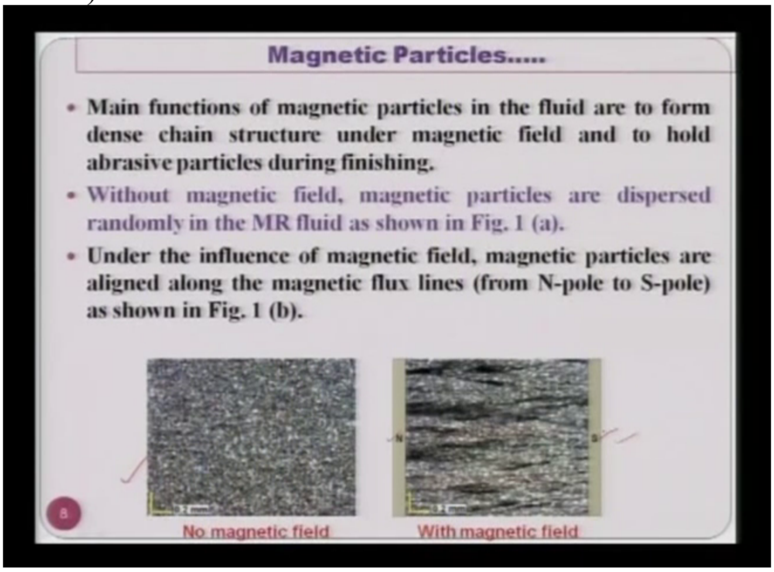

Magnetic particles, main functions of magnetic articles in the MR fluid are to form dense chain structure under magnetic field and to hold abrasive particles during finishing. As I have mentioned some time back this abrasive particles are functioning as the tool, cutting tools so this magnetic particles hold these abrasive particles, so that the abrasive particles can act as a cutting tool or finishing tool in this particular case.

As you can see here when there is no magnetic field abrasive particles as well as magnetic particles in the left hand side figure are randomly dispersed but when you apply the magnetic field as shown over here North Pole and South Pole you can clearly see the difference in these 2 figures these iron particles kept align along the magnetic field along the magnetic line of force.

As you can clearly see here and in between or within these chains you can see large size comparatively large size abrasive particles. Now when these abrasive particles come in contact with the surface to be finished they remove the material from the work piece and they are able to finish the work piece to the nano level surface roughness value, without magnetic field magnetic particles are dispersed randomly in the MR fluid as I have shown to you in the left hand side figure. Under the influence of magnetic field, magnetic particles are aligned along the magnetic flux line as you can see in the right hand side figure.

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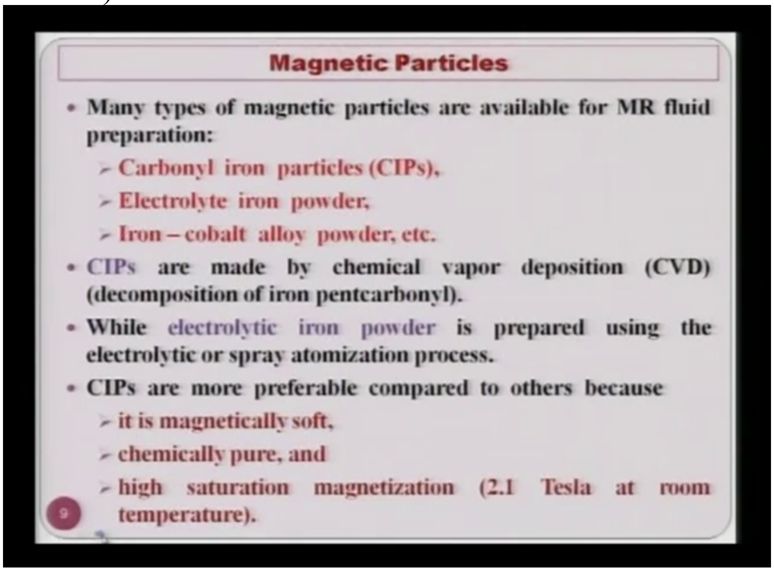

Magnetic particles again, many types of magnetic particles are available for MR fluid preparation, some of them I have already mentioned like carbonyl iron particles, electrolyte iron powder then iron cobalt alloy powder etc then there are CIPs Carbonyl iron particles are made by chemical vapour deposition or that is formed by decomposition of iron pentacarbonyl, while electrolytic iron powder is prepared using the electrolytic or spray atomisation process.

CIPs are more preferable compared to others because it is magnetically soft, chemically pure and high saturation magnetisation this is very important it saturates at 2.1 Tesla at room temperature that is why in many application Carbonyl iron particles are preferred over other types of magnetic particles although they are very expensive compared to especially pure iron powder or pure iron particles.

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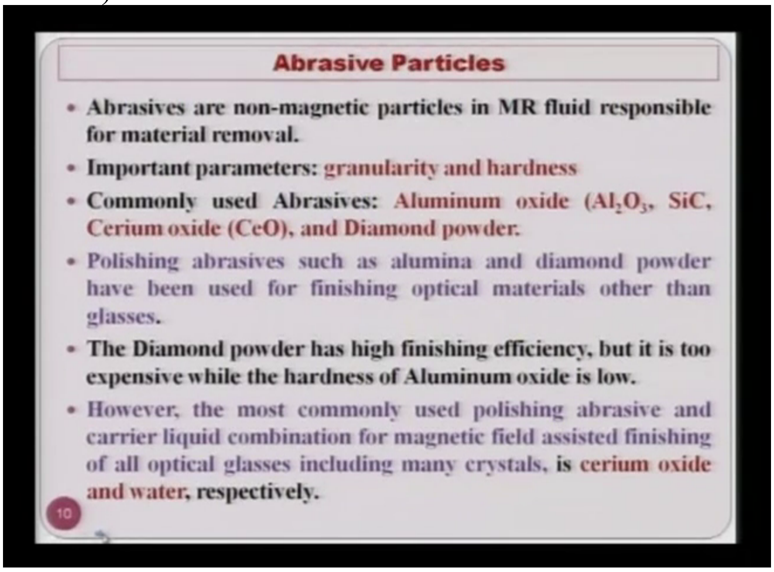

Abrasive particles are non-magnetic particles that are used in MR fluid and they are responsible for removal of the material in the form of micro-nano chips. Important parameters are granularity and hardness both is important parameters as long as abrasive particles are concerned. Commonly used abrasive particles are alumina, aluminium oxide also called as Silicon Carbide, cerium oxide and diamond powder.

Polishing abrasives such as alumina and diamond powder have been used for finishing optical materials other than glasses. Now glass is comparatively soft, so softer abrasive particles are used in case of glasses. Now diamond powder has high finishing efficiency but it is too expensive while the hardness of aluminium oxide is low. So while selecting the abrasive powder cost of the abrasive powder should also be taken into consideration.

If you can work with comparatively less expensive abrasive powder for finishing your particular product then you should not go for expensive abrasive powder like diamond or boron carbide. However the most commonly used polishing abrasive and carrier liquid combination for magnetic field assisted finishing of all optical glasses including many crystals is cerium oxide CEO and water, respectively.

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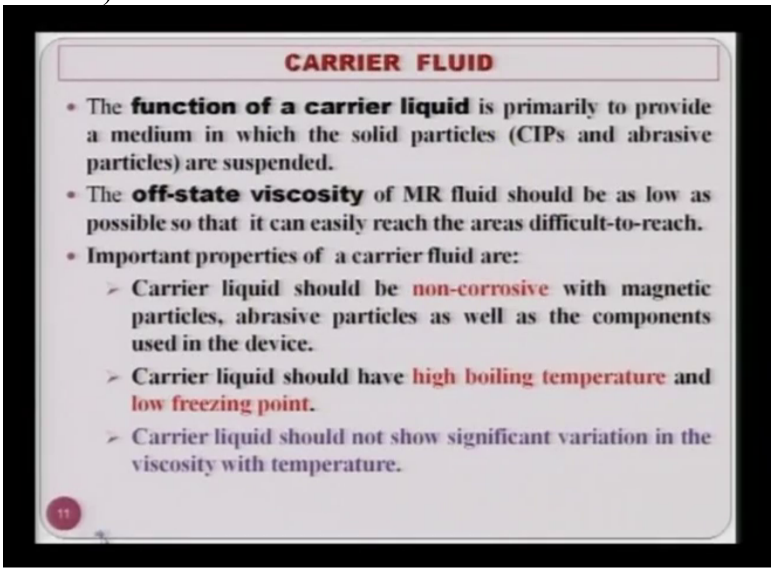

What are the functions of the carrier fluid? Now function of a carrier liquid or fluid is primarily to provide a medium in which the solid particles which includes carbonyl iron particles and abrasive particles are suspended. The off state viscosity of MR fluid should be as low as possible so that it can easily reach the areas difficult to reach; this is very true specifically in case of complicated shapes components.

Important properties of a carrier fluid are, carrier fluid should be non- corrosive in nature with magnetic particles, abrasive particles as well as the components used in the device. Carrier liquid should have high boiling temperature and low freezing point. Carrier liquid should not show significant variation in the viscosity with temperature this is another important for because if viscosity changes of the carrier liquid or carrier fluid than the characteristic rheological properties of the medium are going to change which will definitely affect the surface finish that you’re going to get finally.

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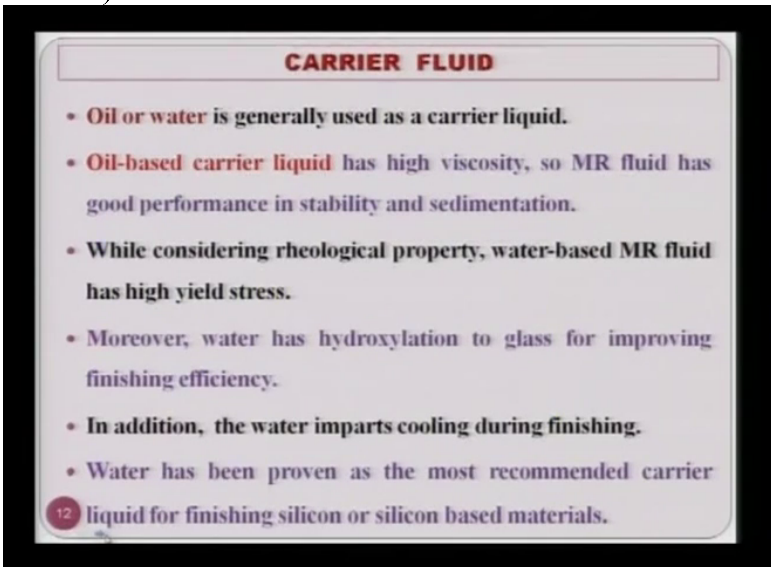

Oil or water is generally used as a carrier fluid. Oil-based carrier liquid has high viscosity; so far fluid has good performance in stability and sedimentation. While considering rheological property, water-based MR fluid has high yield stress. Moreover water has hydroxylation to glass for improving finishing efficiency. In addition the water imparts cooling during finishing because whenever material is being removed heat is generated and that heat remains more or less in the fluid. Hence its temperature is going to rise and the water is the one which functions as a coolant also when it is the carrier fluid in the medium. Water has been proven as the most recommended carrier liquid for finishing silicon or silicon-based materials.

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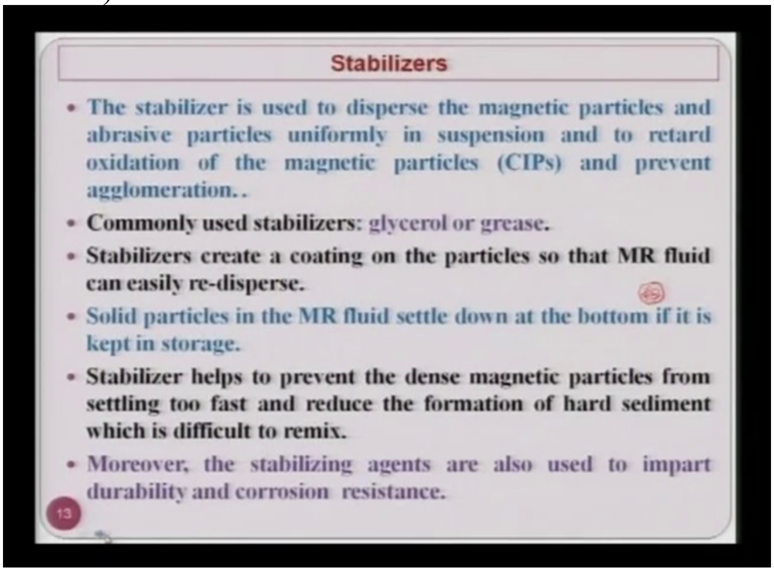

Stabilisers are also used in this particular medium, the stabiliser is used to disperse the magnetic particles and abrasive particles uniformly in suspension and to retard oxidation of the magnetic particles and prevent agglomeration this is very important magnetic properties should not get oxidise otherwise they cannot function properly and secondly they should not agglomerate they should not form the clusters at in a localised area otherwise they are not going to function in a proper way or the in the design way because they should be suspended in the medium as individual particle then only they can form a good quality of chains, chain structure as have shown you earlier in the figure.

Commonly used stabilisers are glycerol or grease. Stabilisers create a coating on the particles, so that MR fluid can easily re-disperse, suppose this is the a particle and then surrounding this particular particle a coating is formed by the stabiliser and that separates out 2 particles in agglomerating with each other hence this is very important. Solid particles in the MR fluid settle down at the bottom if it is kept in storage because the solid particles are heavier than if compared to the constituent of the medium like water and oil in stabiliser.

So the tendency is to settle down at the base of the container but these stabilisers also help in minimising the tendency to settle down and secondly before using any medium it should be uniformly distributed these abrasive particles should be uniformly distributed, for this you know as we will be showing you in the video film they should be uniformly mixed up for at least one hour before they are used.

Stabiliser helps to prevent the dense magnetic particles from settling too fast and reduce the formation of hard sediment which is difficult to remix. If hard sediments are mixed up or hard sediments are formed over there then it will not be easy to mix them or to disperse them the medium. Hence it should be avoided as far as possible. Moreover the stabilising agents are also used to impart durability and corrosion resistance, as we all know that Grease or glycerol they provide the characteristic of corrosion resistance.

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Now let us discuss briefly what is this magneto rheological finishing process of MRF process?

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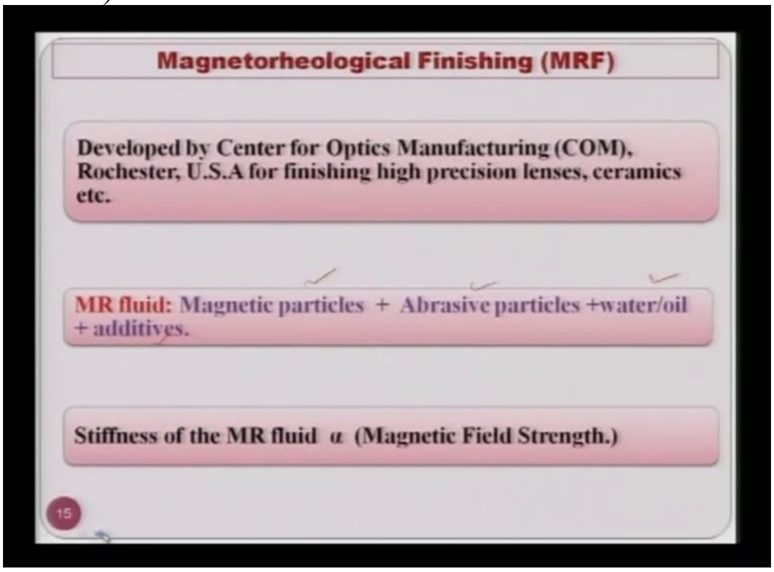

Magneto rheological finishing process it was developed by Centre for optics manufacturing (COM) Rochester USA for finishing high precision lenses, ceramics etc. just similar to what we are wearing on our face this kind of the lenses for that purpose they were initially developed, later on they found many applications in different area. So this MR fluid we have already seen it consists of magnetic particles, abrasive particles, water or oil as the base medium you can say and additives that also I have already mentioned to you just like glycerol or other additives are there.

Stiffness of the MR fluid is very important that provide the strength to the fluid to resist the forces that are acting on the abrasive particle as well as iron particles. So it depends upon the magnetic field strength and definitely the kind of the magnetic particles that are used or their saturation strength.

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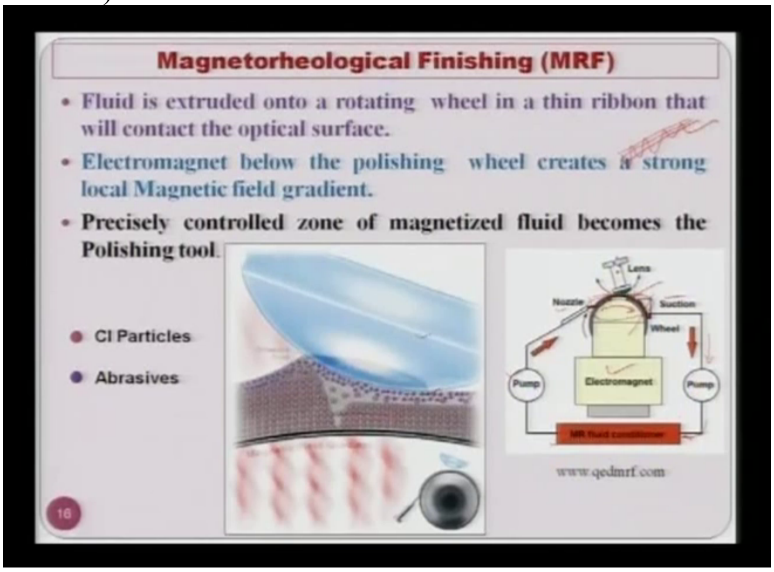

Now as you can see here MR magneto rheological finishing process shown over here, there are carbonyl iron particles and abrasive particles and you will see again that abrasive particles are getting in contact with the lens here in this one and iron particles are getting attracted towards the magnet, so when these abrasive particles come in contact with the lens and there is a relative motion between the lens and these abrasive particles they remove the piece from the surface of the lens.

Just like this slowly slowly and finally you can get a very good surface finish of nano level and this surface finish can lie between 1 to 10 nanometres in some cases they have found even less than 1 nanometre as the surface finish. Now the working principle is shown over here you can clearly see that there is a MR fluid conditioner where the fluid conditioning MR fluid magneto rheological fluid medium conditioning takes place.

It is supplied with the help of the pump and you can see there is a nozzle, nozzle supplies this fluid and here is a rotating carrier wheel, this is rotating wheel and this medium gets applied and this on the rotating wheel and in forms a ribbon, as you can see here shown by the red colour this forms the ribbon. Now this ribbon consists of magnetic particles, abrasive particles, base medium as well as the stabiliser.

Now when it comes in contact with the lens as you can see in this video that these abrasive particles touch the lens or there is a relative motion between abrasive particles and the lens and it starts removing material and once it has finished its function there is a suction pump which takes this MR fluid or medium and pump is there and it brings the used MR fluid to the MR fluid conditioner and here is the electromagnet which is there and which is creating the magnetic field surrounding to this part of the wheel, rotating wheel this is how it works.

Fluid is extruded onto a rotating wheel as you can see here fluid is getting extruded on this, this is a rotating wheel in a thin ribbon that will contact the optical surface and here the work piece is the optical surface. Electromagnet below the polishing wheel creates a strong local magnetic field gradient. This is the electromagnet which is creating a strong local magnetic field in this particular region and that is why these kinds of the chains are formed as you can see on the left hand side in the video and at the top of this change these are the abrasive particles which are in contact with the lens.

Precisely controlled zone of magnetised fluid becomes the polishing tool and you can see the colour of the carbonyl iron particles and abrasives their visible in this particular video.

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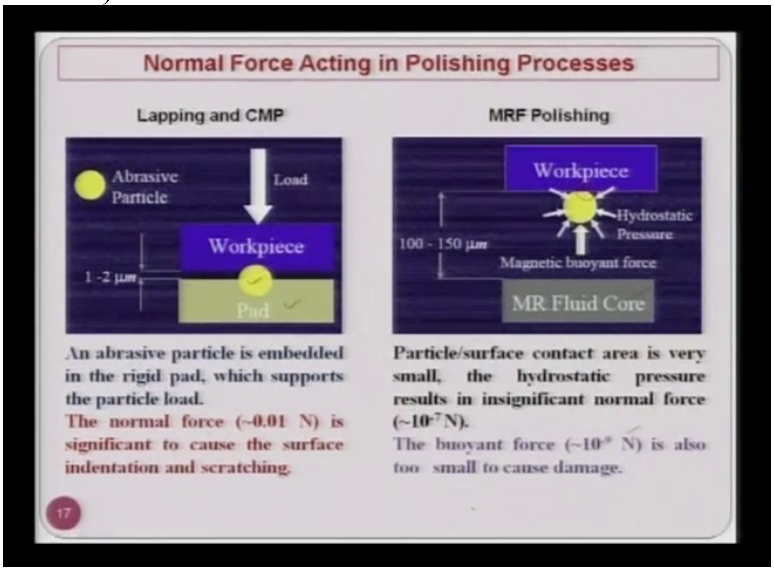

Now the CMP Chemo mechanical polishing is commonly known process and lapping is also a commonly known process. Now in both these processes how what kind of the forces are acting because these processes have the problem that surface of the product or the work piece gets damaged the way forces are acting as you can see here is the pad which is the acting in lapping also as well as CMP both have the pad and here is the abrasive particles and here is the work piece in blue colour.

Now load is being applied on the work piece and abrasive particles gets penetrated into the work piece and this may damage the surface of the work piece the gap between the 2 is just 1 to 2 microns while in here an abrasive particle is embedded in the rigid pad. Now this we all know it is true in the case of lapping process and in CMP also there are the abrasive particles on the pad which supports the particle load.

The normal force that is acting in case of CMP and lapping is somewhere around 0.01 Newton it is significant to cause the surface indentation and scratching this simply means that you can get a scratch formed on the work piece surface because of this hundredth of a nano Newton force that is acting on the average sub particle but in case of magneto rheological finishing process which I have just explained you can see the difference.

Here is the MR fluid core and abrasive particles are at the other end of the core and that is in contact with the work piece and here the hydrostatic pressure is acting on the abrasive particles which is making the abrasive particles to penetrate inside the work piece and this penetration is much smaller than the penetration that you're getting in case of CMP or lapping process.

That's in the gap between the work piece and the MR fluid core is somewhere around 100 to150 micron which is much bigger than 1 to 2 microns that's why the force is acting in case of MR process are much lower than what they are acting in CMP and lapping and this value is somewhere 10 raise to power minus 7 Newton that means 0.1 micro Newton as you can see here and particle surface contact area is very small.

Because force acting is very small so the depth penetration is accordingly going to be very small and the hydrostatic pressure results in insignificant normal force but this is good enough to give that nano level surface finish that's why I told you that even less than 1 nanometre surface roughness value you can obtain. The buoyant force that is acting in this particular case is 10 raise to power minus 9 Newton is also too small to cause any damage to the work piece surface.

So we can conclude from this discussion that there are good chances of surface damage in case of lapping in CMP that is why you have reasonably high value of rejection of the components in these processes while in MRP there are least chance for the damage of the work piece surface. So definitely the rejection rate will be very very low.

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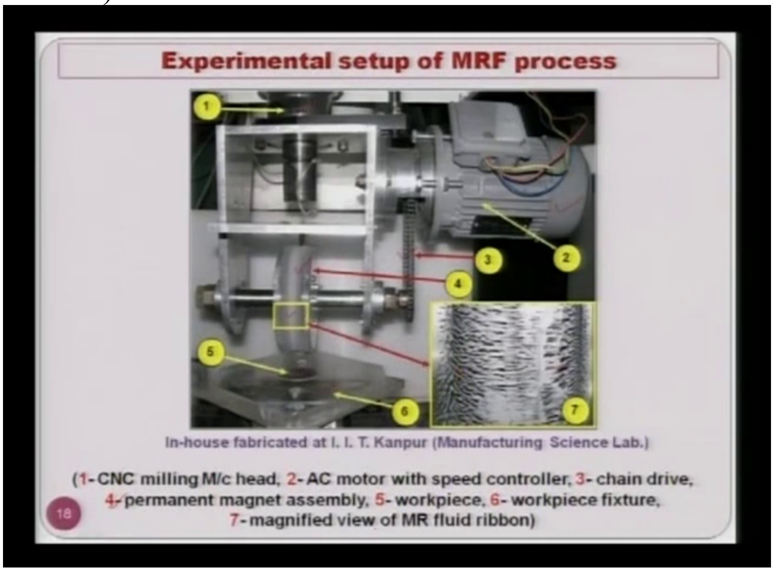

This is the experimental setup that was designed and fabricated at IIT Kanpur you can clearly see the same one which we have seen earlier in the schematic diagram. Here is the 1 is the CNC milling machine head is over here as you can see CNC milling machine head which is holding the setup which has been designed and fabricated for converting this CNC machine into CNC MRF machine.

2 is the AC motor with speed controller, here is the AC motor and there is a variable frequency drive VFD which is controlling its RPM that is rotational speed and 3 is the chain which is transferring the motion from the motor to the pulley over here which is connected to the rotating wheel which is going to form the ribbon. 4 is the permanent magnet assembly and here is permanent magnet assembly over which you can also see the ribbon of the MR fluid.

And 5 is the work piece over here and 6 is the fixture, 7 is the magnetic view of MR fluid ribbon whatever ribbon is being formed over here it's magnified view and you can clearly see the brush being formed over the whole width of the ribbon and this brush when it comes in contact with the work piece surface it penetrates to a very small extent because we have already seen the force acting is 10 raise to power minus 7 Newton or 10 raise to power minus 9 Newton. So definitely depth of penetration is going to be in terms of nanometre level and that removes the chips in the form of micro-nano size and you get finally the surface roughness value somewhere between 1 to 10 nanometre in most of the cases.

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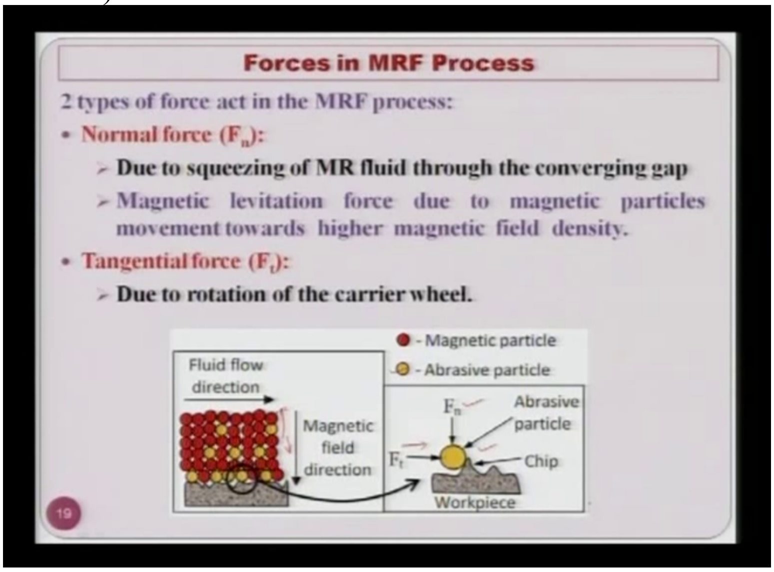

Forces in MRF, how it is functioning as you can see further is explained here with the help of the schematic diagram you can clearly see red colour these are the magnetic particles as you seen in the video also and they are forming the change in the direction of the magnetic field direction is also shown over here and as you go away from the magnet towards the work piece abrasive particles can be seen over here in the yellow colour and they are in contact with the work piece and enlarged view is shown over here.

Now you clearly see here 2 types of forces are acting, one is a normal force Fn which is responsible for the penetration of this abrasive particles into the work piece and Ft is the tangential force which she is responsible for removal of the material in the form of the microchip and when Ft is bigger than the resistance being applied by the work piece surface to form to remove the material in the form of the chip than the material is being removed.

2 types of forces act in the MRF process Ft and Fn and normal force Fn due to the squeezing of MR fluid through the converging gap because the thickness of the ribbon is bigger than the gap between the bottom phase of the ribbon and the top phase of the work piece. So squeezing of the ribbon takes place which is responsible to apply large amount of normal force and that normal force helps in the penetration of abrasive particles into the work piece surface.

And magnetic levitation force due to magnetic particles movement towards higher magnetic field that I have already mentioned that the magnetic particles move towards the magnet and that magnet is surrounding the rotating wheel, so when they are magnetic particles are moving towards the magnet as you can see here they are moving away from the work piece surface.

Then levitation force is acting on the abrasive particles that also help in the penetration of the abrasive particles into the work piece surface as you can see on the right-hand side figure. Tangential force is there due to the rotation of the carrier wheel tangential force is acting Ft on the abrasive particles and this is mainly responsible for removal of the material in the form of the microchip.

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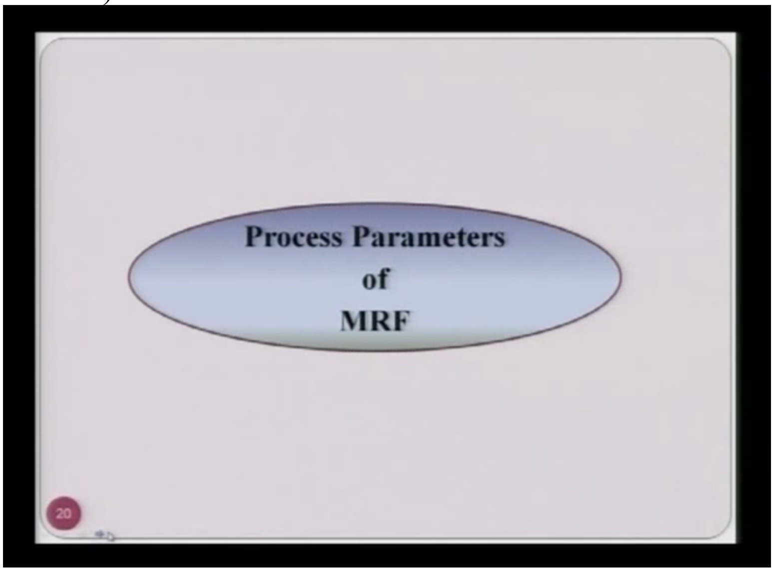

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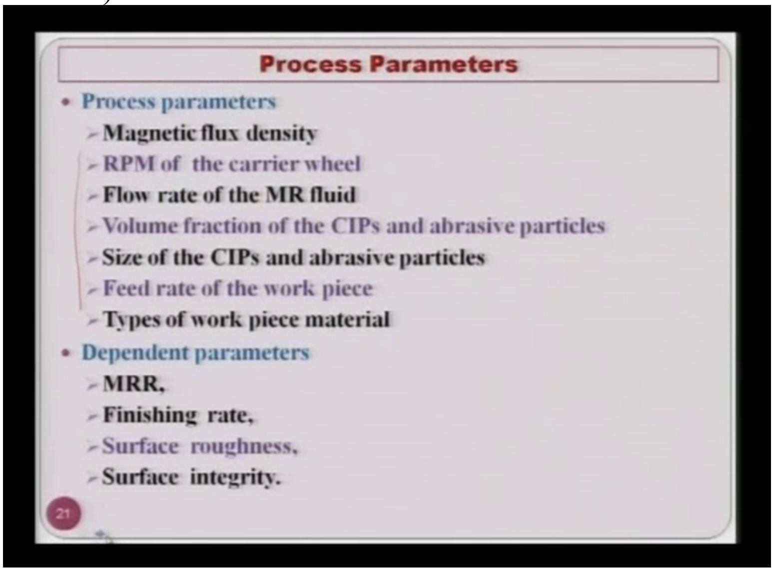

Now there are various process parameters of MRF process. Process parameters are magnetic flux density, RPM of the carrier wheel that is rotational speed, rotation per minute of the carrier wheel, flow rate of the MR fluid, volume fraction of the CIPs that is carbonyl iron particles and abrasive particles. Size of the CIPs and abrasive particles, feed rate of the work piece with reference to the ribbon or the abrasive particle.

Types of the work piece material definitely type of the work piece material is going decide the property of the work piece material that is the hardness shear string etc and which will definitely affect the removal rate as well as the finishing rate. There are dependent parameters, these are the independent parameters and now dependent parameters are material removal rate which depends upon all these parameters that I have just mentioned material removal rate function of those parameters.

Same way finishing rate the rate with which the surface roughness value is decreasing that is what is known as finishing rate and then final surface roughness these are all dependent parameters and surface integrity is very important I have already explained as compared to Chemo mechanical polishing CMP as well as what is that lapping process?

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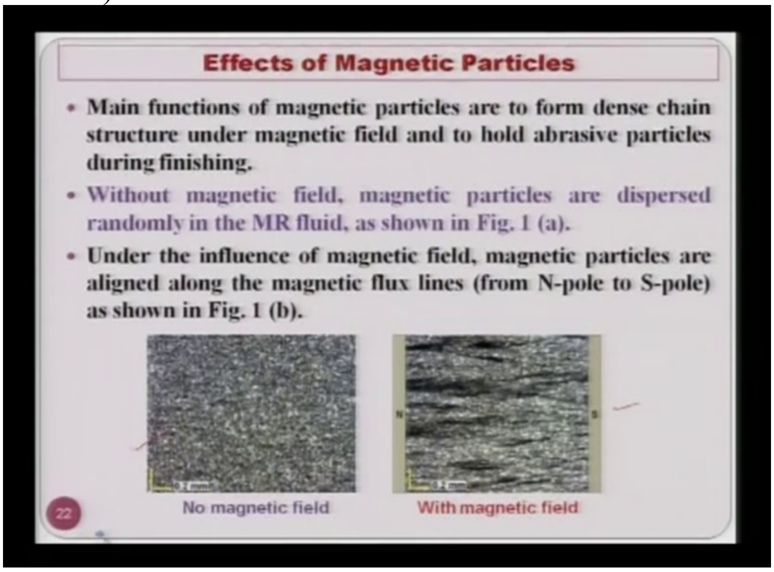

Now effects of magnetic field I have explained this when there is no magnetic field abrasive as well as iron particles are randomly distributed when there is a magnetic field they form the change as you can see here. Main functions of magnetic particles are to form dense chain structure under magnetic field and to hold abrasive particles during finishing residency in the right hand side figure.

Without magnetic field, magnetic particles are dispersed randomly in the MR fluid, as shown in the left hand side figure that is figure 1a and under the influence of magnetic field; magnetic particles are aligned along the magnetic flux lines as you can see in the right hand side figure that is figure 1b.

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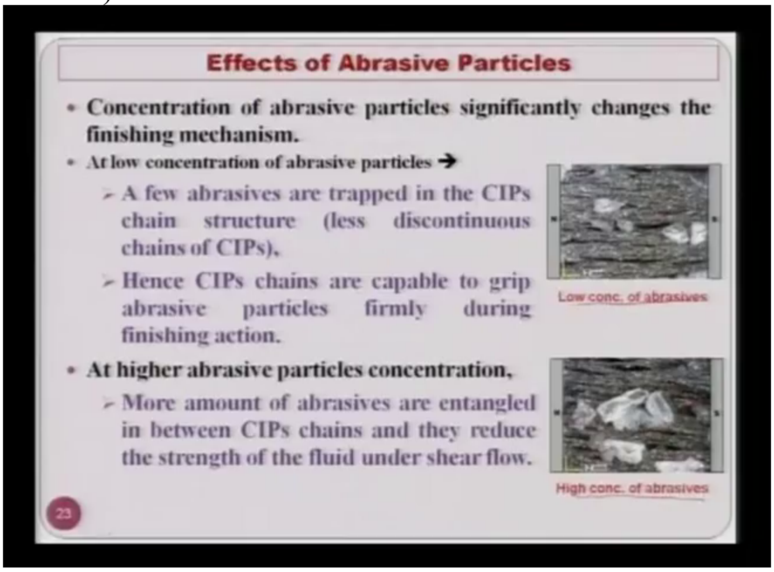

Effects of abrasive particles, this is important figure as you can see here concentration of abrasive particles significantly changes the finishing mechanism. At low concentration of abrasive particles, a few abrasive are trapped in the CIPs chain structure less is continuous, please see it carefully this is a real photograph which we have taken and you can see these are the bigger size these are the abrasive particles.

We have deliberately taken such a bigger size of abrasive particles, so that you can clearly see the status of the abrasive particle, in real life we use the abrasive particle which are of the size close to the magnetic particles as you can see they are forming the change and abrasive particles are held between the chains and in some cases they are tried to be held as you can see here within the chain.

And these abrasive particles when they come in contact with the work piece then they remove the material in the form of micro-nano chip but one thing is clear that these abrasive particles are very thinly distributed because there are very limited number of abrasive particles because abrasive concentration is low but when abrasive concentration changes then the things become different.

Now you can see here with high concentration of abrasive many abrasive particles get agglomerated and they get located in a very small area and this is not what really we want they should be uniformly distributed as you can see other abrasive particles are there. So CIP chains are capable to grip abrasive particles firmly during finishing operation as you can see here the chains are holding these abrasive particles over here.

As well as here also this abrasive particles is between these 2 clusters of chains and once this rubs, these magnetic particles hold these abrasive particles which are removing the material. At higher abrasive particles concentration as you can see on the right side bottom more amount of abrasives are entangled in between CIP chains and they reduce the strength of the fluid under shear flow. Another important point is the fluid strength is reduced when the concentration of abrasive particles is large because concentration of CIP reduces accordingly.

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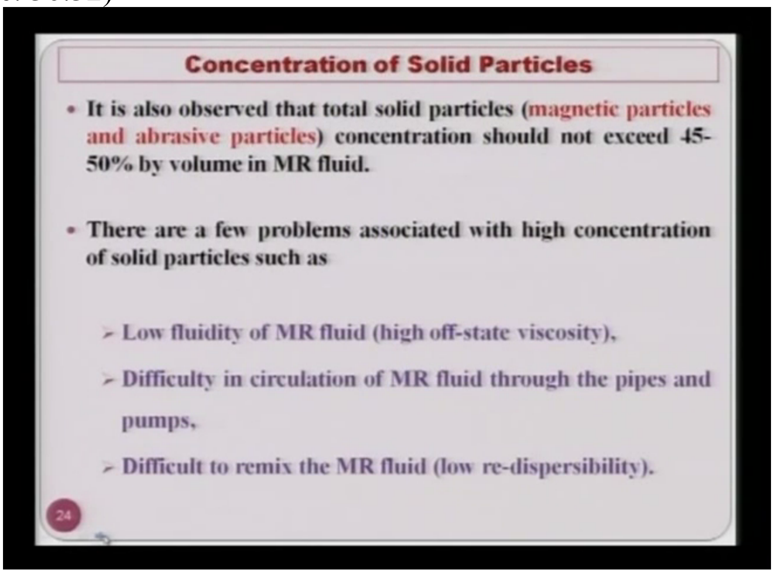

Concentration of solid particles, it is also observed that total solid articles which includes magnetic particles and abrasive particles concentration should not exceed 45-50 percent by volume in MR fluid because if too much of solid particles are aware then flow ability of the medium will be reduced. There are a few problems associated with high concentration of solid particles such as low fluidity of MR fluid and also it leads to high off state viscosity that means when no magnetic field is applied that time viscosity is quite high which is not good for easy flow of the medium.

Difficulty in circulation of MR fluid through the pipes and pumps. Difficult to remix the MR fluid that is low re-dispersibility because once the magnetic field is removed then they should be easily dispersing in the medium that does not happen if solid particle concentration is more than 50 percent or so.

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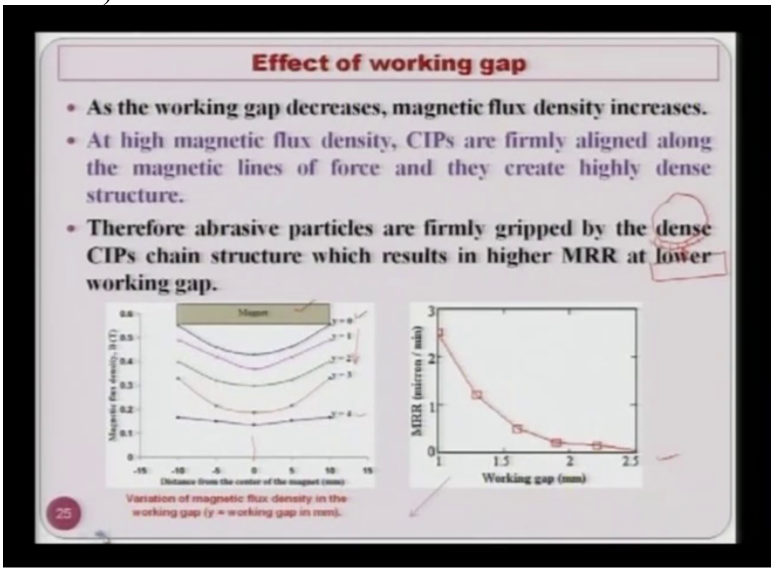

Now effect of working gap is very important parameter. As you can see here in this particular figure. Here is the magnet and on the axis you can see the distance from the centre of the magnet, this is the centre of the magnet left hand side minus 5 minus 10 and so on, on the right side plus 5 plus 10 so on and on the ordinate you will find magnetic flux density the important point to note is that the highest magnetic flux density is obtained when the gap with the magnet and the surface where you are measuring the flux density is 0.

And as the distance between the magnet and the surface where flux density is being measured is increasing the value of the flux density is decreasing and it is minimum in this particular case at 4 millimetre and maximum 0 millimetre, this is a very important point because when ribbon is being formed and there is a certain gap between the ribbon and the work piece and once squeezing start taking place that gap is still there with reference to the magnet. So what is that thickness of the ribbon will also decide how strong the chains that are being formed are there.

Now working gap and MRR also can be seen over here, you can clearly see that as the working gap is increasing material removal rate is decreasing because it can be easily understood from the left hand side figure that as you can see here as the gap is increasing the flux density is decreasing.

So is the true over here as gap is increasing MRR is decreasing because the once the strength of the fluid decreases then the depth of penetration will decrease and the capabilities to remove the material in the form of chip also reduces that’s why MRR is decreasing with increase in the working gap and here you can again see this is the wheel or magnet and this is the ribbon being formed and here is the work piece.

So depending upon the gap between the 2, this gap has to be 0 until this ribbon is in contact with the work piece it will not be able to remove the material because every say particles are at the outer surface of the ribbon. So this contact of the abrasive particles and work piece has to be there for removal of the material. Therefore abrasive particles are firmly gripped by the dense CIPs chain structure which results in higher MRR at lower working gap.

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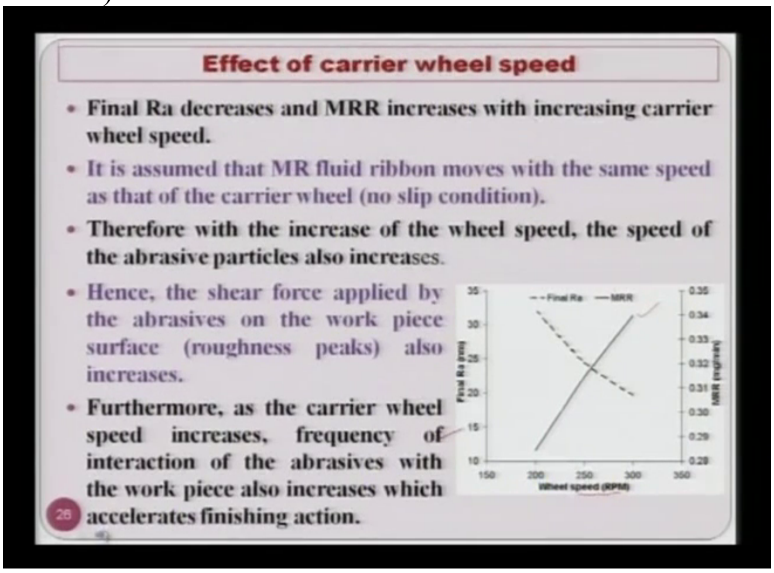

Effect of carrier wheel speed, you can see here as the wheel speed is increasing MRR is increasing because the time or the number of times an abrasive particle is interacting with the work piece increases as the speed of the wheel increases and once the material removed is higher and higher than surface finish value keeps decreasing till it attains the critical surface roughness value which I have already explained in some other lecture.

Final Ra decreases and MRR increases with increasing carrier wheel speed as you can see in this particular figure. It is assumed that MR fluid ribbon moves with the same speed as that of the carrier wheel that is no slip conditions. No slip conditions between the ribbon and the carrier wheel therefore with increase of the wheel speed, the speed of the abrasive articles also increases.

Because abrasive particles are part of the ribbon and once the ribbon is rotating with the same speed as the carrier wheel, so it means that abrasive particles are also rotating with the same speed as the ribbon. Hence the sheer force applied by the abrasives on the work piece surface also increases. Furthermore is a carrier wheel speed increases, frequency of interaction of the abrasives with the work piece also increases which accelerate finishing action.

As I have already explained that interaction between the abrasive particle and the work piece increases as the rotational speed of the carrier wheel increases because suppose 50 rpm and 100 rpm, 50 rpm means 50 times in 1 minute the particular abrasive particle will be in contact with the work piece. In 100 rpm 100 times in every minute it will be in contact with the work piece surface that means time of interaction is increasing then removal of material will also increase.

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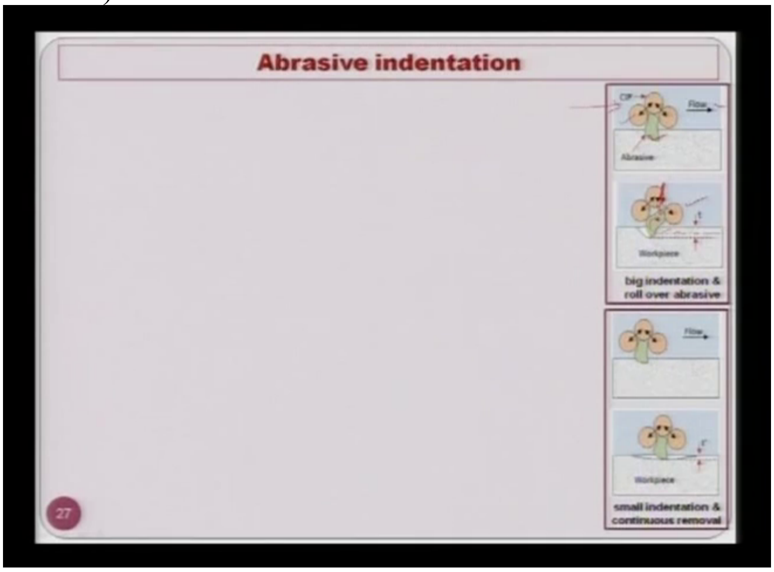

How this indentation of abrasive particle is taking place just see here nicely shown, this is the abrasive particle which has penetrated inside the work piece surface and this is the change being formed by the CIPs carbonyl iron particles and there is the axial force which is shown here which is pushing the abrasive particles forward to remove the material in the form of a chip as you can see over here.

But a penetration is large, if the penetration is large then in this particular case second figure the abrasive particle is not able to remove whole of the material that’s why it is slightly rotating reducing the depth of penetration as you can see here and once this depth of penetration reduces to the extent that the axial force is able to remove the material then this removal of the material may take place something like this rather than this t.

So this rotation of the abrasive particle becomes very important for the removal of the material if very large normal force is acting that is the force which is responsible for penetration of the abrasive particles into the work piece surface as you can see in the first figure. Now if there is a small indentation then you can see here in this particular case that indentation depth is smaller than the first case and here the axial force is large enough to remove the material and you can see in this way it is able to remove the material as the t dash depth of penetration.

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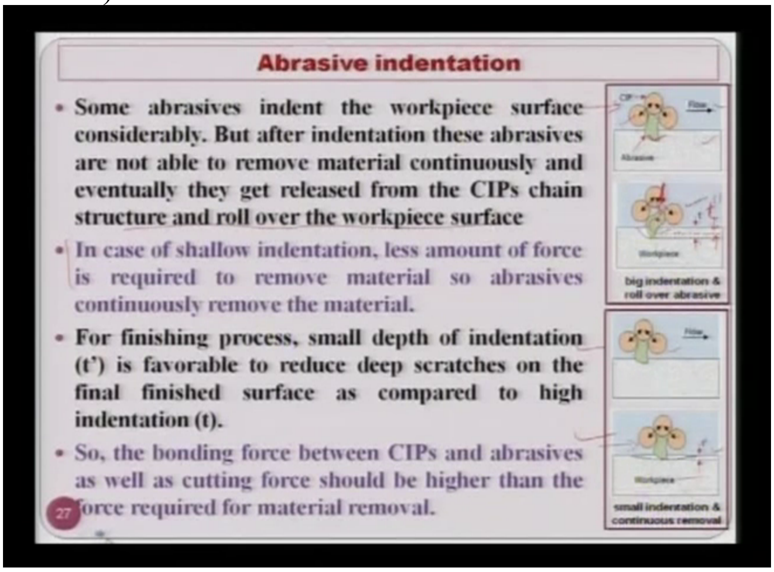

Some abrasives indent the work piece surface considerately because at that particular time normal force is large but after indentation these abrasives are not able to remove material continues and eventually they get released from the CIPs chain structure and rollover the work piece surface this is another situation, as I mentioned in the little time earlier that it may rotate and its depth of penetration may reduce from t to the t double dash that is one situation.

Another situation has mentioned over here that it may get released from the CIP chain structure and rollover the work piece surface that means it may get released and rollover the work piece surface without really removing the material from work piece surface it depends upon the strength of the fluid as well as depth of penetration both. In case of shallow indentation that is shown in this figure 3 and 4 less amount of force is required to remove materials.

So abrasives continuously remove the metal as you can see in the fourth figure. Now in fact here it is important to note that the, how much force axial force it can apply or tangential force it can apply to remove the material from the work piece depends upon the strength of the medium, magnetic flux density, concentration of the CIPs it is something different from what you see in case of grinding wheel where bonding material decides the strength of the abrasive particles.

For finishing process small depth of indentation that is t dash in the third case and fourth case is favourable to reduce the scratches on the final finished surface as compared to high indentation as in case of first and second figure. So the bonding force between CIPs and abrasives as well as cutting force should be higher than the force required for material removal.

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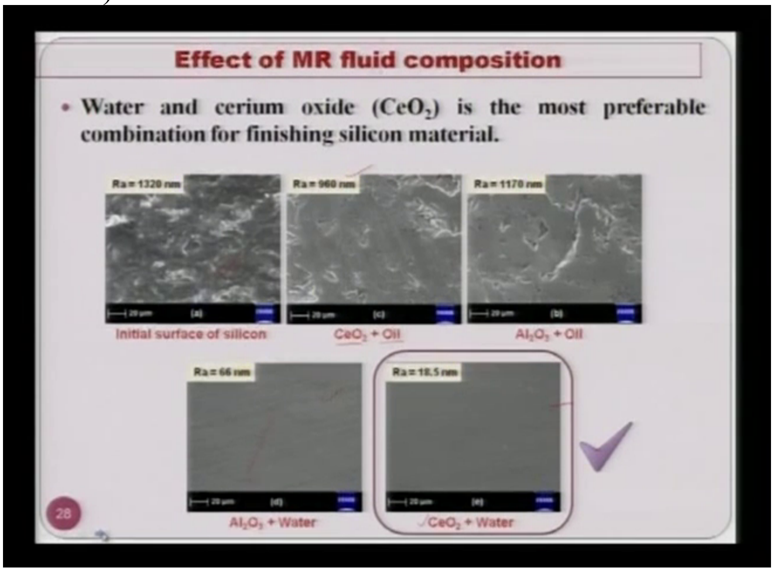

Effect of MR fluid composition, water and cerium oxide is the most preferable combination for finishing silicon material. You can see this is the initial surface of the single crystal silicon which had 1320, 1320 nanometre as the surface finish. Now we finished it and used cerium oxide is the abrasive particle in oil as the base fluid and you can see the surface roughness came down to 960 nanometres.

Then alumina plus oil was used and somehow the surface roughness was there as 1170 nanometre then alumina and water was used as the medium constituent then you can see clear difference the surface roughness came down to 66 nanometre from 1320 nanometre. So you can calculate by what percentage the surface roughness has reduced and you can clearly see qualitative difference in the initial surface over here and the surface obtained after a certain period of time and you can see a deep scratch is there in this particular case which is not desirable.

And then in place of alumina because alumina is the harder abrasive particle, so we use in place of alumina we used cerium oxide as the abrasives in water as the base medium and you can see the difference between the left hand side figure at the bottom and right-hand side of the figure of the bottom and the surface roughness value in this particular case is 18.5 nanometre. On the left hand side it is 66 nanometre and it has some scratches also, on the right-hand side there are no scratches. So you can see clearly that qualitative difference between the 2 surfaces.

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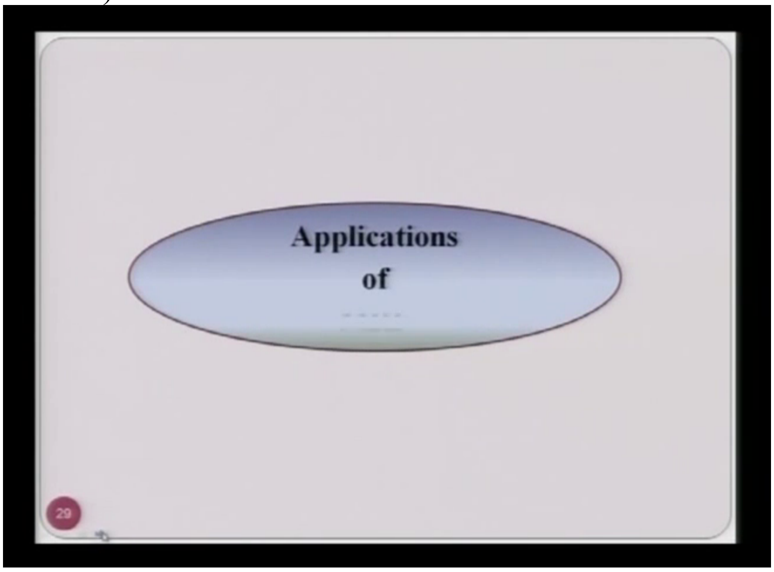

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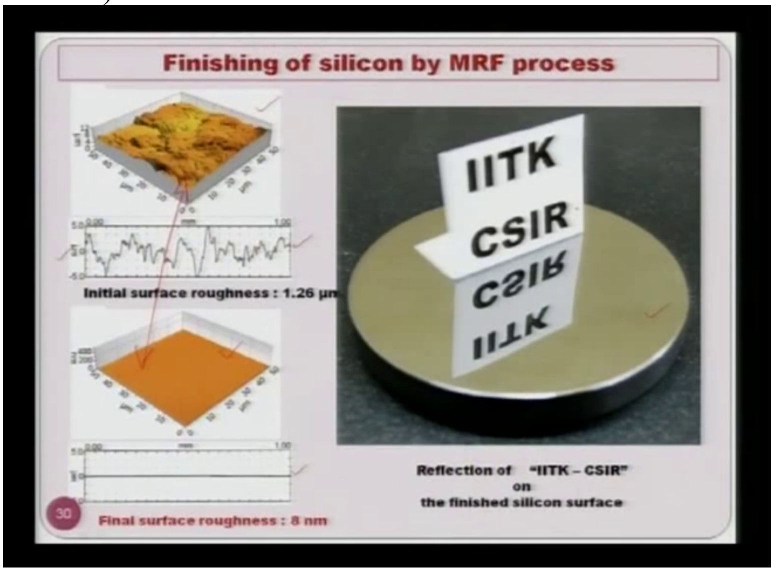

Now let us see quickly some of the applications of the magneto rheological finishing process. Now you can see the initial surface roughness as I have shown you earlier those pictures were of the surf analyser and scanning electron microscope. Now here is the surface analyser picture which we took it and here is the atomic force microscope picture of the initial surface that is 1260 nanometre.

Now after finishing we got surface analyser picture over here which looks like a straight line and you can compare this with the initial surface roughness peaks and valleys are there and this is the final surface after finishing with 8 nanometre, so you can clearly see the qualitative difference between these 2 surfaces and this is an interesting picture, this is the surface that has been finished with 8 nanometre and we took the 2 letters written on a piece of paper IITK and CSIR and you can clearly see the mirror reflection of these letters.

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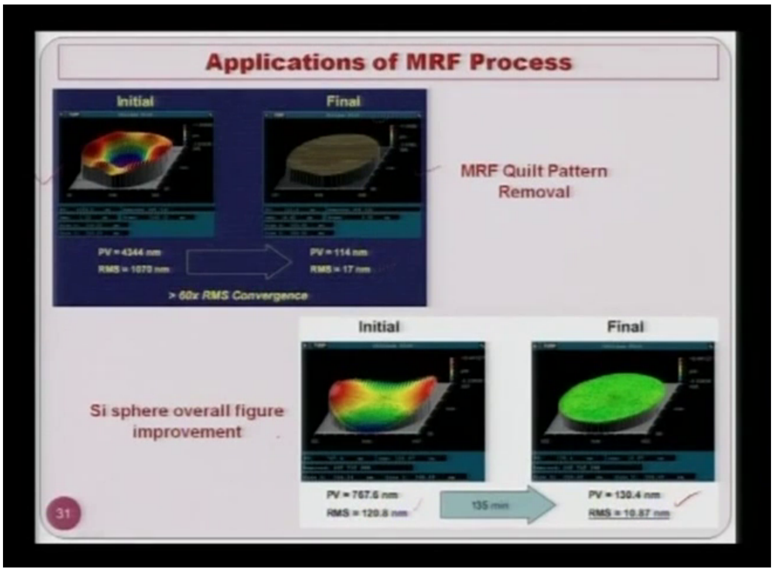

There are other applications of this process you can see this is normally the surface which you obtain by some other process which has peaks and valleys in some kinds of scratches etc in this particular case and it cannot be accepted in the final product and with MRF you get just a flat surface which is where you can see clearly the difference in the qualitative difference in the 2 surfaces.

The PV is 4344 nanometres RMS is 1070 nanometre, in this particular case RMS comes out to be 70 nanometres, so there is a drastic difference between the 2. Again here on the left side initial surface is somewhat curved, type of the surface at nano level and it has RMS value 120 nanometre, 120.8 nanometre and after MRF magneto rheological finishing you get the surface roughness as 10.87 nanometre and there is a flat surface. So you can see more than 10 times the surface roughness value in terms of RMS has decreased and this is the silicon sphere overall figure improvement by MRF process in this particular case.

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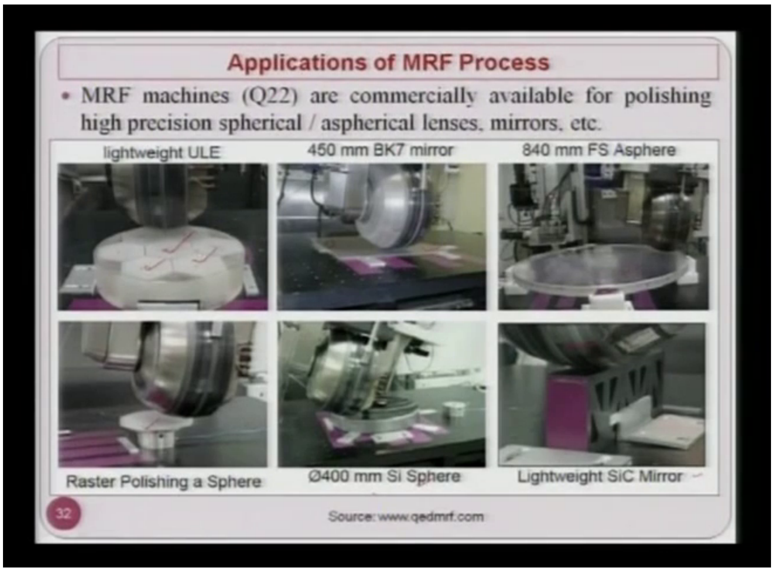

There are some other applications which are shown over here which have been taken from the Internet site and you can clearly see lightweight ULE been finished over here these are the work pieces which are being finished and then mirror finishing is there this is the ribbon being formed, this is the carrier wheel over there and this is the S sphere surface which is finished with the help of your MRF process you can see this is the wheel.

And this is another raster polishing a sphere this is the work piece over there then silicon sphere over there you can see in this particular case and then lightweight silicon Carbide mirror is there which is being finished you can see over here and this one. So there are various kinds of applications and you can see clearly that this can be applied for spherical a spherical or flat surfaces, you cannot use it as such for complicated shapes, thank you very much.

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Hello everybody my name is Ajay Shitpara, I am Ph.D. student at mechanical engineering Department IIT Kanpur. Today I'm giving you a brief introduction of magneto rheological finishing process and shortly called is MRF process. The basic component of MRF process is magneto rheological fluid and presently I'm giving you a preparation of magneto rheological fluid, how it is prepared here?

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Abrasive particles are required to increase material removal, in other words to reduce finishing time. In the present case the abrasive is aluminium oxide.

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Carbonyl iron particle, in other words magnetic particles are required to met (()) (52:54) under the effect of magnetic field. When the magnetic field is applied iron particles are aligned along the lines of magnetic field and they create a dense structure.

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Water is required to provide a liquid medium, so that magnetic particles as well as abrasive particles disperse uniformly.

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Some (())(53:18) are also required in the MR fluid, so that magnetic particles as well as abrasive particles remain suspended in the MR fluid and to reduce the sediment in the program. In the present case it is glycerol.

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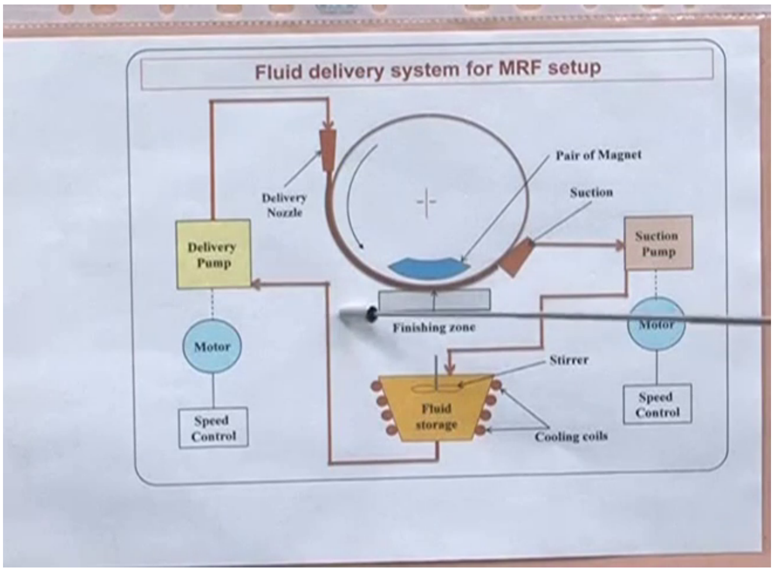

This is a schematic diagram of MRF process which is developed by University of Rochester USA and later on it is commercialised by QED technology USA this is a carrier wheel on which MR fluid is supplied by the delivery nozzle. Here the work piece is fixed when the magnetic field is applied either by permanent magnet or electro magnet the MR fluid gets stiffen due to presence of magnetic particles.

When the stiffen MR fluid comes in the contact with the work piece surface, it creates a finishing zone which is given here where the material removal takes place due to interaction between stiffen MR fluid and the work piece. After that the MR fluid is selected from the carrier wheel by this suction pump from there the fluid is collected to the mixing chamber it is also called a collector from where in the mixing chamber MR fluid is mixed continuously by the stirrer, so that particle gets mixed there homogeneously.

A temperature control is also provided to maintain a constant temperature and additional provision of the water supply is also attached, so that the loss of water due to evaporation can also be compensated. From the storage fluid is again circulated by the delivery pump and it supplied to the carrier wheel by this delivery nozzle.

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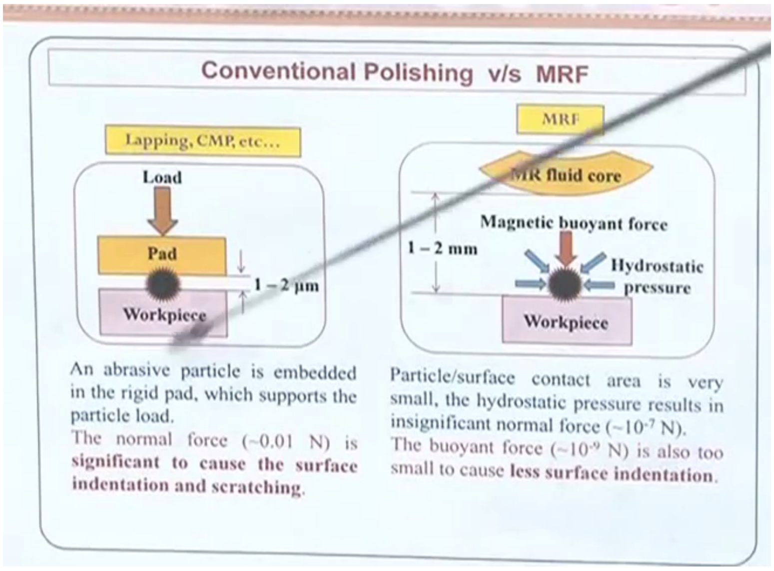

This diagram shows that force is acting in conventional polishing versus MRF process. In conventional polishing such as lapping or Chemo mechanical polishing shortly it is called CMP process in which an abrasive particle is embedded in the rigid pad, which supports the particle load. Therefore the normal load around 0.01 Newton is significant to cause surface indentation or scratching in case of nano finishing.

While in another case in MRF process, the particle surface contact area is very small, so that the hydrodynamic pressure results in insignificant normal force around 10 raise to minus 7 Newton. Furthermore the buoyant force it is also around 10 raised to minus 9 it is also too small to cause surface indentation in case of MRF process. So from this comparative view you can say that the MRF process is far better than this conventional polishing process in case of nano finishing of different components.

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All the constituents such as magnetic particle, abrasive particle, water and glycerol are mixed together in a proper concentration after adding all these constituents it is stirred for at least one hour to get it mixed homogeneously.

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Now you can see all the constituents of MR fluid are homogeneously mixed, now this fluid is ready to use in MRF process, okay.

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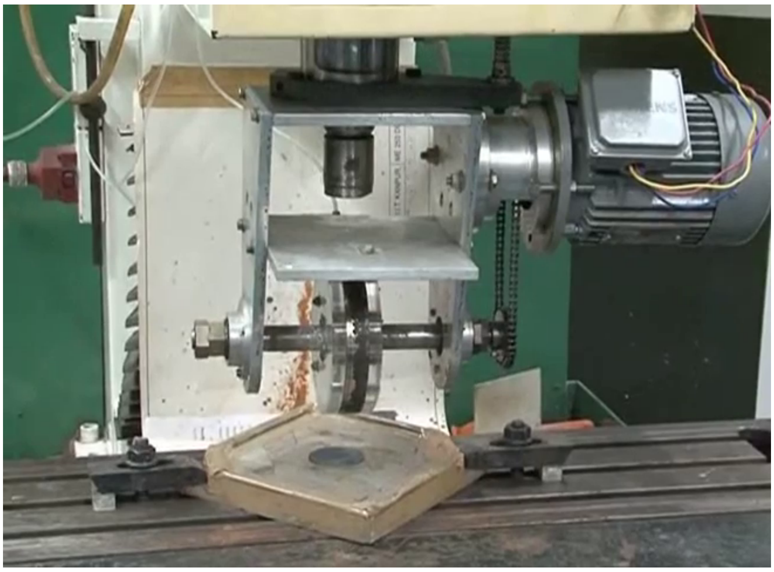

The whole setup is connected to the z axis of milling machine, so that the working gap can be adjusted by the computer control.

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You can control x, y and z simultaneously by giving the motion.

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This is a permanent magnet which is covered by 2 prospect sheets and this whole assembly is called a carrier wheel. The carrier wheel is connected to the AC motor through this timing chain and this AC motor is again connected to the variable frequency dye, so that the wheel speed can be controlled automatically by this variable frequency dye. Even you can give a particular value of the wheel speed, so that it can rotate at that particular value only.

And this is also required that most of the components should be (())(57:53), so that the magnetic field of line should not be distracted by this components, this is a work piece and this is a work piece fixed here in the present case this workplace is single crystal silicon which is to be finished up to nanometre level by this magneto rheological finishing process.

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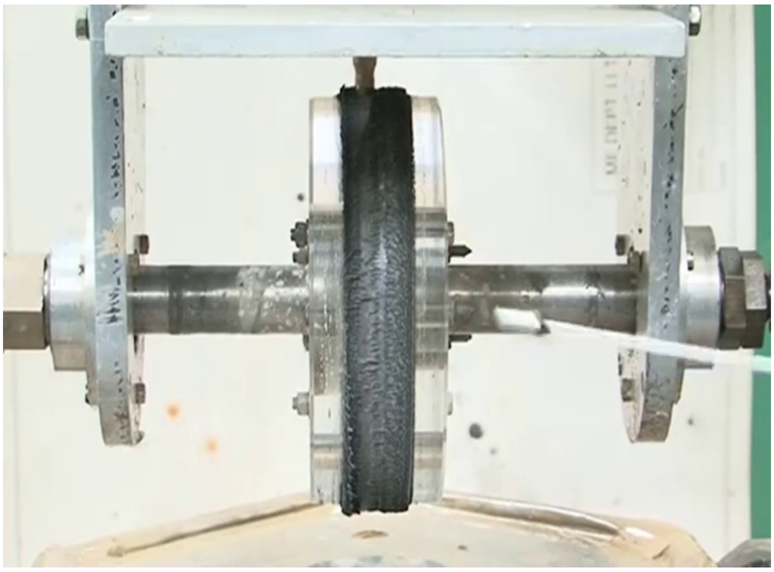

Now MR fluid is applied on the carrier wheel. Now you can see the MR particles or magnetic particles are aligned from the North Pole to South Pole from the magnet. You can clearly see the chain structure of the MR fluid particle. After that a particular gap is set between the work piece and the carrier wheel by changing z axis position. Once the gap is fixed rotation to the carrier wheel is given and x and y unit can also be given to the carrier wheel, so that the whole work piece surface can be covered.

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Here you can see (())(60:11) MR fluid is interacting with the work piece surface. At the finishing zone here 2 types of forces are exerted on the work piece surface, one is tangential (())(60:22), it is applied by the rotation of the carrier wheel and other one is the normal force in this direction, it is due to flow of stiffen MR fluid (())(60:33) because gap is little bit smaller than the thickness of the ribbon which is applied on the field and the hydrodynamic action of the MR fluid also creates a normal force this process is continued till the desired surface finish is achieved.

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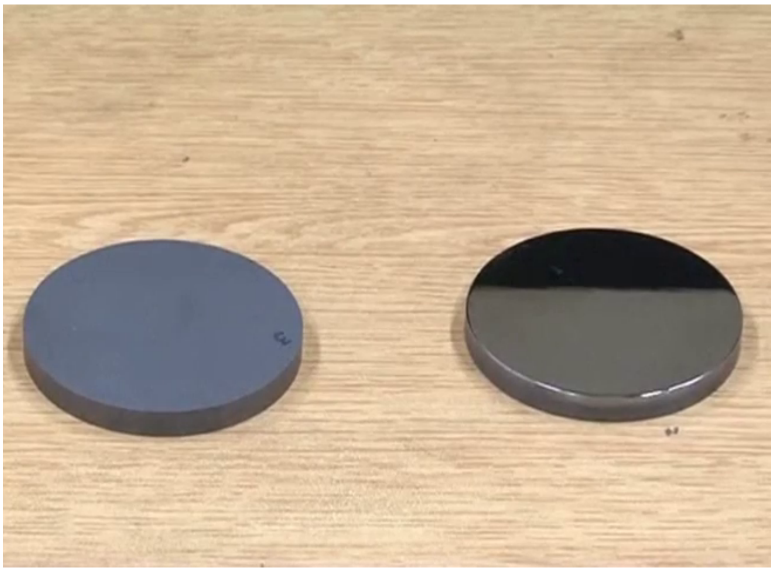

Now I will show you the finish as well as unfinished silicon work piece surface, you can easily see the difference between unfinished and finished silicon surface.

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This is an unfinished silicon surface you can see there is no any type of reflection is visible on the surface of the unfinished silicon surface.

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Now this is finished silicon surface and you can easily see the reflection of IITK and CSIR on the finish surface of the silicon surface. The present results shows that the MRF process is very efficient process for finishing optical as well as hard material, thank you for your attention.