Introduction to Abrasive Machining and Finishing processes

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Lecture – 24
Magnetic Field Assisted Abrasive Finishing Processes

Now, we are moving to another set of Magnetic Field Assisted Abrasive Finishing Processes, where in we will see some of the hybrid version of what we have seen in the previous class initially, just few slides are glimpse of that one. Glimpse of hybridization of magnetorheological finishing process then we move on to the sum of the hybrid processes that can be developed with a basis of magnetorheological finishing process.

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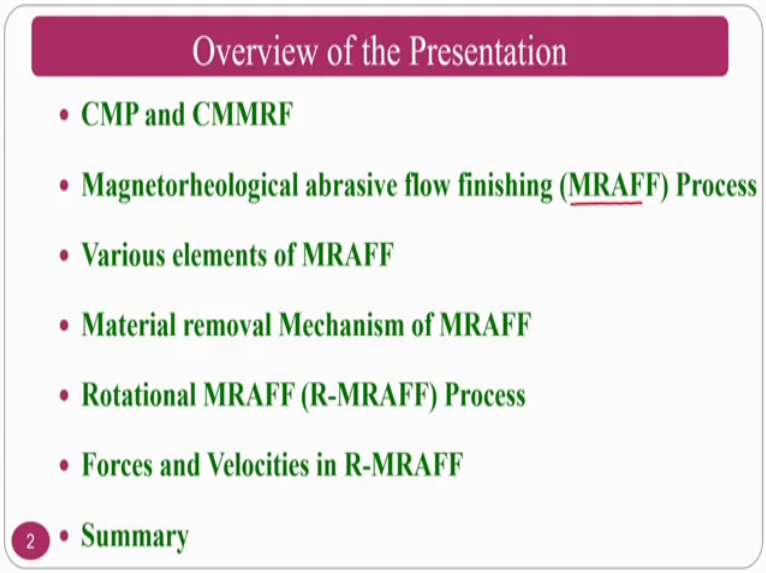

So, in the overview of presentation just we look into what is the chemo mechanical polishing process just a glimpse of it we will see then we proceed to how this particular process can be hybridized to magnetorheological finishing process that we have seen in the previous classes. And then we will move into some of the hybrid versions of the MRF process.

The first hybrid version that we can see is the MRAFF that is Magnetorheological Abrasive Flow Finishing process where in you are going to blend the MRF process along with the abrasive flow finishing process so, that you can get the new process. Various elements of magnetorheological abrasive flow finishing process we will see then material

removal mechanism, how the material removal mechanism is different from MRF process to MRAFF process.

And then we will see a advancement in the MRAFF process that is called rotational magnetorheological abrasive flow finishing process where the rotational motion is given to the work piece fixture and where in the magnets are embedded. So, the force and velocities that are evolved in the MRAFF process as well as how this force and velocities will vary in the rotational magnetorheological abrasive flow finishing process. We will see then we will see the summary of this particular class.

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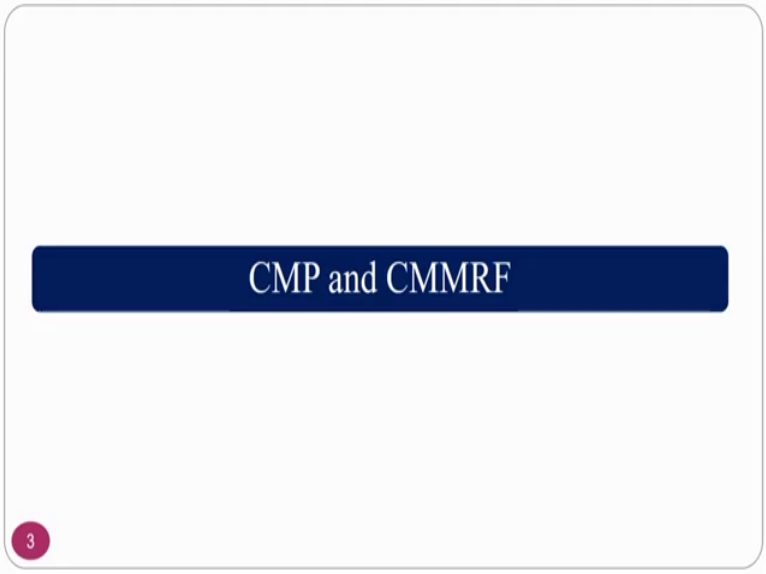

So, first we will see what is meant by CMP, so CMP is Chemo Mechanical Polishing and some people call it as chemo mechanical planarization also. This depend on whether if you are using for polishing applications you can say that it is called chemo mechanical polishing if you are using for planarization.

So, you need a perfect flat surfaces some of the mirror applications and other applications you required not only the surface roughness we also required perfect flat surface. In that circumstances mostly the CMP is used normally silicon industry or the electronic industry is the major user of chemo mechanical polishing process. So, how this particular process can be clubbed to magnetorheological finishing process that we have seen in the previous class.

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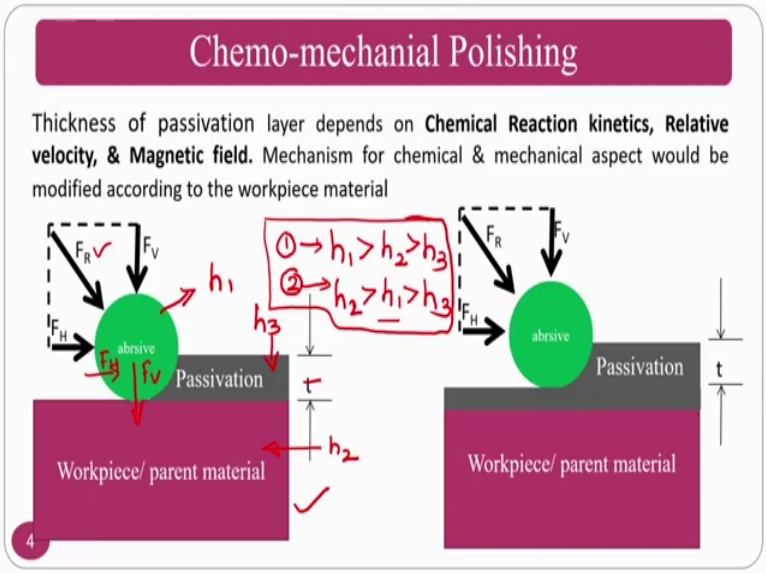

So, chemo mechanical polishing thickness of passivation layer depend on the chemical reaction kinetics, relative velocity and magnetic field mechanism of chemical mechanical aspect would be modified according to work piece. What is your going to see is chemical mechanical action will be there how you are going to achieve this one? So, what you are going to do is you have a polishing fluid it is looks this particular process looks like a lapping process. So, the additional thing that the people are going to do in this particle processes that they are going to mix, some chemicals that makes a passivation layer on the work piece surface.

So, you have a work piece material and on top of it you are going to put the polishing fluid that contain some of the chemicals that react with the workpiece material and form a passivation layer. So, passivation layer of normally the hardness will be much less compared to your parent material.

Now how the mechanism works in this one is you can choose the abrasive whose hardness is h 1 and the workpiece material is h 2 and the passivation layer hardness is h 3. So, normally you can also choose your h 1 will be greater than h 2 and greater than h 3 also or if we are wise enough the people will always choose h 2 will be greater than h 1 will be greater than h 3.

So, what is the advantage that you are going to get in case 1 and case 2. So, in the case one what you are going to get is you also get some of the scratch marks of your abrasive

particle, because your abrasive particle hardness is higher than your parent material. It is similar to your conventional machining process where your feed marks will be there which define the surface roughness values. In the second case the beauty about this your hardness of parent material is slightly higher than your abrasive particle, but the passivation layer that is forming is softer than you are abrasive particle.

In that circumstances your abrasive particle cannot shear or cannot dominate the work piece parent material because the hardness of your work piece is higher. That means, that what you are going to get is that passivation layer will be removed and you are not going to get any scratch marks of your slightly less harder abrasive particle compared to your parent material.

So, that is a beauty about this is CMP process if you are going to blend this particulars p with many process CMP can be blend with what we have studied MAF that is called magnetic abrasive finishing CMP can be blended with MRF that is what we have seen magnetorheological finishing.

And you can blend this chemo mechanical planarization to many, many finishing applications and you can have or you can rename those processes which is prefix by chemo mechanical so on so on eyes. For example, chemo mechanical magnetorheological finishing process like that you can rename the process and you are going to have the advantages of chemo mechanical polishing as well as you are going to have the advantages of MRF process. So, that you can get the better outcome from that one how we are going to get the better outcome from this one that we will see in the next slide.

So, if you are going to see the horizontal force and vertical force; the horizontal force we will try to shear it and the vertical force is tried to going to indent on top of it. This is F V and this will give so F H because of which the resultant will be like this and F R will remove the material from the passivation layer. So, hope you understood about h 1 h 2 h 3 where I want to repeat again, what I want to say is your parent material hardness whatever the parent material hardness is slightly higher than your abrasives.

That means, that you are going to choose the software abrasives compare to your parent material because of the chemicals that are presenting in the your fluid that is chemo mechanical fluid. What is going to happen is this particular chemical will react to the top

layers of your parent material and makes it passivation layer, is passivation layer is formed from the workpiece material itself. But the passivation layer hardness is much lower than your parent material and this is also lower than your abrasive particle that is why abrasive particle can only remove the passivation layer not the parent material so, that you do not get any scratch marks that means, that you are going to get a very good polished surface using the chemo mechanical polishing process.

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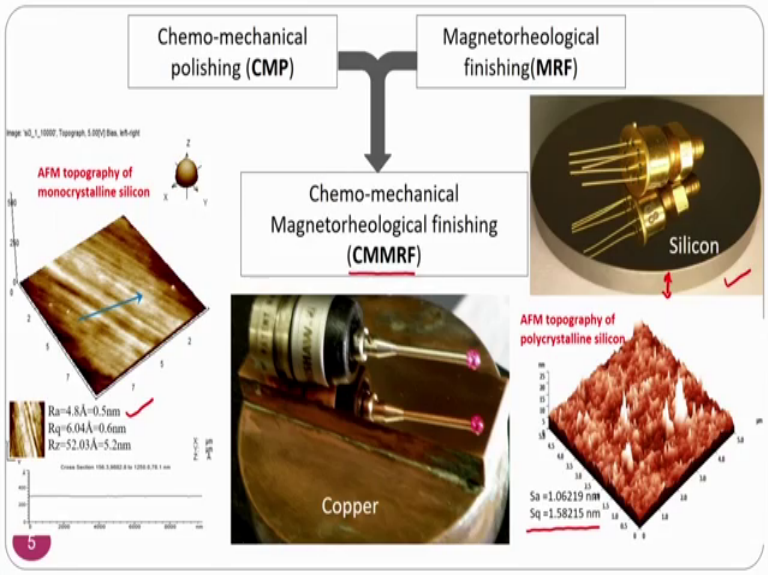

You can see the advantage of this one, so chemo mechanical polishing that you have seen in the previous slide along with that in the previous class you have seen in the magnetorheological finishing process. And both are clubbed, if you are going to club what you are going to get is chemo mechanical magnetorheological finishing process that is CMMRF. If at all you want to go through more literature of this particular process you can see Prabhat Ranjan and professor VK Jains paper; Prabhat Ranjan is currently the scientist in BARC Bhabha Atomic Research Centre and this is taken from his work only.

So, I am very thankful to Prabhat Ranjan and Professor VK Jain also so what you are going to achieve here is that you are clubbing the advantages of CMP along with the MRF process and you are naming as CMMRF.

If you see the silicon surface, if you see the copper surface, the surface roughness that you are going to get is Ra is approximately on silicon, if you see the Ra average

roughness you are going to get is 0.5 nanometer. That mean that you are going to get sub nanometer surface roughness. At the same time you can see the surface of polycrystalline silicon also you can see where your area surface roughness is approximately 1 nanometer that is a beauty about this particular process.

And moreover, if you see the copper the greatest thing that one can do using the chemo mechanical magnetorheological finishing process is that you can achieve the sub Nano metric surface roughness in the softer materials. Why I am saying is whenever you want to polish the software materials it is very, very difficult because the indentation will be very high for the same force that is applied by the abrasive. If I have two surfaces, one is copper surface another one is hard and steel.

If I am applying the same load what will happen the indentation you will be very high on your copper surface because it is a softer material compared to my hard and steel. That means, that the peak to valley that is going to generate on copper will be very, very high if you are going to get a super finishing on this software materials like aluminium, copper and other materials that is a good achievement.

So, silicon is a brittle material you can achieve on this one because you have very less indentation. At the same time one thing you are to be careful about is silicon is a brittle material and the material may fracture if you are going to choose a silicone blank thickness. You have to choose good amount of silicon blank thickness otherwise what is going to happen is this will break into pieces. Care should be taken whenever you are going to finish the silicon components.

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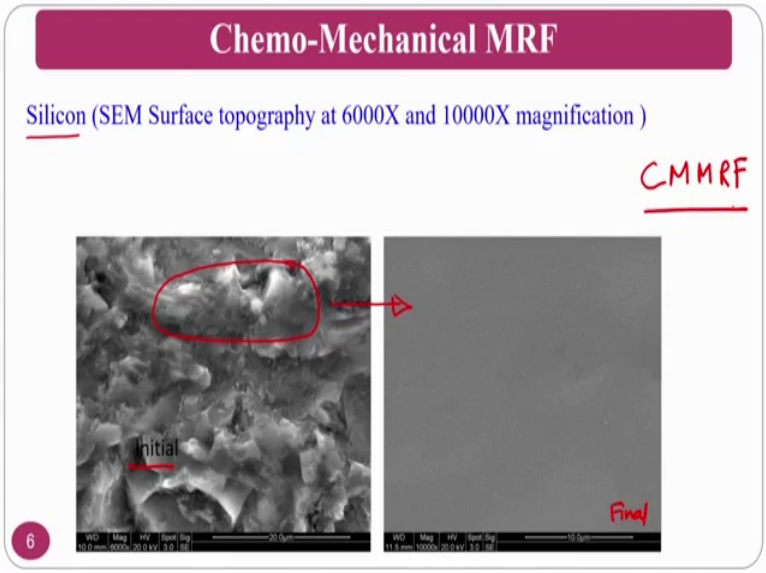

So, at the same time you can see here silicon initial surface and final surface, this is the initial surface and this is the final surface and how the surface is transformed from one surface to another surface. In case of silicon especially the thing is that you can go by water based fluids because water will interact with the silicon and water will act as a chemical.

So, what I mean to say is that chemo mechanical action will be taken care by the abrasive particles along with the career medium is water. So, you can get the you, in the water will react and what it is going to make is it is going to make this particular rough surfaces smooth. And so that whenever the abrasive particles will shear the surfaces it will comes or it will obtain a very good flat surfaces and the surface roughness will be normally in the range of sub nanometers to Armstrong surface finish also you can get.

So, this is about the extension or hybridization of what we have seen in the previous class that is called magnetorheological finishing process this is the one hybridization. That means that you have a chemo mechanical planarization which is blended with magnetorheological finishing process. And you are getting a one hybrid process that is called chemo mechanical magnetorheological finishing process that is in short you can call it as CMMRF process.

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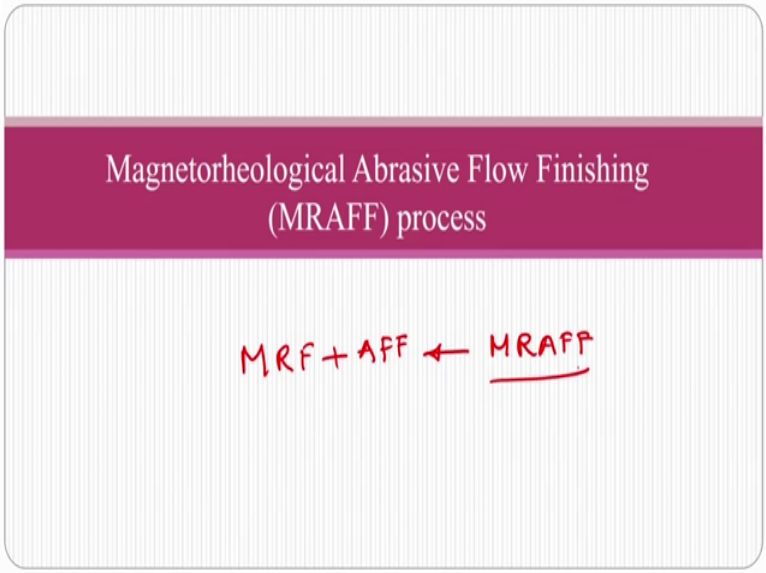

So, the other variety that we are going to see in this particular class is where you are going to blend the magnetorheological finishing process along with abrasive flow finishing process. So, that you are going to get is magnetorheological abrasive flow finishing process.

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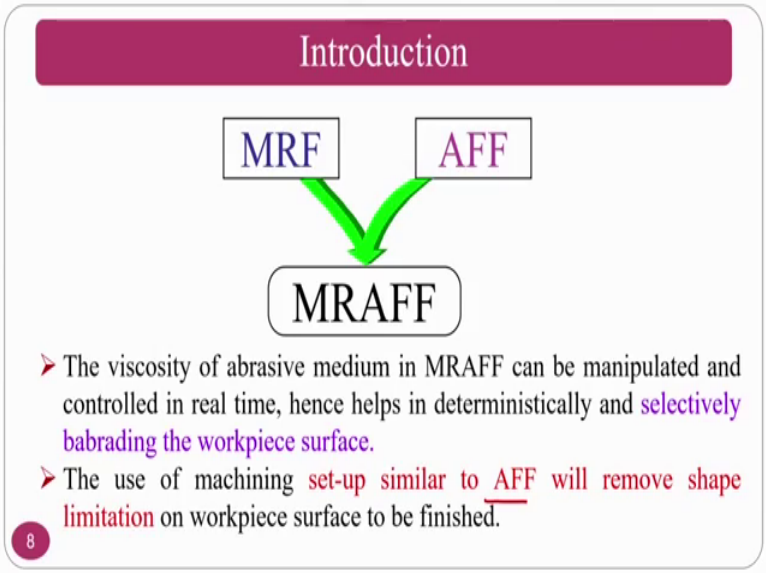

So, introduction to this particular process as I said this is a blend of MRF process that means, that this is one of the hybrid, second hybrid version of MRF process. Where it is blending with abrasive flow finishing process and it is turning out to be

magnetorheological finishing process. The viscosity of abrasive medium in MRF process can be manipulated and controlled by the real time hence it helps deterministically and selectively a onto the workpiece surface.

So, the use of machining setup similar to abrasive flow finishing and will remove the shape limitation on the workpiece surface to be finished. That means, that you can use cylindrical surface, you can use another improper or freeform surface is also you can do finishing up finishing by MRF a process. But the only constraint you have to use, you have to take care about is you should maintain the uniform magnetic field strength on across the surfaces.

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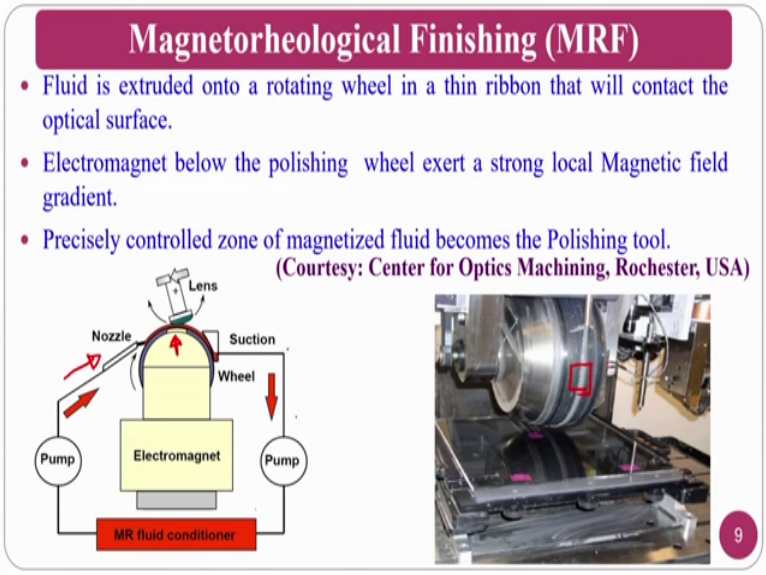

As I said this is the combination of MRF process as well as abrasive flow finishing process just we will see the glimpse, this will also brush up for your chemo mechanical magnetorheological finishing also. This is how the magnetorheological setups looks like, fluid is the excluded to the rotating wheel in a thin ribbon type of structure and whenever it is exposed to the magnetic field it will form a thin rubber otherwise it is a fluid in nature.

So, electromagnet below the polishing wheel exert the strong local magnetic field, because of which what will happen is that it will form a ribbon precisely controlled zone of magnetized fluid become a polishing tool and the polishing will be taking care.

Here nozzle is going to input the fluid because of the magnetic field here it will become a stiff ribbon once the magnetic field is gone what is happening is here again it will become a fluid and the suction pump will suck and will send to the fluid conditioner. So, this is what you have seen in the MRF process also.

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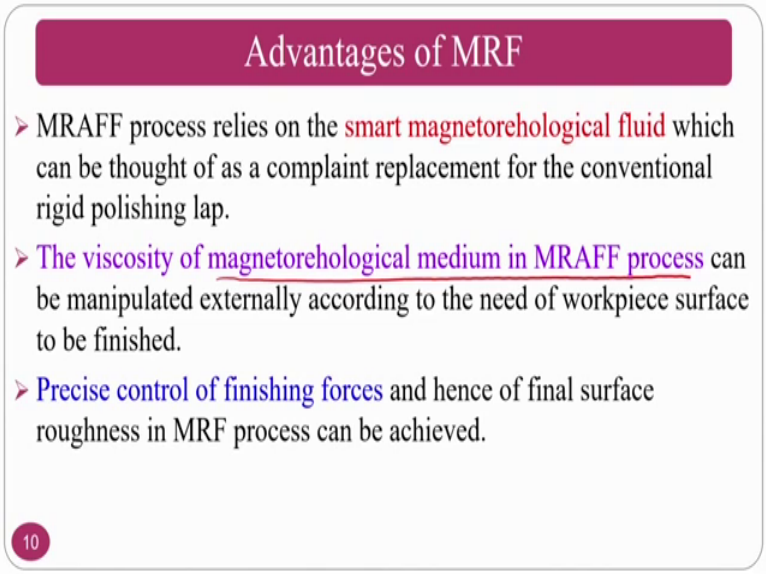

And at the same time MRF process advantage is that MRF process he utilizes the smart magnetorheological finishing fluid and the viscosity of magnetorheological medium in the MRF process can be manipulated. So, precise control of finishing forces and can be a good advantage in the MRF process.

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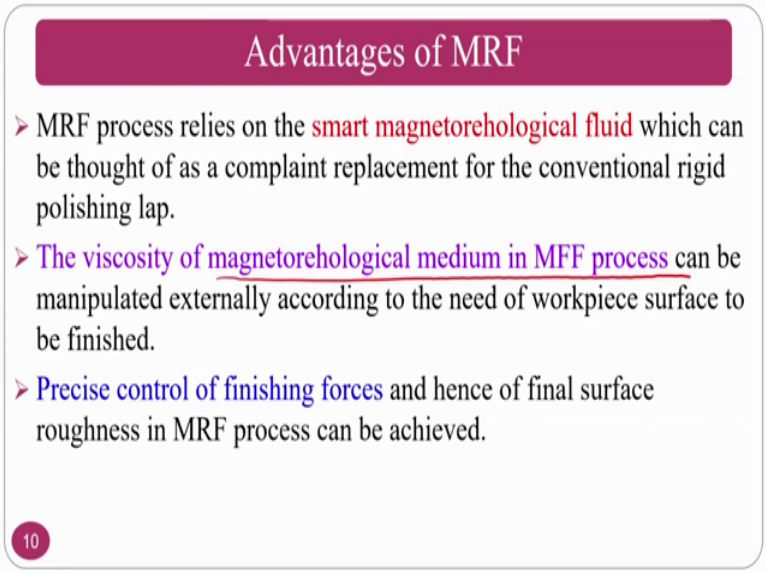

If you see the advantages of MRF process what is going to takes place is MRF process relies on smart magnetorheological fluid, where you can control the fluid viscosity by the magnetic field.

So, that is the beauty about this particular process and precise control of finishing force. If you have can control the viscosity of this MR fluid what is going to happen is you can control the finishing forces. If you are changing the magnetic field, the field intensity will change and the chain strength the CIP particle strength will change.

If you are going to put more magnetic field what will happen the chain strength will be more that means, that chain holding strength of the abrasive particle will be high. That mean that the hard grade will be come into picture that means, that what you have studied in the grinding wheel is the soft grade and hard grade. If you are going to increase and increase the magnetic field strength the abrasive particle is held firmly, that means, that the soft to grade will convert into hard grade.

If you are going to put only less amount of magnetic field what you are going to have is your magnetic particle chains will hold the abrasive particle in a flexible manner. That means, that you can play with a magnetic field and you can get the strength of the magnetic chains according to your fluid. So, you can play with a magnetic field and you can get the magnetic chains as per your requirement, if you want you can go for low magnetic field. So, that your chains are flexible and data it will hold softly the abrasive

particle if you increase a the magnetic field strength then what will happen the abrasive particles are held family so in between also you can choose.

So, you can vary from the soft holding to the hard holding that mean that soft grade to hard grade you can play in a same grinding wheel. But in case of a conventional grinding wheel you have other complete wheel be will be a soft grade or complete wheel will be a hard grade, but the beauty about this particular process is you can vary with respect to magnetic field, if you are going to use the electro magnets.

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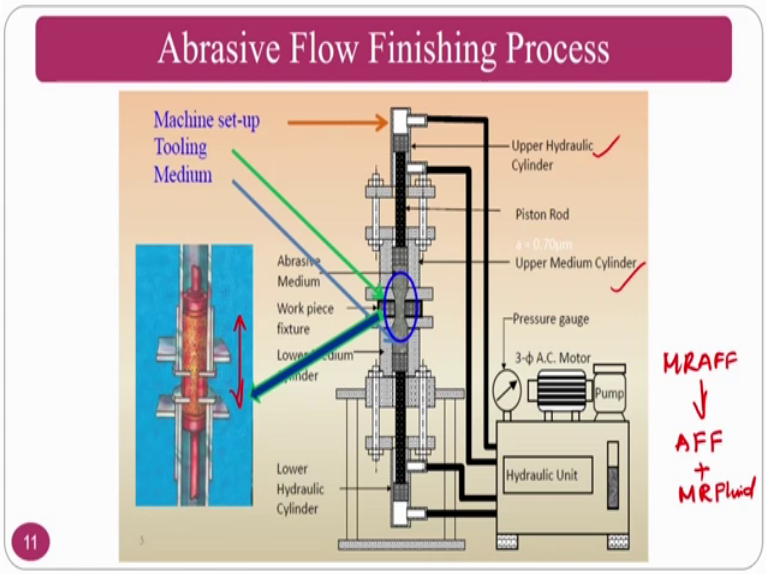

The at the same time if you see the abrasive flow finishing process as we have seen since, why we are seeing the abrasive flow finishing process is this is the MRAFF process is a blend of MRF process and abrasive flow finishing process that is why we are seeing this particular process also. So, the MRAFF process follows the similar structure of AFF process, but only thing that you are going to change is the fluid.

So, it will have a upper medium cylinder, lower medium cylinder and upper hydraulic cylinder, lower hydraulic cylinder and so on. You will have and you will reciprocate the medium in the finishing region, so that the finishing action will takes place. So, MRAFF process will be look exactly similar to AFF process only thing additionally what you are going to have is MR fluid along with the mag electromagnetic units another things.

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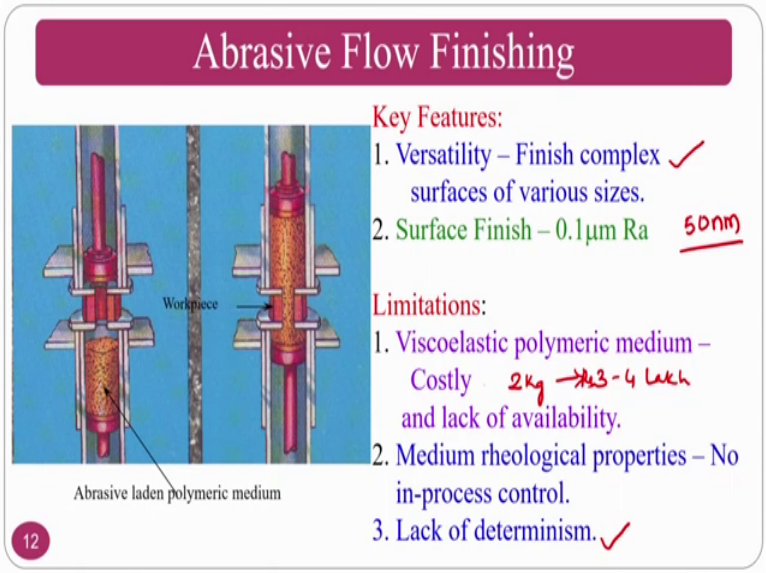

The key features of this abrasive flow finishing versatility it can finish the complex surfaces and it can finish up to 0.1 normally the best surface finish can be achieved is 50 nanometers using this one. So, these two limitations can be improved, so limitations viscoelastic polymer medium is costly normally the cost it will be like in Indian scenario. So, 2 kgs is approximately like 3 to 4 lakhs or sometimes it will be 5 lakhs also.

So, medium rheological properties no in process control because here the medium itself is a viscoelastic medium. So, you are not going to control any forces by using a any magnetic or something that is why this is the problem is there. So, that is the one problem with the abrasive flow finishing process, but nowadays people came out with a some of the innovative solutions and forces also can be controlled in abrasive flow finishing process.

Lack of determinism compared to MRF process that means, that in MRF process what you are going to do is your fluid action or penetration or the viscosity can be controlled externally by the magnetic field. But in case of abrasive flow finishing you do not have that perfect control, but you can control up to certain extent this particular controlling and other things if at all you want to know you can enroll for the polymer assisted abrasive flow finishing process which is going to be in the early part of 2019.

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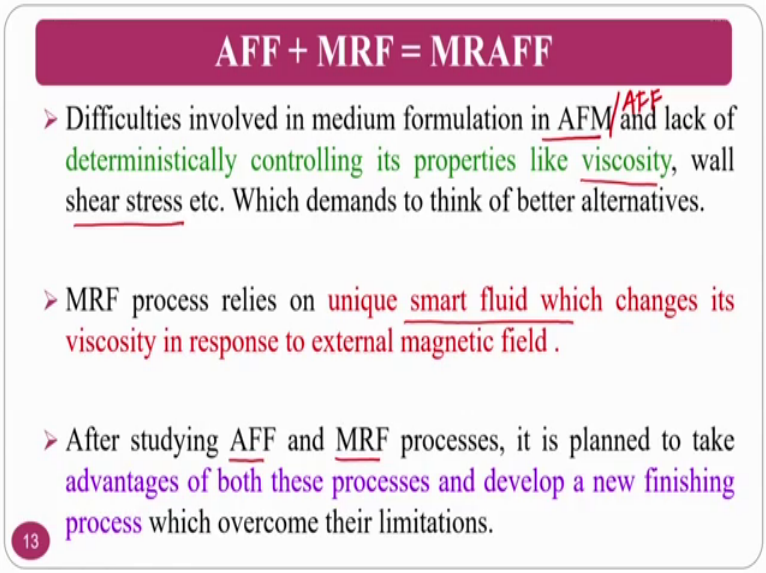

So, abrasive flow finishing and MRF process we will lead to a good hybrid process that is called MRAFF process. The difficulties involved in medium formulation in abrasive flow finishing process sometimes this particular process also called abrasive flow finishing machine and abrasive flow finishing process also.

And lack of deterministically controlling the properties like viscosity wall shear stress and other things which demands for better thinking for the alternatives. MRF process lies on Unix smart fluid which changes its viscosity in response to the external magnetic field. So, after studying AFF and MRF because, AFF process can finish complex surfaces, but the problem with AFF is medium rheological properties cannot be controlled because there is no magnetic field control in that one.

But in MRF process it cannot finish the complex surfaces it can finish up to concave convex and other things, but it cannot go beyond certain level. That what are the advantages of MRF a the fluid can be controlled the rheological properties the viscosity and shear strength of this fluid can be controlled. That is why the complex features finishing capability of abrasive flow finishing and the controllability of the fluid both are mixed and came up with a hybrid version that is called magnetorheological abrasive flow finishing process.

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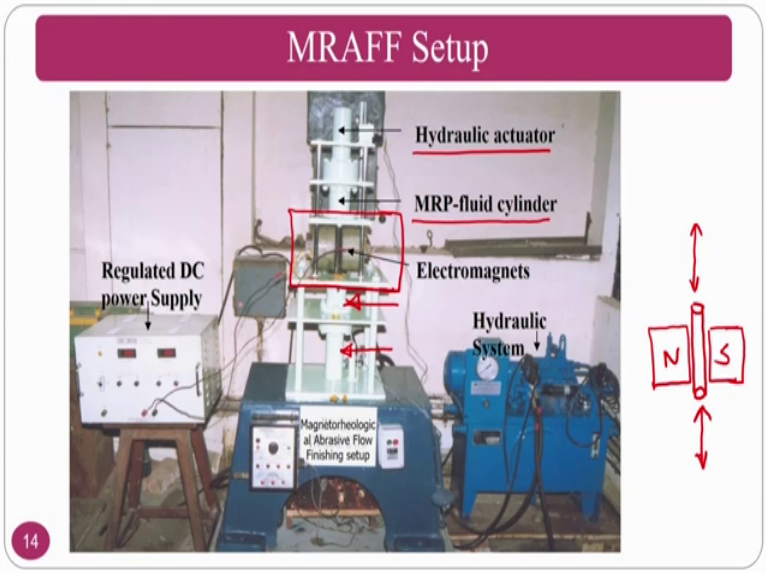

This is what is the magnetorheological finishing set up that is developed by Professor Sunil Jha who is currently professor in department of mechanical engineering at IIT Delhi, so this is developed along with professor VK Jain when he was doing is PhD program.

So, here the set up looks like abrasive flow finishing set up only because you have lower hydraulic cylinder and lower medium cylinder, upper hydraulics cylinder and actuator and upper medium cylinder that is nothing, but MR fluid cylinder. And the only change that people have to look into it is the finishing region this particular thing is the only change where you have the work piece assume that my work piece is a hollow cylinder. And my fluid is coming from top and it will go like this, in the circumstances what it is going to do is you are going to put a electromagnets here.

Electromagnets you are going to put because of each what is going to happen is field of lines will flow from north to south because of each you are fluid that is passing through this magnetic field. What will happen is this will form the magnetic chains and where magnetic chains where in the abrasive particles are embedded, because of hydraulic pressure that medium will reciprocate this chains that are processing the abrasive particles we will shear the surface peaks of the work piece.

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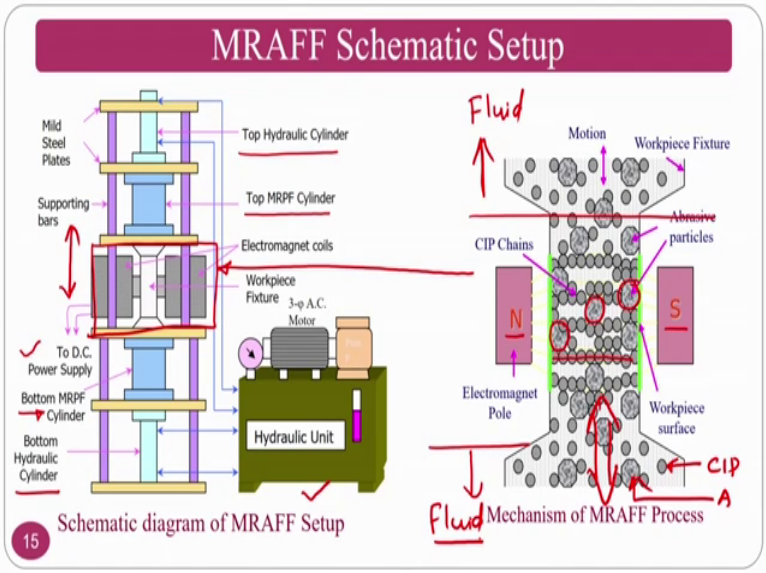

The schematic setup if you see what is happening here is the schematic setup that you can see here. So, bottom hydraulic cylinder and top hydraulic cylinder, top magnetorheological polishing fluid cylinder, bottom magnetorheological polishing cylinder and you have two electromagnetic coils that are connected to a DC supply and your actuation to the hydraulic is controlled by the hydraulic unit. So, the medium will be reciprocated using the hydraulic power pack and medium will be stiffened using two electromagnets, the only difference that I was saying you compare to the abrasive flow finishing process is the electromagnets that are there and corresponding fixture.

If you see what is going to happen in the mechanism you have a north pole you have a south pole whenever the fluid, whatever I am explaining you here is this particular section of. What you are going to see is the finishing region of magnetorheological finishing process, your fluid is at the normal state here. Because there is no magnetic field, till this portion it is in the fluid state and after this one also it will be in the fluid state. Whenever this magnetorheological fluid is entering into the magnetic field zone that is the north to South Pole, what this randomly oriented CIP particles this is, these are the CIP particles these are all abrasives.

So, this form a chain between North to South Poles this chains whenever this chains are there; there will be abrasive particles held in between and because of the hydraulic power what is going to happen is it will reciprocate like this. Because of this what is happening

is the shearing action will takes place. Indentation will be done because of the magnetic field and a shearing action will be done because of the hydraulic power.

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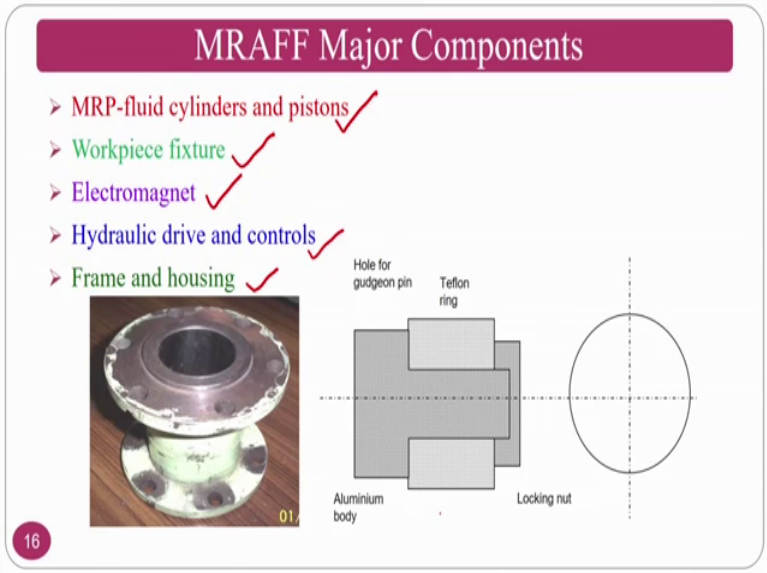

And the major components of this one is MR fluid cylinders and piston, work piece fixture, electromagnet, hydraulic drives and controls and frame and housing these are the sum of the components wherein, you are going to see in this particular slide is MR fluid cylinder. Where you can put the this particular fluid and you can also holds the piston also so that it will retain inside the medium cylinder.

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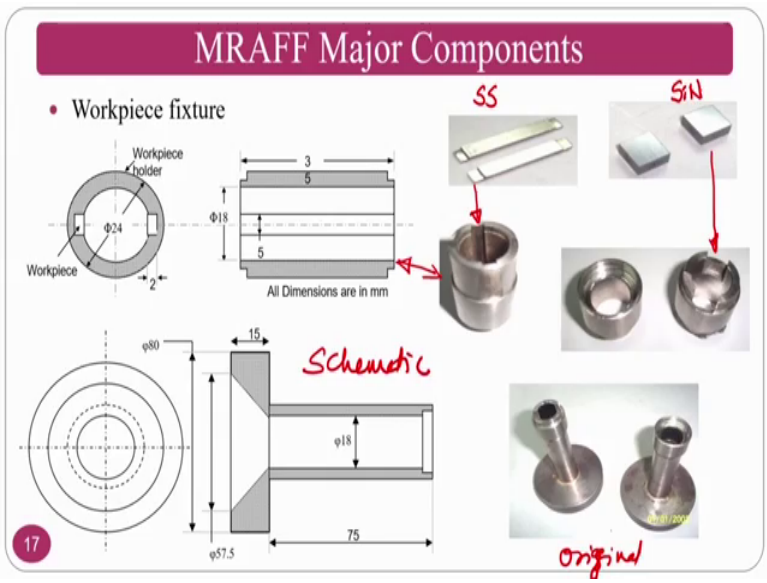

You can see the workpiece fixture where the workpieces can be housed and at the same time these are the schematic and this is the original how it looks like. So, at the same time you can see the workpieces you can have varieties of work pieces, if you see this fixture and this fixture the schematic and this one and corresponding workpieces that you can house in is this type of work pieces. If at all you are to hold this one you have to go for this type of fixtures.

So, whatever the workpieces the here are stainless steel work pieces and these are probably silicon nitride work pieces. The finishing ability will be much better if the workpieces are much, much harder because you are depth of indentation that you can generate using the same magnetic field strength will be very less.

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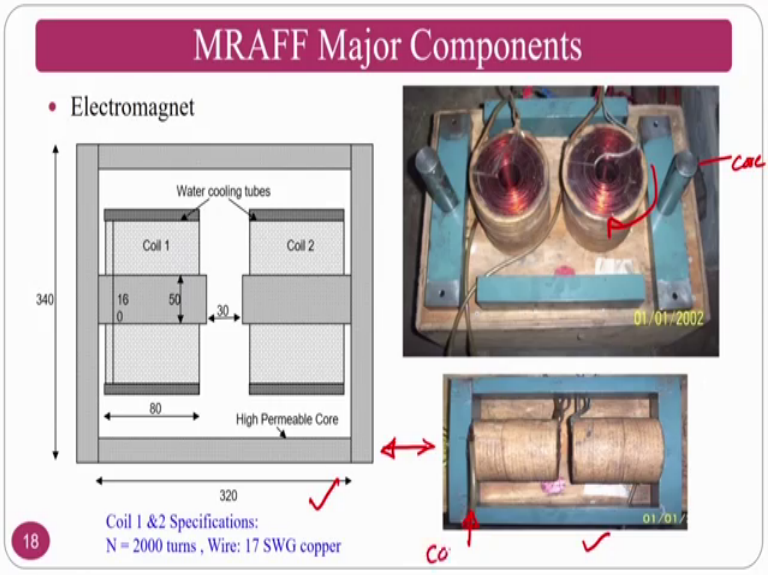

So, the another component is electromagnet as I said this is the only part that is completely different from the point of abrasive flow finishing process as well as the magnetorheological abrasive flow finishing process. Since you are using in place of viscoelastic medium or the polymer rheological abrasive medium here you are using magnetorheological fluid. So, your fluid has to be converted into a semi solid with chains, for that purpose what do you have to do is you have to put the electromagnet.

Electromagnet you can see here the schematic and how this schematic is there, these two are the same, if this is a schematic and this is the original. But if you see that dismantled position are this is the course and these are the windings; windings are there and this will

get heated up also. So, you need a cooling of this winding cooling you need a cooling also for that purpose a not only the electrical connection people also have to connect the water circulating system or coolant circulating system that is the another thing that require in MRAFF process.

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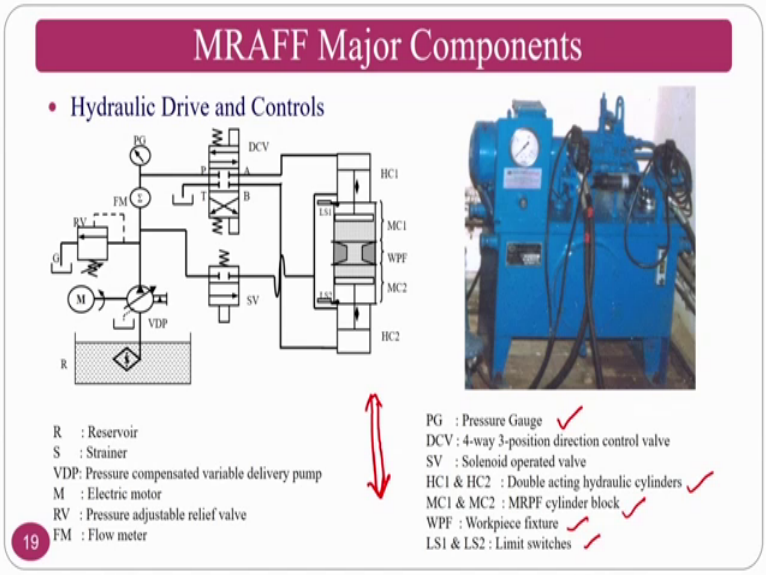

This is the hydraulic power pack which is common in abrasive flow finishing also and here also because of this what is happening is your medium or the fluid that will reciprocate across the work piece to be finished. This hydraulic power pack will have lot of components like pressure gauge, DCV, solenoid a valve, double acting hydraulic cylinders and MRPF cylinder block, workpiece fixtures these are all the limit switches and all these things can be connected to the hydraulic power pack. Let me again repeat the function of this hydraulic power pack is to reciprocate the medium across the surface to be finished, so that the medium will finish the workpiece surfaces.

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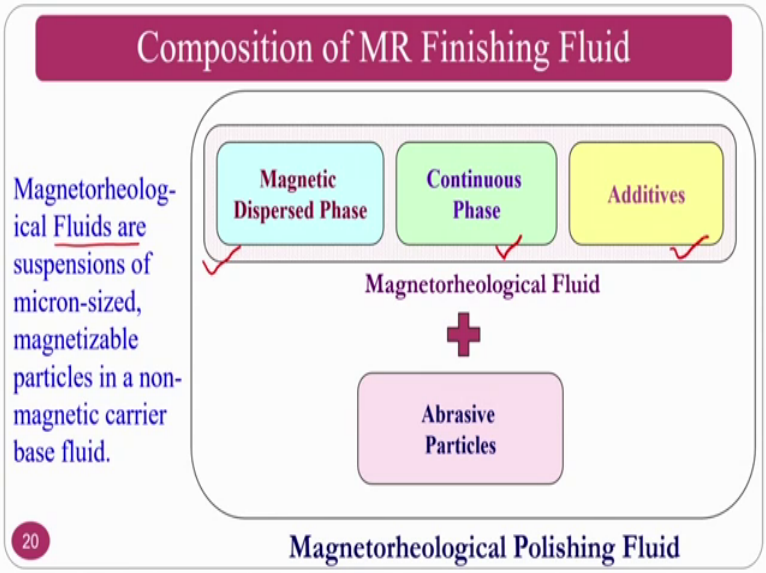

The composition of MR fluid if you see the magnetorheological fluids are exactly same that you are going to see, that you have seen in the MR fluid. As I previously mentioned that you are using the AFF setup along with a MR fluid.

MRF process, from MRF process what you are going to take is a fluid from the structural point of you the equipment structure is concerned you are going to take from abrasive flow finishing and these two are club that is why the fluid that you are going to use is magnetorheological finishing fluid. The magnetorheological finishing fluid will have magnetic dispersed phase, continuous phase as well as additives.

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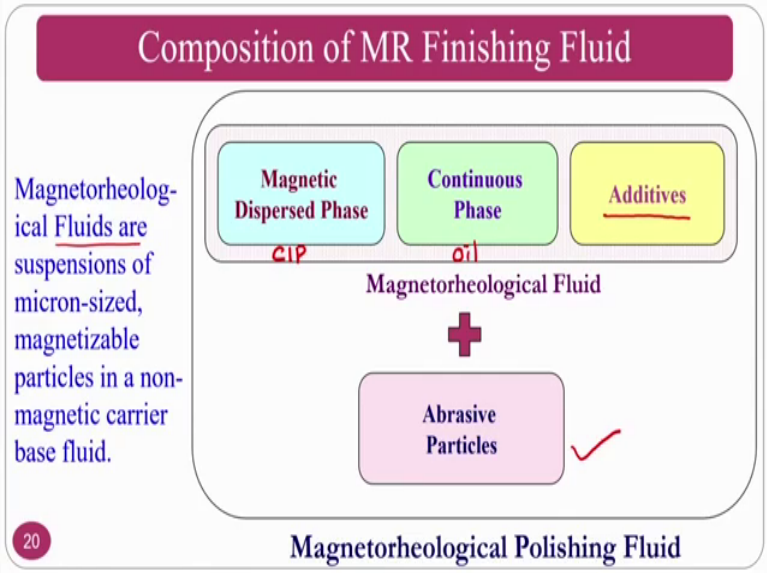

So, the first one magnetic dispersed phase you are going to use CIP particles, carbonyl iron particles; that means, that these are the ones that will form a chain from the North Pole to South Pole. So, continuous phase normally you will use suitable oils like silicone oil, grease depend on your viscosity and other things. And you will use additives whereas, I mentioned when I was teaching that MR fluid this can be as many as it used as possible depend on the functions of those additives.

For example, you can use functionalizers to bind you can use a functionalizers you can use those additives which do not allow the abrasive particles to sediment like glycerin and these are the sum of the additives along with that one you are going to add the abrasive particles. If you see all this combination one is CIP particles another one is a continuous phase of oil, because you need a liquid type of thing that is why you have to go for a continuous phase that is called oil. And you are going to add the additives, that additives will help the abrasive particles are CIP particles to not sediment at the bottom and you are going to use abrasive particles.

This abrasive particles CIP particles and your oils have completely varying densities because of each what will happen is this abrasive particles may have tendency to sediment. That is why you have to use the additives and these additives plays a major role in various applications at the same time additive can be your chemical also as we have seen in chemo mechanical magnetorheological finishing process. If you want such

action you can add some chemicals that will react or that can form only passivation layer on the workpiece only. But here it is a completely closed system if you are at all you are using a chemical that can generate a passivation layer and workpiece, if iron based workpiece you are medium cylinders also will form a passivation layer because you are medium cylinders and other things will be made up of cast iron.

Because it requires absorbing ability that is why caste iron is selected for the medium cylinders where carbon will be in the form of graphite to act as a absorber. And this type of fluids are smart fluids, because whenever this fluids are coming into the magnetic field this will become stiff and whenever these are going out of the magnetic field again it will become liquid, so these are one variety of smart fluids.

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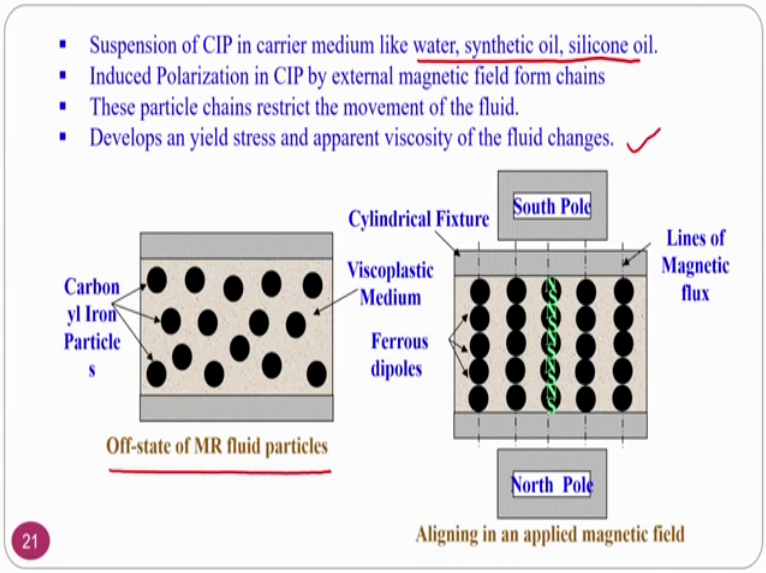

So, you can see the suspensions of CIP particles in the carrier medium like water synthetic oil, silicone oil these are the career mediums and CIP particles can be blended along with this one. And induced polarization in CIF by external magnetic field to form chains that means, that whenever you are not going to apply any magnetic field. The CIP particles are randomly oriented whenever you are going to apply the magnetic field it will form North to South Pole chains. This particle chain restrict the movement of the fluid because whenever you are going to get the chains so, the motion will be restricted or reduced the it develops certain yield tress and apparent viscosity of the fluid will

change then whenever the apparent viscosity and fluids strength changes what will happen it will increase the finishing ability.

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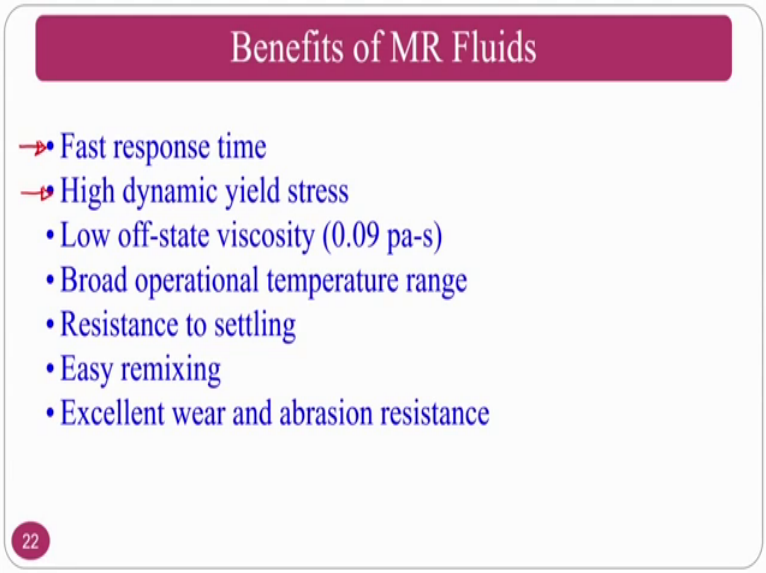

Benefits of magnetorheological fluids, the fast response time these are very responsive within no time this will respond, high dynamic yield stress is another advantage low off state viscosity, broad operational temperature range, resistant to settling, easy remixing, excellent wear and abrasion resistance. These are the few benefits of magneto rheological fluids.

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So, this fluids can be used in the finishing applications, so synthesis of magnetorheological finishing fluid as I said this is all mixed one where you will have the continuous phase that is silicone oil assume that. And a CIP particles along with abrasive particles and additives additive can be a chemical additive can be a glycerin and other things. So, if at all you want to make you can make as per your requirement, so it can be low viscous or it can be medium viscous and normally MR fluids will be slightly lower viscous compared to abrasive flow finishing process.

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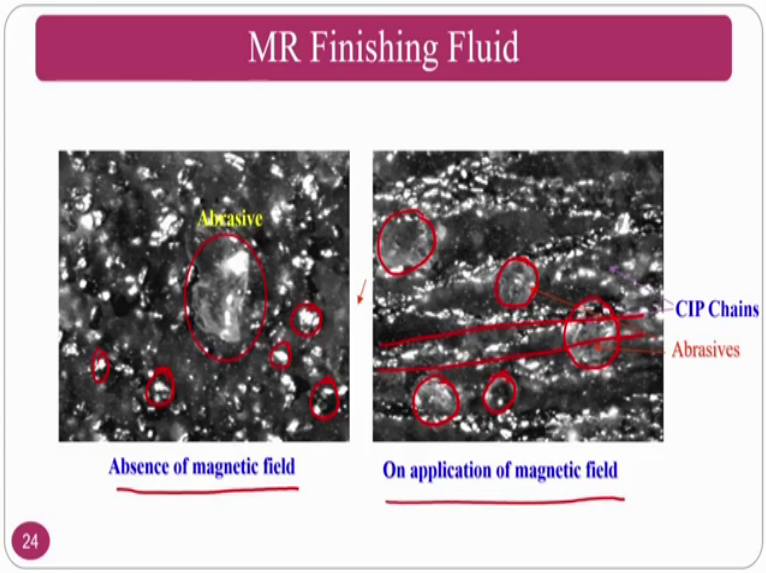

And the beauty about this particular process as I was saying that you can see in the absence of magnetic field your abrasive particle, your CIP particles are randomly oriented, but whenever on application of the magnetic field you can see this are forming the chains. And in between the abrasive particles are held this is the beauty about this particular process whenever you are applying the magnetic field and this forms and this chains will hold the abrasive formally. The formats of this chain holding the abrasive will be always depend on the magnetic field strength.

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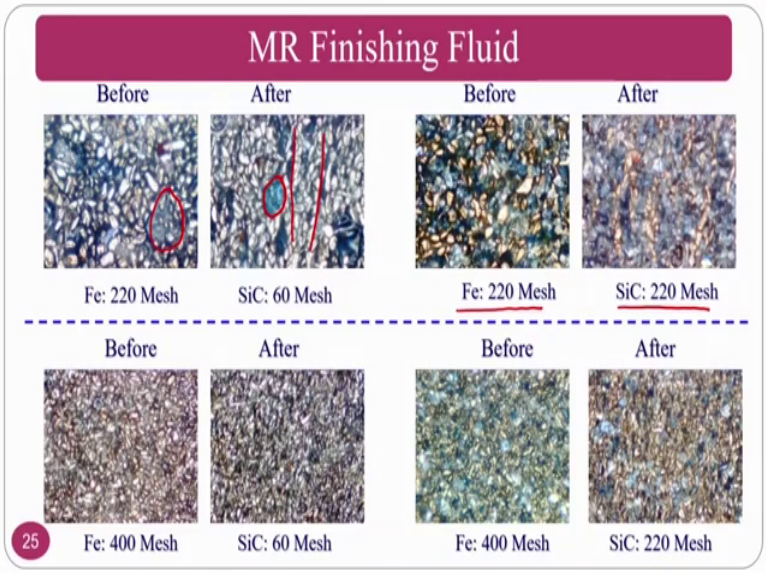

So, you can see here again whenever you are using the magnetic field along with the abrasive particles and CIP particles before and after the chains ar forming and in between abrasives are there. And before and after if you see 220 mesh and SiC's are also they are the different colour is given to different, different particles to give a good visual effect of how the chains are forming and how the abrasives are held in the chains. You can see here again the how the abrasive particles and the chains are forming before and after another things.

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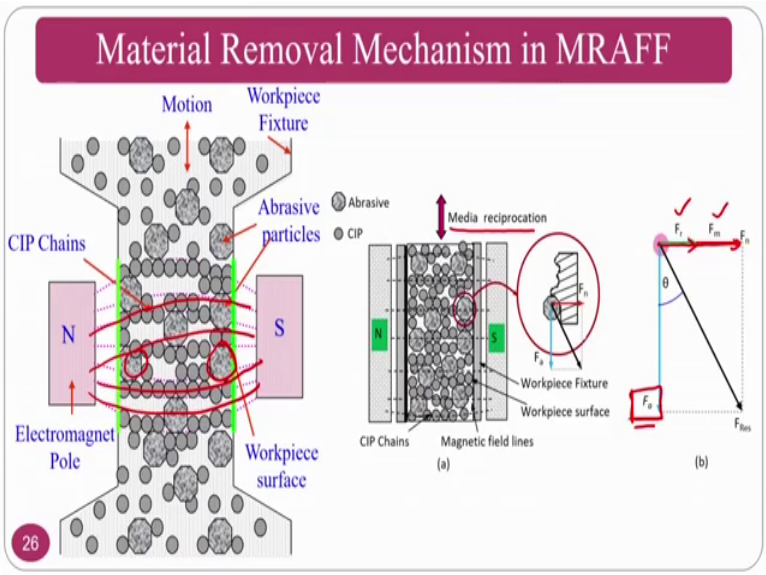

As I was saying material removal mechanism whenever you have a North to South Pole chains formation is there what is going to happen is you are abrasive particles are held, and this abrasive particles along with CIP particles chains will be reciprocated by the hydraulic power.

So, these are media is reciprocated whenever reciprocated you are going to get the radial force along with that magnetic assistant force and you have axial force because of the reciprocation nature. That means, that you have two forces one is a radial force by the composition at the same time magnetic field also is applying certain force because you are chains are gaining some magnetic field strength. That is why you are going to have a radial force which is a combination of composition as well as magnetic field and your reciprocation or the axial force is a function of your hydraulic power.

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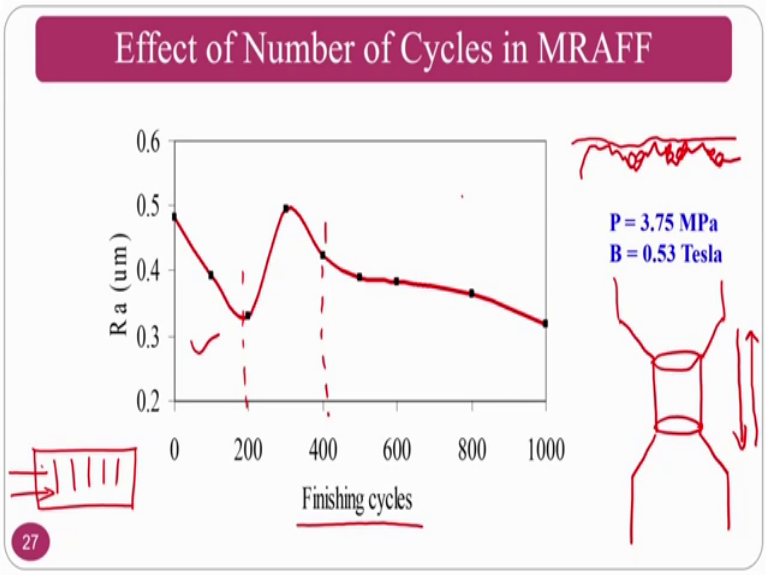

So, we will see, now we will see in the effect of number of cycles as I mentioned cycle means like if you are going to have two strokes that means, at one cycle. So, this is your work piece wherein you have fixture so one time coming is one stroke and going back is another stroke.

So, one forward stroke and one reverse stroke comprises of one cycle. So, initially the surface is ground that means, that it is developed or it is prefinished process is the grinding process. That means, that you have the surface lay in a straight line and you are going to apply the MRAFF process like this in that circumstances what is going to

happen is. Initially as the number of finishing cycles increases gradually the peaks will comes down I have the surface peaks like this and these are all sheared off.

Where this sheared of materials will go there is a chance that it is go and occupy this locations that is why whenever you are going for second set of experiments that is after 200 what is going to happen is. If you are going to measure then the surface that you are going to measure is not the original surface, because you are removed material is there and if you are probe moves on the surface the most critical part is between 200 to 400. As the number of cycles increases the roughness value will decrease that is the common trend that is no problem because if you are going to increase the number of cycles.

So, the surface peaks will shear off, so whenever this shear off some of the materials will be filled in the valleys. So, in between 200 to 400 Professor Sunil Jha, Professor VK Jain found that this material that is smeared in the valleys will give you are wrong interpretation. That means, that if the surface is like this and where you have material smeared material is like this what is happening is the probe will move on the top of this material and it will give you a surface roughness that is why the surface roughness will be low at 200. So, if you were going to increase still more what is going to happen is that you are this smeared material will goes off.

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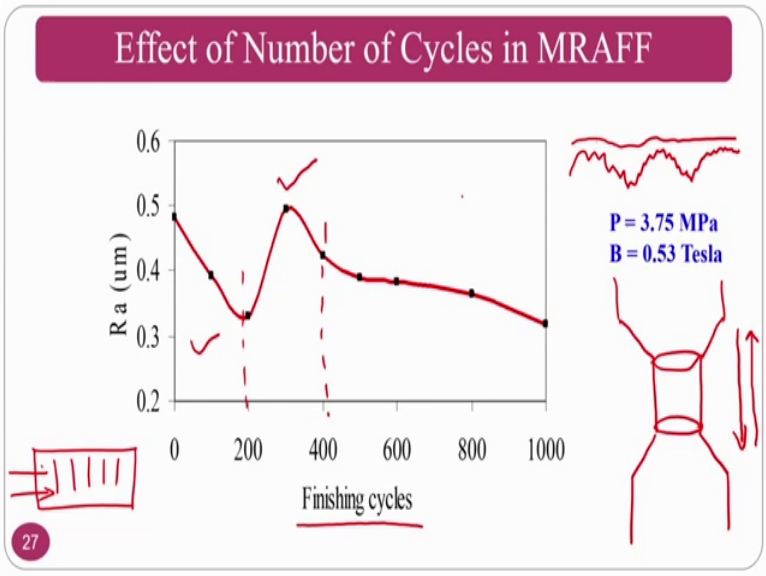

Once the smeared material goes off what will happen is you are exposed to if the real surface profile, whenever you are exposed to real surface profile what is going to happen

is your surface roughness will again increases. And once it is exposed then for still continuing the finishing process what will happen is it is going to finish.

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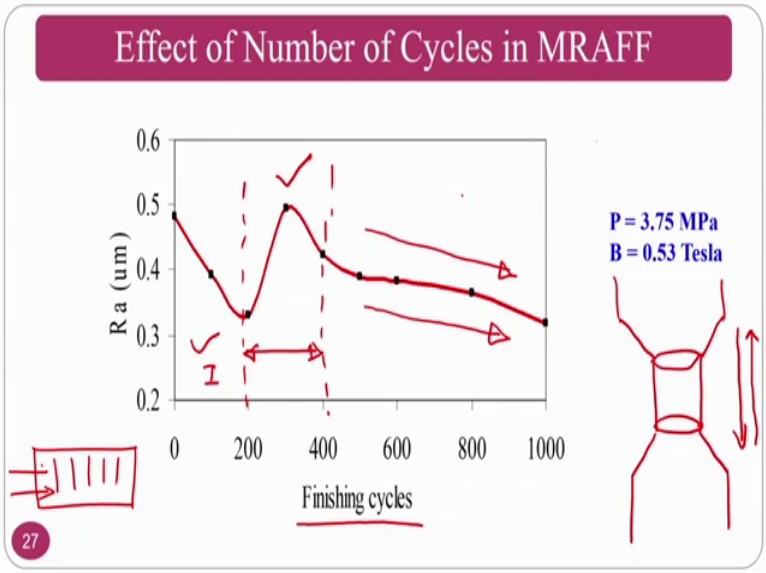

That that is why as the number of cycles increases the finishing will improve that means, that R a value will decrease. And only the new thing about this particular graph which is personally which I like is that the novelty is lying in between 200 to 400 where even though you are increasing the number of cycles the surface roughness is increasing which is against the nature, but there you have to study about the surface morphology, scanning electron microscopy images and other things.

What they have done is what is happen between 200 to 400 I am repeating again because you might have not got the point what I mean to say is that whenever you are going to start up to 200 phase I what is going to takes place is you are peaks; surface peaks are sheared and some of the sheared material will fall into the valleys. That is why whenever you measure at 200 cycles what you are going to achieve is a not a real surface.

So, if you are going to increase the number of cycles the surface roughness increases because this is a liquid like fluid and this fluid will reach to nook and corner of the peak and valley and it will washes away the material that is hiding in the valleys. That is why the surface profile if you are going to check when the valleys are cleaned by this MR fluid what is happening is your roughness value will increase. Once your valleys and peaks are clean now, if you are still using the surface finishing process MRF a process,

now the real finishing will takes place and the surface roughness value will decrease that is the beauty about this particular process.

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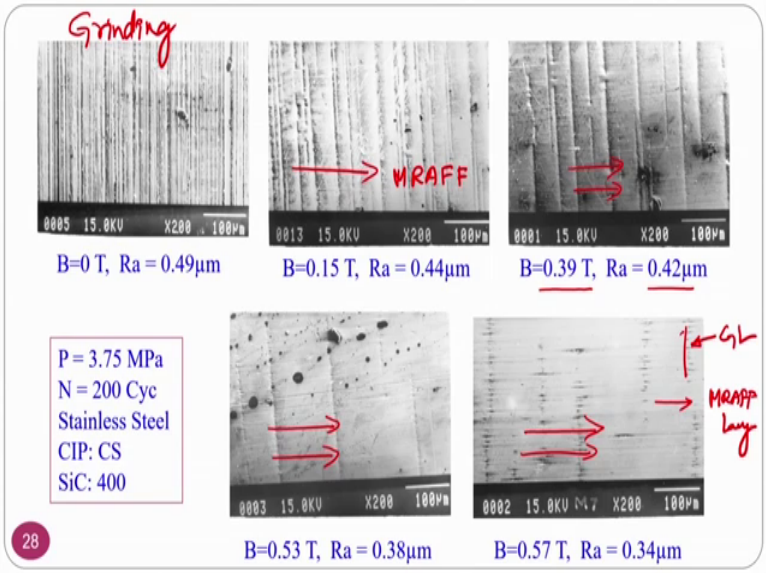

You can see here the surface and how the grinding marks are removed, so these are the grinding surface and these are the MRAFF surface. MRAFF follow the straight line path similar to abrasive flow finishing process; abrasive flow finishing process medium is reciprocated. So, the path followed is reciprocating that means, that linear path if you are going to give a rotary motion to abrasive flow finishing process or magnetorheological finishing process there will be a rotational affect which you are going to see in upcoming slides.

At the same time reciprocation because of the reciprocation and rotational motion what you are going to achieve is a helical path. Please note that MRAFF process and abrasive flow finishing process follow the straight line path if you are going to give the rotational effect to the magnetic field or rotational effect to the workpiece, then you are going to club the rotational motion plus reciprocation motion which in tern you are going to get the helical path.

So, again if you are increasing the tesla so the surface roughness is improved and you are going to see the MRAFF process and gradually you are removing the grinding lay. Whatever you are seeing here is a grinding lay and whatever you are saying in this

direction this direction is grindingly this direction is MRAFF lay that means, lay is nothing, but you are predominant direction of surface roughness.

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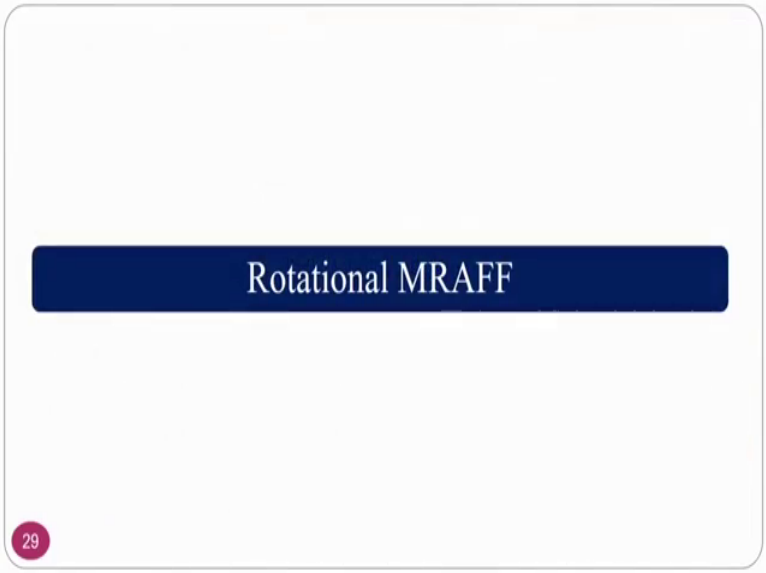

Now we move onto rotational magnetorheological abrasive flow finishing process wherein, in the magnetic field is given some rotary motion why this motion is given by the researchers we will see.

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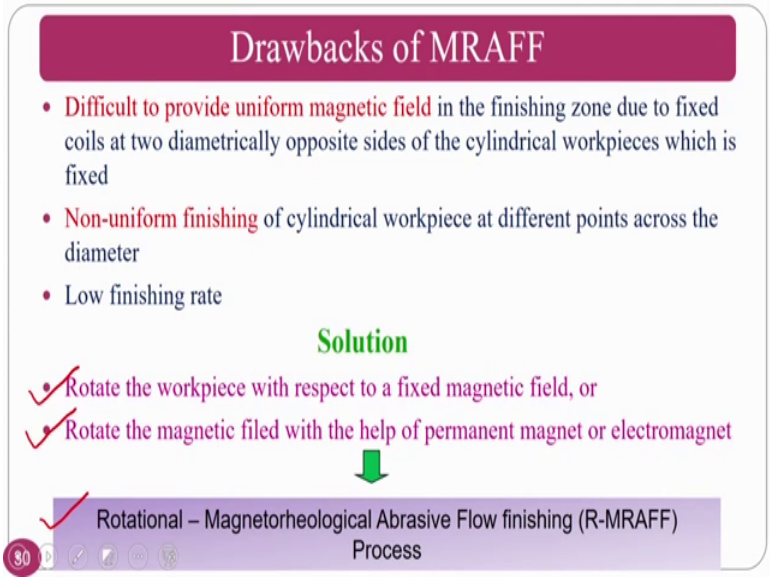

It is difficult to provide uniform magnetic field in finishing row zone due to fixed coils and two dimensional opposite side that means, that if at all I want to finish a cylindrical

hole. If I have two electromagnets the magnetic field will be very good on this side and this side, but not on this sides for that purpose you have to rotate the magnetic field; whenever you rotate the magnetic field you can easily finish the cylindrical surfaces.

Non-uniform finishing of cylindrical workpieces a different point, but that is what I was saying that if at all I want to the uniform then you have to give the rotary motion. For that purpose rotate the workpiece or rotate the magnetic field that is why in this case rotate station of the magnetic field is taken and that is why this process is called rotational abrasive flow finishing process.

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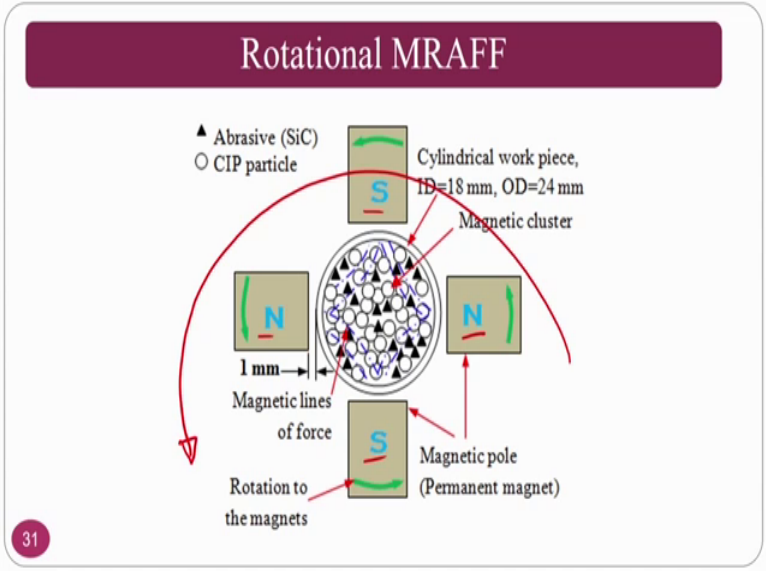

As you can see here North Pole and North Pole, South Pole and South Pole is there and these are given rotary motion, these are given rotary motions so that the finishing will be proper.

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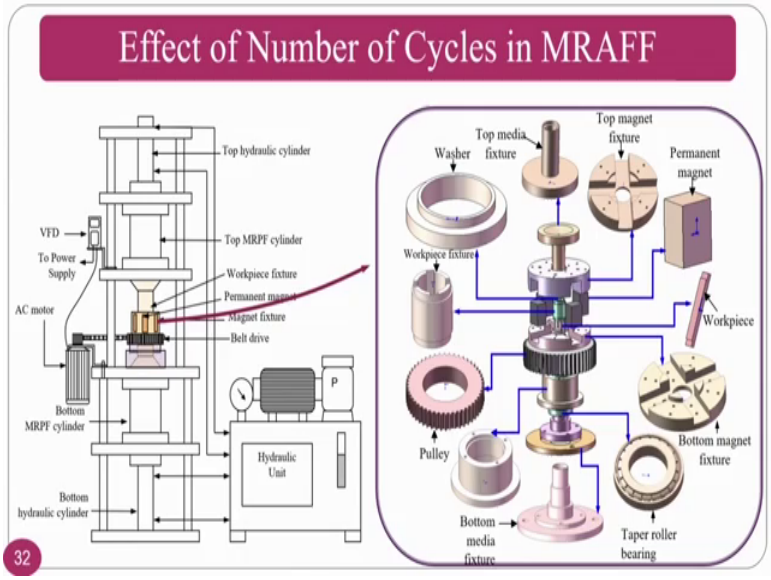

You can see the anatomy version of the fixture, so the change here is only the rotary motion is given to the magnetic field. The magnetic field that here is a fixed magnetic field because electromagnets is not possible to rotate that is why the researchers have used the fixed magnetic field.

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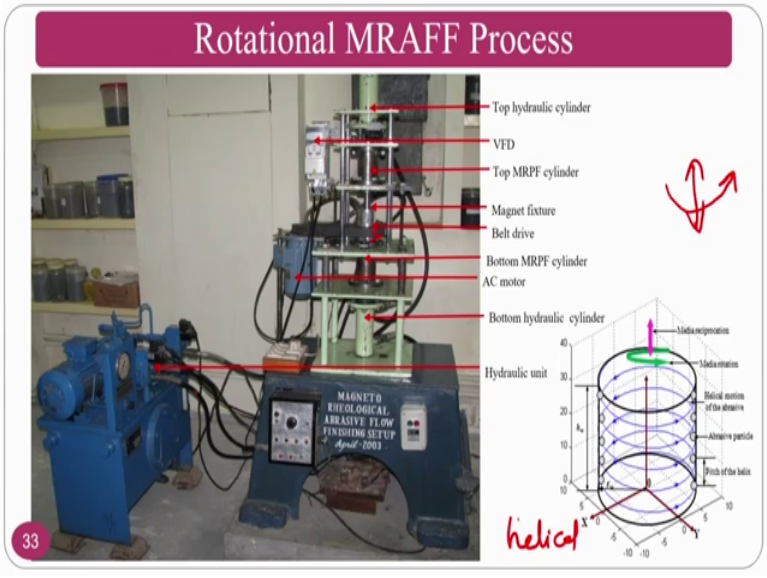

And this is the same set up that is developed by Sunil Jha which is amended the rotary motion by Professor Manas Das who is working currently at IIT Guwahati. So, the rotary motion is provided here to the magnetic field and the cylindrical surfaces are finished.

So, as I was saying your medium is reciprocating by the hydraulic power pack and you rotary magnetic field is provided because of which what you are going to get is the helical path same thing, some of the researchers done at IIT Kanpur on rotational abrasive flow finishing process where the motion is helical again.

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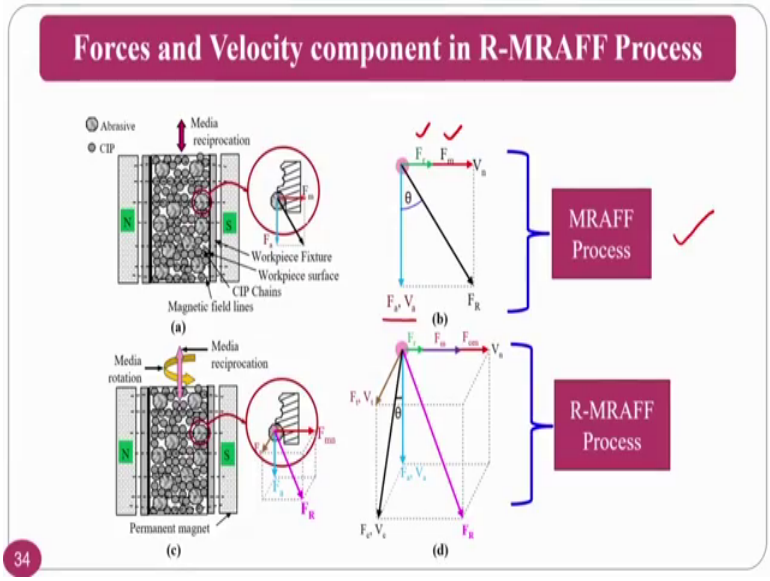

As you can see the forces and velocity components in rotational magnetorheological finishing process compared to magnetorheological finishing process. As we have seen in magnetorheological finishing process you have the radial force by the virtue of the composition, magnetic field indentation force because of the magnetic field intensity and axial force and axial velocity because of hydraulic power pack. And whenever you are going to add the rotary motion you are going to add the centrifugal force also into it and because of which and at the corresponding velocities also come into picture.

Because of additional force and additional velocity then the material removal rate will increase at the same time finishing rate will improve. That means, that the same component that you can finish in the MRAFF process in 1 hour you may finish that particular component in 45 minutes or 40 minutes or even 30 minutes in the rotational magnetorheological finishing process.

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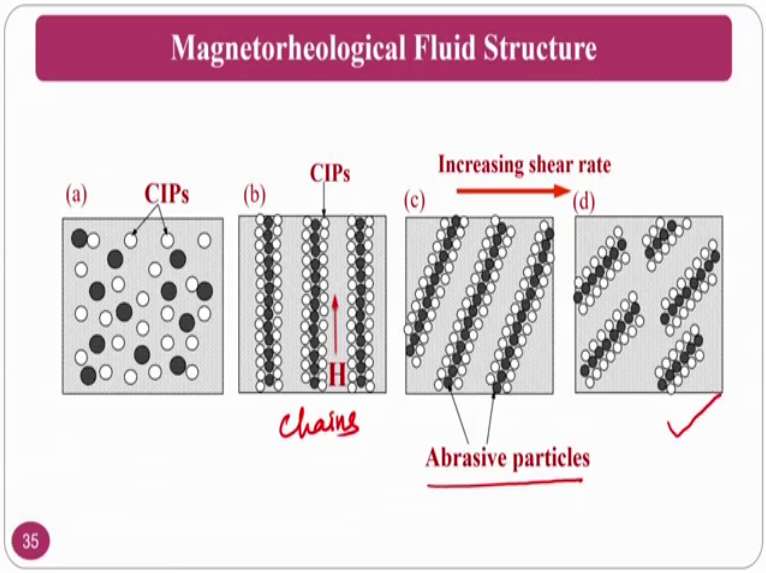

And you can see here that magnetorheological fluid structure normally the CIP particles abrasive particles are held randomly whenever you are going to apply the magnetic field then what is going to see here is this form the chains. And these chains whenever you are going to give rotation if the rotation is up to certain limit what will happen this chains will sustain that rotation if you are going to increase the rotation what is going to happen is this will break the chains and the viscosity maybe reduces slightly.

That is what is happening if you are going to increase the shear rate or if you are going to increase the rotational speed. So, you cannot go for higher rotational speed because this chains will break and the finishing efficiency of rotational magnetorheological finishing process will go down that is why you should be very careful about using the rotational speed. For more details and other things you can see Professor Jain and Processor Vijay Kumar Jain and Professor Manas Das papers for magnetorheological abrasive flow finishing as well as rotational magnetorheological abrasive flow finishing process.

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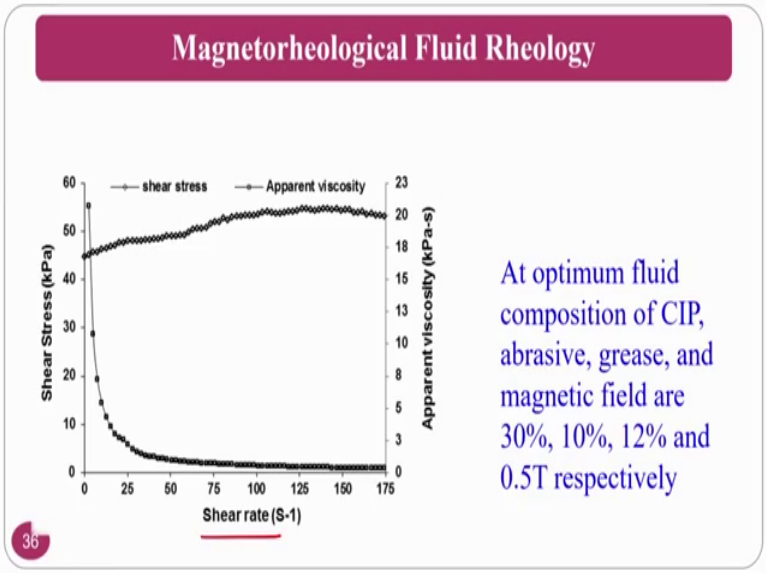

If you see the rheology the rheology also similar, but only thing is that in the antenna power you will have additional magnetorheological attachment will be there, so you can do this one.

So, flow test is done for the shear rate versus shear stress and you can see the apparent viscosity is gradually decreasing at the same time shear stress will be approximately constant after certain time. So, you have to play with the composition so that you are required shear strength and you required viscosity can be obtained.

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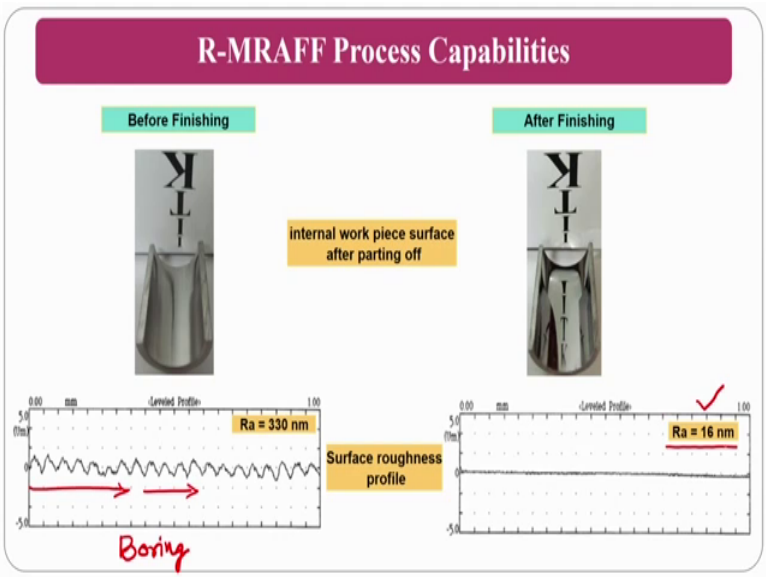

You can see the best surface finish that you can achieve is 16 nanometers by a finishing the cylindrical surfaces and this particular process is very good for the cylindrical surfaces because in MRAFF process you can do only flat surfaces which are placed on two sides. In the rotational magnetorheological finishing process what you can achieve is uniformly and the cylindrical surfaces. It is the workpieces initially boring surface and that is why you are going to get the morphology like a turning process, then you are going to do the finishing process and you can achieve the surface finish approximately 16 nanometers from 330 nanometers.

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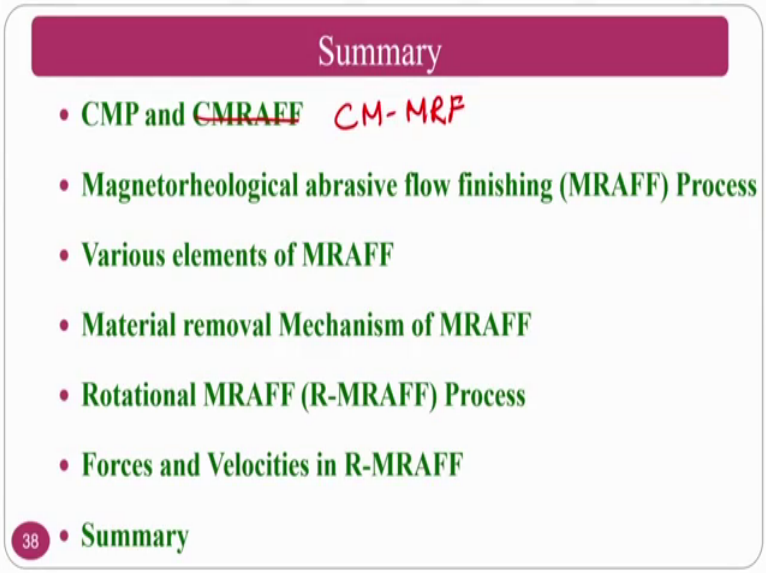

Summary of this particular class you have seen the chemo mechanical polishing process and we are blending this particular chemo mechanical polishing process along with magnetorheological finishing process. At the same time, then you are going to blend the MRF process magnetorheological finishing process along with the abrasive flow finishing process. And we achieve the second hybrid process from the family of magnetorheological finishing process and we have gone into the details like various elements of magnetorheological finishing process. How the material removal mechanism works in the magnetorheological finishing process, what are the forces that are involved in this process like radial force and magnetic field force along with axial force.

Whenever then the move on to another advanced version of this magnetorheological abrasive flow finishing process that is called rotational magnetorheological abrasive flow

finishing process. We have seen the forces difference here in the rotational magnetorheological abrasive flow finishing process we are going to add d up some of the forces some of the velocities because of which you are finishing rate can be improved and at last we will, we are seeing the summary of this particular class.

Thank you for your kind attention.