Polymer Assisted Abrasive Finishing Processes
Dr. Mamilla Ravi Sankar
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Lecture – 07
Surface Morphology and Surface Metallurgy

Welcome to the class. And now we are going to deal with elastic polymer assisted abrasive finishing process as a part of Polymer Assisted Abrasive Finishing course ok. So, this comprises of three processes, one is elastic emission machining or elastic emission finishing, hydrodynamic polishing or hydrodynamic finishing, and elasto abrasive finishing process ok.

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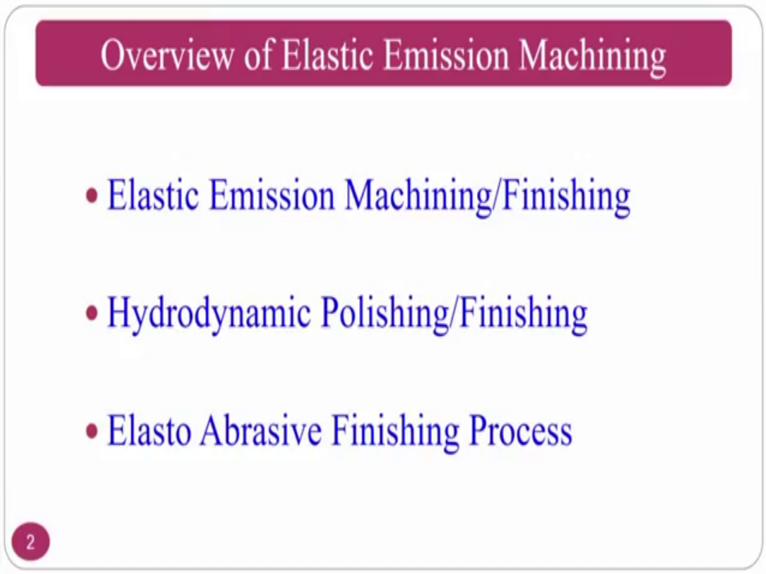

First we go with the elastic emission machining which is a non contact type. Later on we will see the contact type that is hydrodynamic polishing as well as elasto abrasive finishing process.

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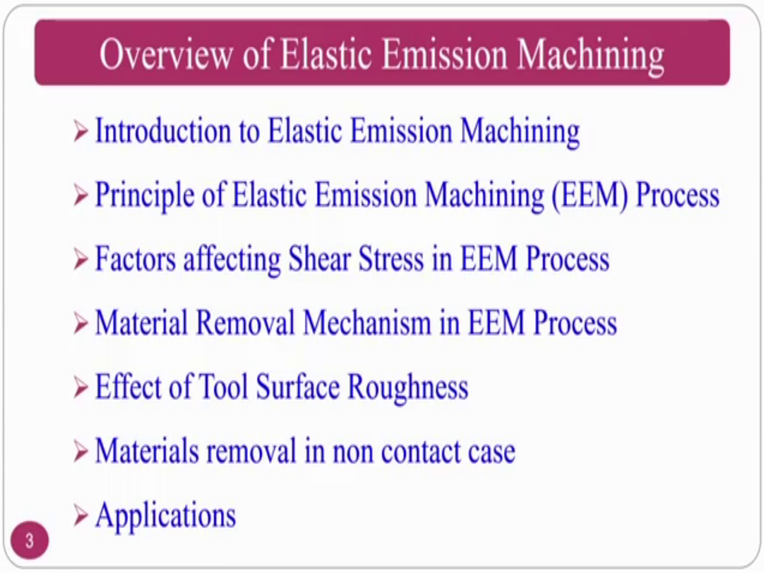

So, overview of this elastic emission machining process, we just see into the introduction of elastic emission process, principle of elastic emission machining process, how the material removal rate will occur. At the same time how the material removal mechanism will takes place, factors affecting the shear stress in elastic emission process, material removal mechanism, effect of tool surface roughness if the surface roughness of the tool is too high normally what will happen is the roughness that you are going to achieve is also high.

The material removal in non contact case what are the different, different phenomena, how the material will remove in case of non contact regime of elastic emission machine. Then the applications of this one, normally this particular process uses for the finishing of optical lenses glasses and other things.

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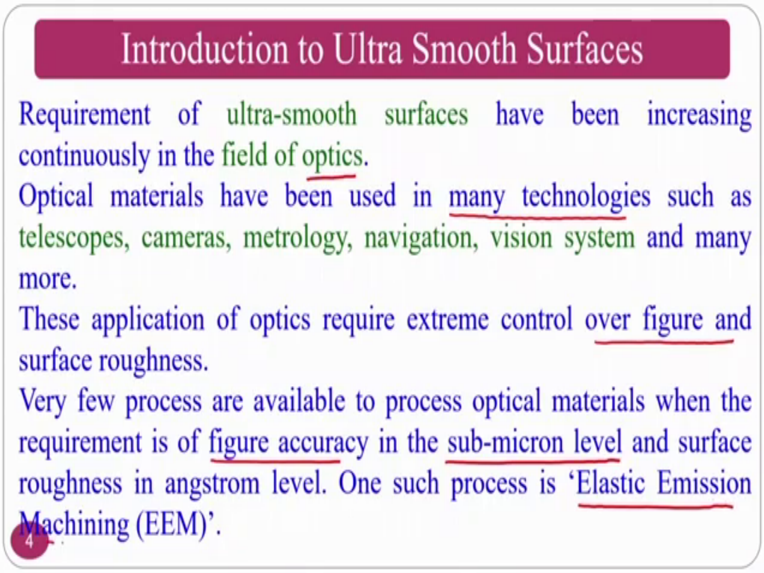

So, introduction to ultra smooth surfaces where you required ultra smooth surfaces, requirement of ultra smooth surfaces basically have increased continuously in the field of optics basically ok. So, the optics means lens, contact lenses, to the lenses, whatever I was seeing on my face, the lenses and all these are the eye lenses or the X-ray lenses. Or if you are going to see the lenses different, different lenses in a telescope, different, different lenses in a microscope and other lenses has to be done ok.

Optical materials have been used in the technology such as telescopes, cameras, metrology equipments, navigation, vision system and many more, that means, that you all going to see this lenses in a huge applications and you do not want any scratch mark on it. So, if at all I have a scratch mark on my eye specs, what will happen, so always my vision will be disturbed. So, you should not have any type of the scratches on it for that purpose normally people go for elastic emission machining process.

This applications of optics require extreme control over the figure as well as the surface roughness, that means, that you require figure, roughness is there at the roughness obviously you know the central and average value or rms value or maximum peak to minimum value. At the same time you require the figure, big figure means you need to certain sculptures structures. Assume that if at all the people want on this particular specs, you require a convex on one side concave on another side ok. This is always required along with the surface roughness also.

If you are going to give better surface roughness, but you are not going to give proper figure, what will happen the vision system of that particular person will greatly affect. Processes for optical materials processing which require the figure accuracy in sub-micron level surface roughness is required. And even people require angstrom level.

Nowadays, if you go to telescope, SLR cameras are very high end cameras that are used in either formula-1 racing or sports these are all high speed cameras. These are the cameras where you require a very very good surface roughness like angstrom surface roughness. Or if not some of the cases you can be happy with submicron level surface also. So, one of such process is elastic emission machining ok. Why this particular process only that we will see in the upcoming slides.

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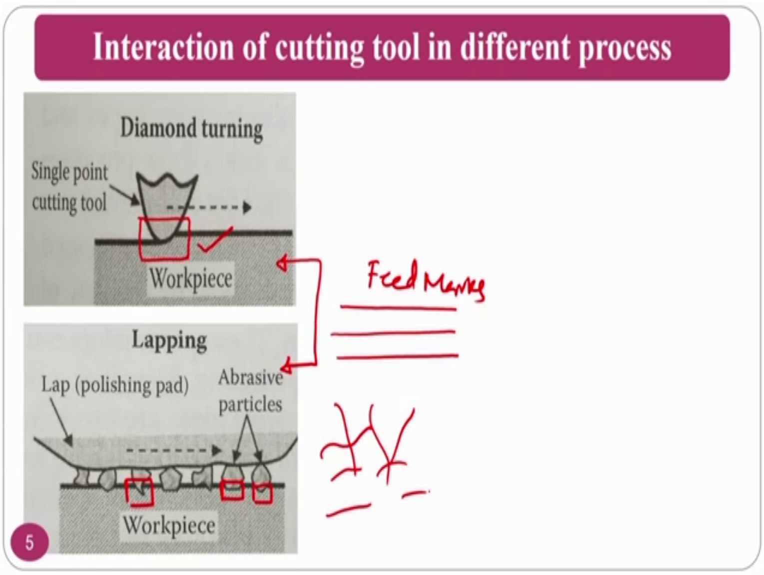

Interaction of cutting tool in different processes, how the cutting tool will have the interaction. You can generate the mirror surfaces using diamond turning process ok, as well as you can also do by lapping process ok. The problem in this particular two techniques, these are the one technique, these are the second technique. This is what the drawback of this one, you will get the feed marks on the surface. Because in both conditions you will have the contact of your tool with respect to workpiece, in the diamond turning process, you can see the contact with respect to workpiece. Because of this what will happen, you will get always the feed marks ok, so that is a drawback.

At the same time, if you see here in the lapping process also, the lapping process there three-dimensional or three body operation will takes place wherein you will have a random surface roughness marks ok. So, this is another disadvantage because of this feed mark the vision system that are used in optical, so that may be destroyed ok.

For that purpose what will be the solution the solution is in this particular thing, we do not want feed marks. Even though we are getting a very good surface roughness and the figure in terms of diamond turning as well as lapping, but the problem in this conditions is that you are going to get the physical feed marks which is nothing but the scratches or lines on the lenses.

You I said if you have a scratches or the lines on the lenses, if you if the scratches and the lines are there on the lenses, then it will disturb the vision or it will disturb my vision. Because if at all I want to see a microbes in a microscope, there is a clear scratch is there on the lens, then it will disturb. At the same time, you have to grab into the computers and other things. So, complete vision systems will disturb.

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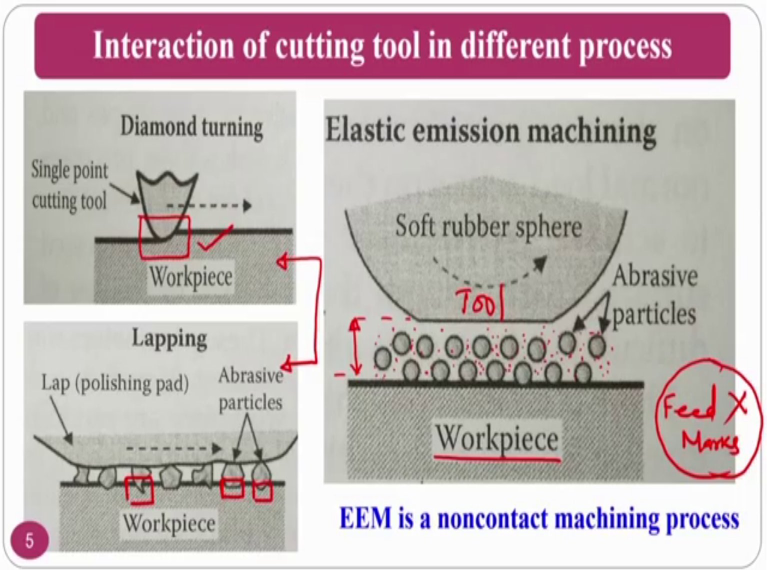

For that purpose, elastic emission machining is one of the solutions because you do not have direct physical contact. If you see here in the elastic emission machining, my tool is here at the same time workpiece is here; in between there is a submicron to micron gap will be there. If you see here, there is a gap. In this gap, you have abrasive particles at the same time you have the carrier fluid also ok. Whatever the red dots that I am putting here in the carry along with carrier fluid that is nothing but your career fluid; normally carrier fluid will be water or any other compatible liquids can be used in this particular thing ok.

So, in this particular case, as you see diamond turning as well as lapping which is complete contact is there, here there is no contact. If there is no contact, what will happen is you may not get any feed marks ok. So, this feed marks will not be there in this one because of which the lenses or any optical things that are produced by elastic emission technique will be scratch free or it will have a good surface roughness along with the figure also ok. So, this is a one of the good process for producing the lenses.

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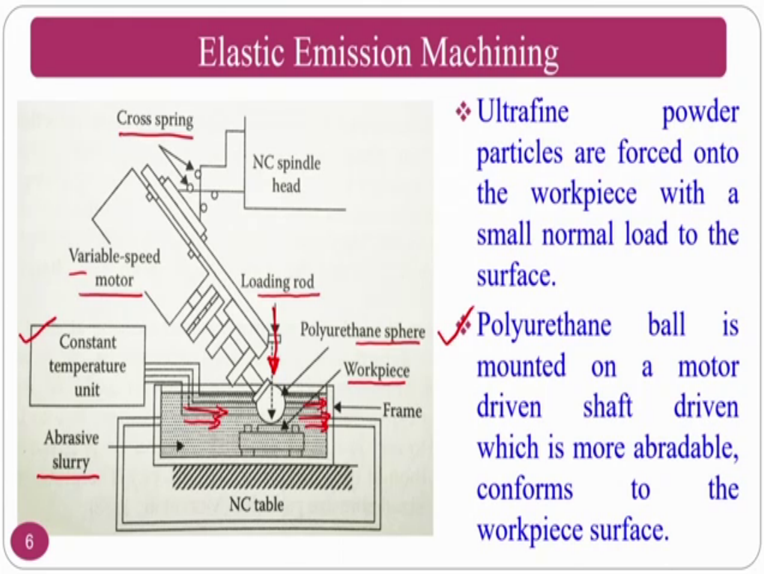

So, how the elastic emission works? If you see the elastic admission process what will happen? See there will be a polyurethane ball here, this is a polyurethane ball which is a tool basically on a workpiece. And you can find there is a micron gap ok. There will be a micron gap with between your polyurethane sphere as well as a workpiece. This is flooded with abrasive particles which are very, very fine in nature, and along with the water or any other fluid ok. What will happen here you have a loading rod. So, you can put the normal load whatever the load required. At the same time you are to make sure that the spherical ball or the polyurethane sphere should not touch with the workpiece ok.

You have a NC spindle head, so that you can control the cross spinning; at the same time variable speed motor, it will give you what are the speeds at which your spherical ball has to rotate. And you should maintain the constant temperature unit because you are going to finish the optical lenses. Lenses are normally brittle materials. If you are not going to maintain the temperature or the temperature difference is there, then there will be a problem of brittle fracture.

Normally whatever the temperature that you are maintaining here, it may not happen, but there maybe because your focal point will vary if there is a thermal expansion contraction and other. So, in order to maintain all these things, you have to always go for constant temperature unit. If there is a contraction and expansion in a sub nano level or a nano level also, the focal points will drastically vary. So, for that purpose, you have to maintain the constant temperature.

Abrasive slurry says that it has abrasive particles as well as a carrier medium ok. So, in a lapping process also, you will have always a carrier medium which is water or oil or any type of thing along with a abrasive particles ok. At the same time, some of the people they call it as a vehicle also ok, some of the textbooks follows the vehicle, because it is carrying the abrasive particles ok. Do not confuse between career fluid, vehicle and other some slurry also the some people will say ok.

So, if you see here, a polyurethane ball is mounted on a motor driven shaft which is driving a abradable, conform to the workpiece ok. So, there will be a sphere. Then what will happen, there will be a ultra fined powder particles that means, that abrasive particles are forced into the workpiece with a small normal load to the surface. Normally what will happen is your abrasive particles are moving like this ok. So, you are going to put a normal load on top of it, but make sure that work piece and your polyurethane sphere are in no way contact, but because of this normal pressure at the same time flowability what will happen abrasives particles and this fluid will go in touch with the work piece.

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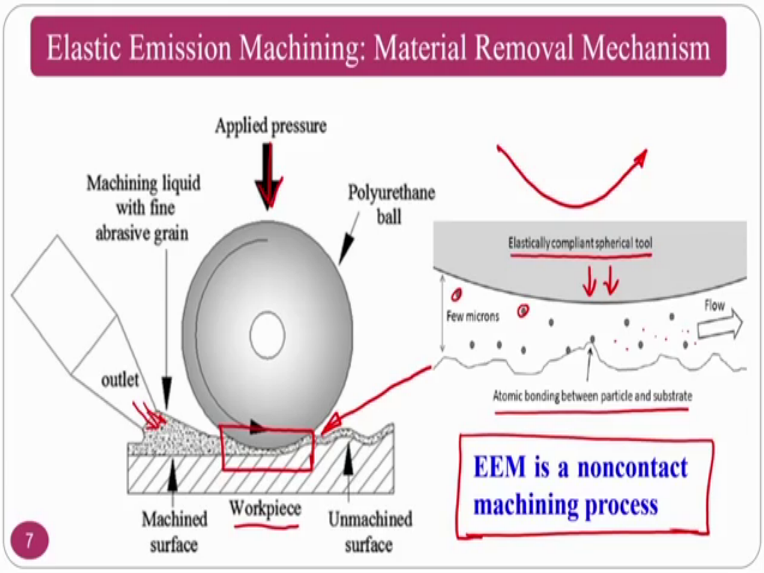

So, material removal mechanism, if you see the zone version of the previous slide what will happen is this is how the outlet where the abrasive slurry is coming here, and there will be a microns gap between your sphere that is the polyurethane ball or the polythene sphere and the workpiece ok. This is the normal load and this is the rotation because of which what will happen is you will have the it will force the abrasive particles or the abrasive slurry towards the finishing region that is why the finishing will takes place. And this finishing is not by the virtue of shearing or something, but it might be the virtue of chemical reactions and other things.

We assuming this particular portion and what here it is happening if you see here, so there will be a few microns gap between elastically compliant spherical tool that is nothing but polyurethane ball or a polyurethane sphere and you are putting a load normally in this direction at the same time you are rotating it ok. Because of this what will happen these particles are forced towards the surface of the workpiece, and at the same time slurry is there this slurry is a liquid and it will remove the material.

How it will remove the material that we will see; what are the chemical reactions that is going to takes place, how the material removal takes place in the noncontact region is different. As a mechanical engineers what you can guess is shearing action as well as abrasion is a normally the material removal action in terms of grinding, in terms of lapping and other things, but in terms of elastic emission process this is not so. It is a non contact type of machining process. So, even it is non contact is there, how the material removal is taking place that we will see in the upcoming slides.

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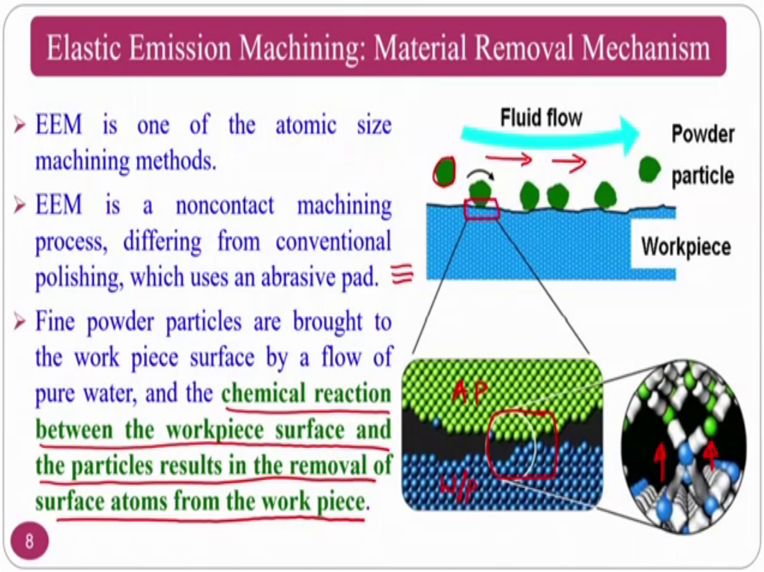

So, EEM is one of the atomic size machining methods where you can remove the material in terms of atom by atom. So, elastic emission machining is a non contact type machining process differing from the conventional polishing which uses abrasive pads because of this what will happen you will get the feed marks or the predominant direction of the surface roughness that is nothing but the lay, so which we have seen in the grinding process and other things; whenever you see the grinding process, where you will see a straight lines.

So, fine powder particles are brought into the workpiece surface by the flow of pure water, and the chemical reaction between the workpiece surface and the particles results in the removal of surface atoms of the workpiece. This is how the mechanism of material removal takes place. It is not by the virtue of the shearing action; it is not by the virtue of abrasion or something.

So, what will this happening is your spherical ball is rotating at the same time you are giving a normal load on it because of which what will happen it is directing the slurry the slurry is compresses of the carrier fluid as well as abrasive particles, those are going near to the workpiece and it is chemically reacting and taking by atom by atom that is how the mechanism works in case of this for the material removal. The schematically if you can see what is happening is your fluid that is a carrier fluid is flowing like this and abrasive particles are also there in the carrier medium that is called as the slurry. Slurry is a combination of your carrier fluid plus abrasive particles ok.

So, this is what is happening whenever the abrasive particle is in contact with respect to the workpiece, if you see here, this is the abrasive particle and this is the workpiece material. And there will be a contact here and this particular contact is making a chemical contact and taking away the atom by atom ok. In this circumstances, what is happening here is that the material are removed by atom by atom by the chemical action not by the mechanical abrasion or scratching or the shearing action because of which you do not find any type of shearing marks or the feed marks like this. So, you are going to get a better surface finish without the mechanical shearing action.

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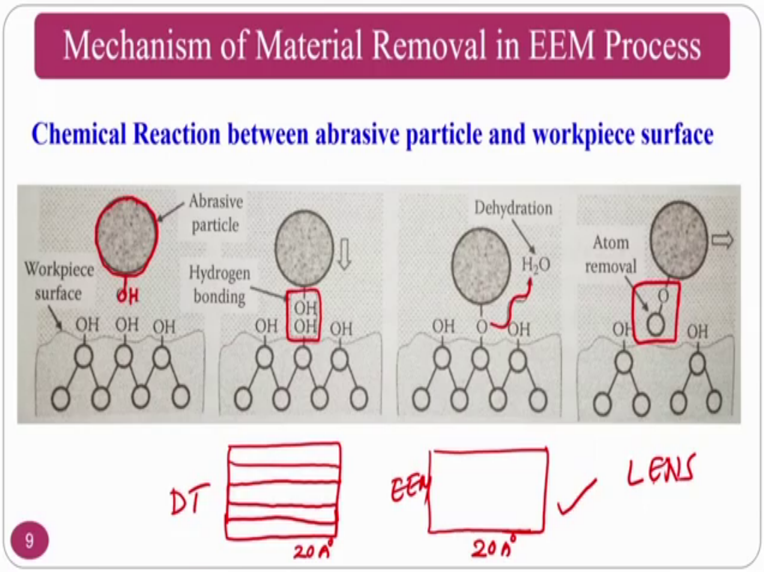

Mechanism of material removal if you see the chemical reaction between abrasive particle in the case 1, what is happening it has a water molecules which are there is a part of your abrasive slurry. This water molecule you have OH group and this OH, at the same time workpiece is also on the surface of the workpiece the abrasive slurry is moving. So, it has OH molecules are on the surface, this OH molecules OH molecules having a hydrogen bonding and it will goes off as the water ok. Then it will retain the oxygen bonding, and this oxygen will remove one atom.

So, this is how the material removes atom by atom not by mechanical action because of which what you are going to get if this is a surface in terms of grinding or the diamond turning, your tool will go you, again it will come back; your tool will go again it will come back. So, this type of scratch marks will be there even though you are going to get the surface roughness about 20 Angstroms or something ok. But the same surface you can get achieve by the elastic emission process diamond turning process, elastic emission machining in this circumstances you get 20 angstroms just I am assuming, but there is no scratch marks on this particular process.

This you can use for the lens applications or mirrors applications or superfine mirrors for example, synchrotron mirrors are made up of, some of the synchrotron mirrors are made up of this particular process where you do not get any scratch marks ok. Not only you are getting a surface finish of 20 angstroms, you are also eliminating the feed marks that you predominantly see on the mechanical process that is why this particular process is much more efficient compared to the mechanical processes.

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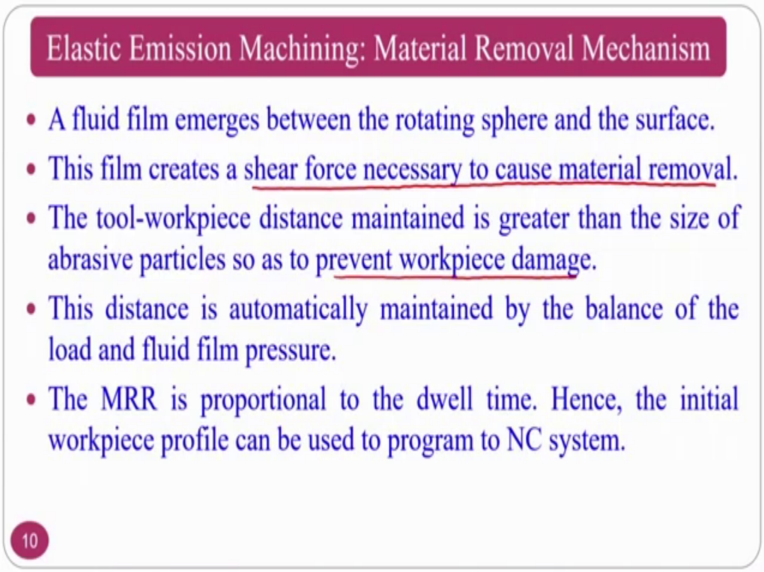

So, elastic emission in the material removal mechanism a fluid film emerges between a rotating sphere and surface. This film create the shear force necessary to cause the material removal; that means, that this particular sphere is rotating which it rotates tries to move the abrasive particles in the direction of their motion tangent to the motion. Assume that my sphere is moving like this, what will happen abrasive slurry is coming like this, what will happen, it tries to give the motion along the tangential direction at that particular position ok.

So, this will empower the abrasive particles to possess the shearing action the tool workpiece distance is maintained is greater than the size of the abrasive particle, so that to prevent the workpiece damage. That means, that always your abrasive particles also fine that that the gap should be always much bigger than the abrasive particles, so that there would not be any mechanical shearing action. This distance is automatically maintained by the balance of the load and fluid film pressure. So, there will be a closed loop system will be there, and always they will measure the forces and it will be maintained the pressures.

The MRR is proportional to the dwell time. Hence initial workpiece profile can be used to the program to NC system numerical control system or computer numerical control system you can go ahead. Assume that I want to finish a convex shape. Assume that this is a convex shape that I want to measure. So, just I measure with the CMM and the all the points and I will make into m-codes and normal all the codes then you can feed this to the CNC system when. So, you are going to feed to the CNC the system, the CNC the system will take care of the x, y, z motion and other things.

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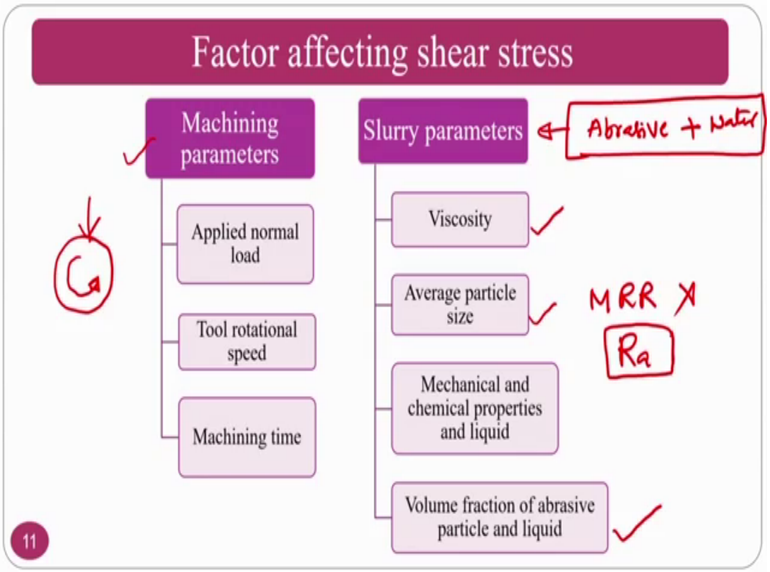

So, factors affecting the shear stress: normally the first one is a machining parameters that is nothing but the applied load, how much load that the machine is applying on the sphere, so that it will give some pressure on the fluid. The tool rotational speed that is nothing but how fast you are rotating sphere, so that you will give the shearing action to this one at the same time machining that where you are going to machine for 10 minutes or 10 hours or something depend on your workpiece material condition and workpiece initial surface roughness condition, your time, your rotational speed, your applied load, all these things will vary.

Where the slurry is nothing but abrasive particles at the same time you will have a water or any other fluid, this is nothing but your abrasive slurry. So, the viscosity of the abrasive slurry this is nothing but the suspension, the viscosity if at all you want to high, viscosity if at all low that is always is the function of what is the flowing characteristics that you require. You need very low flow rate, then you can go for high viscous fluids; if you want very high flow rate, then you can go for low viscous fluids and other things.

Abrasive size of the particle whether you want to get a good surface finish, then you are to go for superfine or ultra fine particle; whether your material removal is the criteria, then you can go for coarser size particles. Normally this particular process uses for the finishing of the lenses. So, in that circumstances material removal may not be a criteria in this condition, consideration is the surface roughness and figure accuracy and other things.

Mechanical and chemical properties of the liquid. So, the mechanical properties also required. Abrasive particles should have some mechanical strength and other things, and the chemical properties whether OH bonds are forming easily or something. So, volume fraction of abrasive particles, if the abrasive particles are more what will happen as we have seen in the previous slide, the abrasive particles OH group is reacting with the OH group of your workpiece.

In that circumstances what is happening, if you have more and more number of abrasive particles, OH to OH bonding will be very good. At the same time many places these OH-OH bonding will be there and it will release as H 2 O, and the remaining oxygen will bind to the surface atom and takes away in terms of oxide atom. So, it will form the oxides and it will remove the material ok. So, as we have seen the oxide films are very easy. For example, if you are putting a mild steel in a rail after few days if you see there will be rust formation, you can scratch the rust with respect to your nail also. But if you want to scratch on a mild steel you cannot scratch that is the beauty about this particular process.

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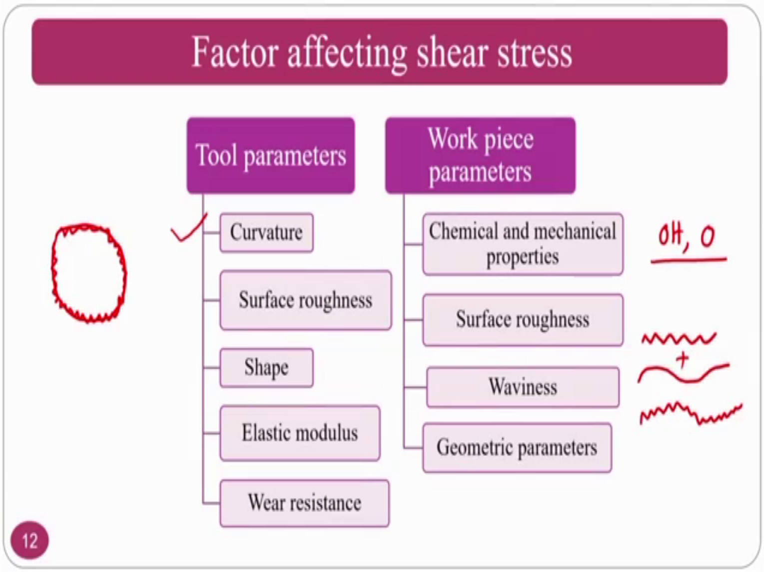

So, the next set of factors that affecting the shear stress is tool parameters ok. The curvature, normally spherical curvatures are the common curvatures. If the surface is like this, what will happen, the workpiece also get the bad surface finish ok. The shape always your shapes to be maintained precisely and the elastic modulus, you should have the appropriate elastic modulus that you require for that particular process, and where is.

It should be wear resistant, because if the wear of this particular polyurethane sphere is too high, what will happen you are rechanging time or the changing time between these two spheres will be high that is called as a non-productive time and that non-productive time should be reduced. For the purpose, so you should always go for high wear resistance, so that the wear will be very low.

The workpiece parameters that you have to see is chemical and mechanical properties, because it has to form OH bonds, again oxygen bonding and other bonding it has to do. The surface roughness, initial surface roughness should be good, so that the final surface roughness can be achieved at earliest possible that mean that if you are having the surface roughness as 1 micron and your final surface roughness is 1 angstrom, then it will be a very big trouble for to get that particular surface roughness ok.

The waviness, waviness as you have seen the surface roughness is like this, and waviness series like this. So, both if you combine what will happen is this is the profile roughness ok. So, waviness also should be maintained properly, because this particular sphere cannot correct the waviness, it can correct to the surface roughness up to certain level, but form or which is nothing but the high amplitude thing is very difficult to correct. So, the geometric parameters and other things should be proper.

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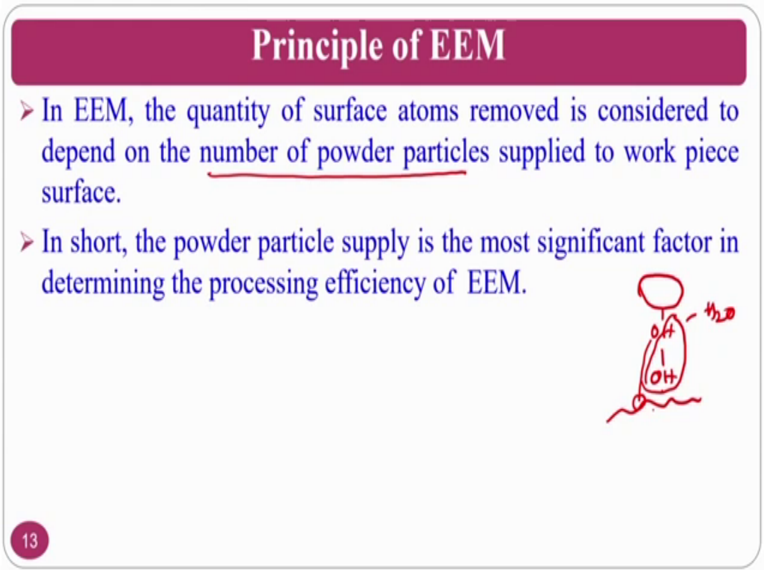

The principle of EEM, in the EEM the quantity of surface atoms removed is considered to depend on the number of powder particles. As I said abrasive particles because the each abrasive particle will form OH bonding of that workpiece surface, and it will remove. In short the powder particles supply is the most significant factor in determining the process efficiency; that means, abrasive particle will form OH bonding with respect to OH bonding of your workpiece surface.

So, this will go as H 2 O, and the remaining oxygen will bind to the atom of the surface and it will remove ok. So, this is always if you are sending maximum number of abrasives, then what will happen maximum number of OH bonding will be taking place.

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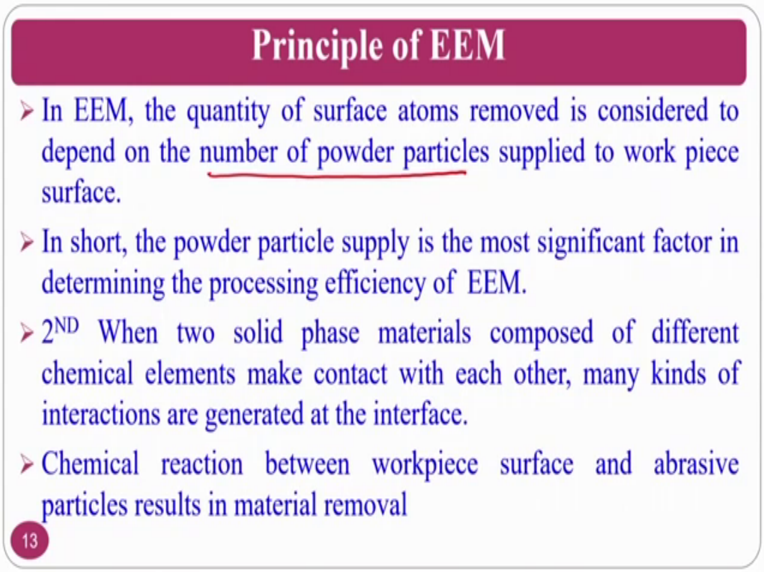

Second when two solid phase materials composed of different chemical elements make the contact with each other, then interactions generated at the interface will be very good. At the same time chemical reaction between the workpiece surface and the abrasive particle results in material removal that is what I was saying that OH bonding and OH bonding will takes place.

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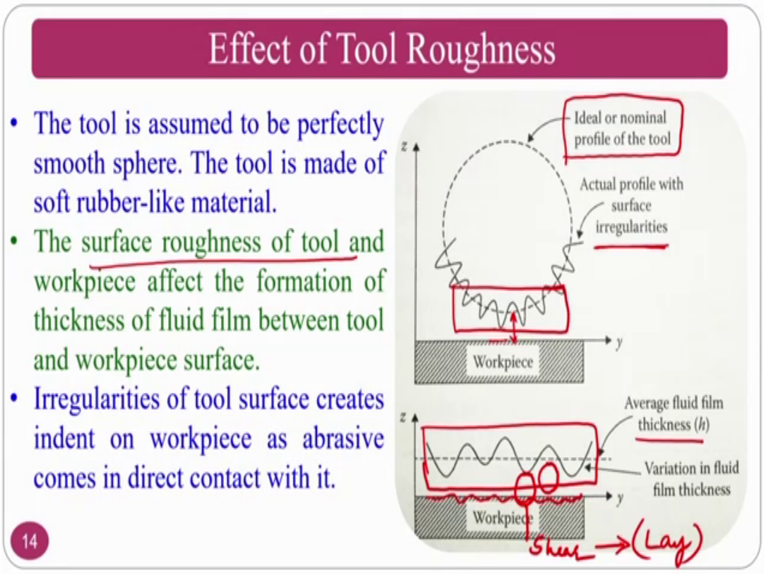

Thus so if you see the roughness of the tool that is a sphere, what will happen your require ideal surface is this particular sphere, but normally if you want to see you will have always a actual profile will be lot of roughness will be there ok. This is assumed to be perfectly smooth sphere, but the normally tool will have soft rubber like material, the surface roughness of the tool workpiece affect the formation of thickness of the fluid film between the workpiece. That means, that if this is a surface, what will happen, this maybe a thickness of the profile; if this is a surface, then this thickness will vary.

If the surface roughness is too high, what will happen, it will affect greatly the film thickness and other things. So, if the film thickness is varying that for location to location, what will happen, the surface roughness also will be very poor. So, this is the actual fluid film thickness, because if you see here, this is the variation, because of this variation this is a fluid film thickness is generating. If because of this what will happen, your surface also will have wavy surface characteristics.

So, irregularities of the tool surface create indent and the workpiece, and it will also create some indent. Assume that the abrasive particle as I said the distance between the sphere and the workpiece should be higher than your abrasive particle. If you see in this particular case, it may be higher in this case, but it may be lower in this case, because of which what will happen you will get a shear marks, because the abrasive is completely in contact or it is squeezing between your spherical ball at the same time the workpiece.

So, it has chances to shear ok. So, then it will create a lay that is nothing but predominant surface roughness direction because of which what will happen the shear marks will be generated.

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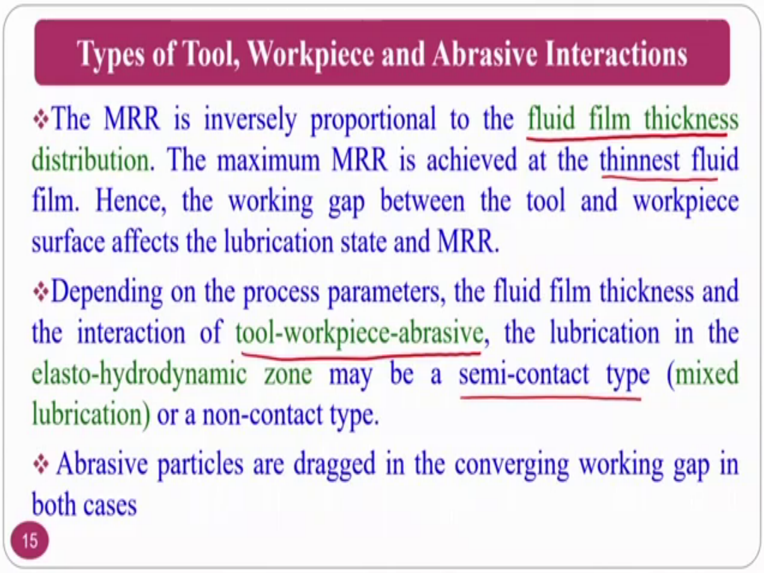

The types of tool workpieces and abrasive interactions, the MRR inversely proportional to the fluid film thickness, that mean that if the MRR want to be more, what will happen is you have to use very less fluid film thickness. If you have very less fluid film thickness, if you have same number of abrasive particles and the fluid film thickness is low in one case and high in another case, in that circumstances what will happen is number of abrasive particles coming in contact with respect to work piece will be high in terms of less fluid film thickness. That is why it is always inversely proportional that mean that MRR will be very high if the fluid film thickness is low.

The maximum MRR is achieved at the thinnest fluid film, and hence the working gap between the tool and workpiece surface affect the lubrication state and MRR. So, you need to have a proper lubrication, at the same time you need to have a proper material removal rate.

Depending on the process parameters the fluid film thickness and the interactions of tool-workpiece and abrasive, and the lubrication the elasto-hydrodynamic region maybe semi-contact type that is that nothing but the mixed lubrication or non-contact type. That means that mixed lubrication is nothing but you will have very very fine thin layer. In non-contact zone means you will have a hydro dynamic layer. So, the abrasive particles are dragged in the converging working gap in the both cases. So, what is meant by this semi-contact type or mixed type of lubrication or the non-contact type.

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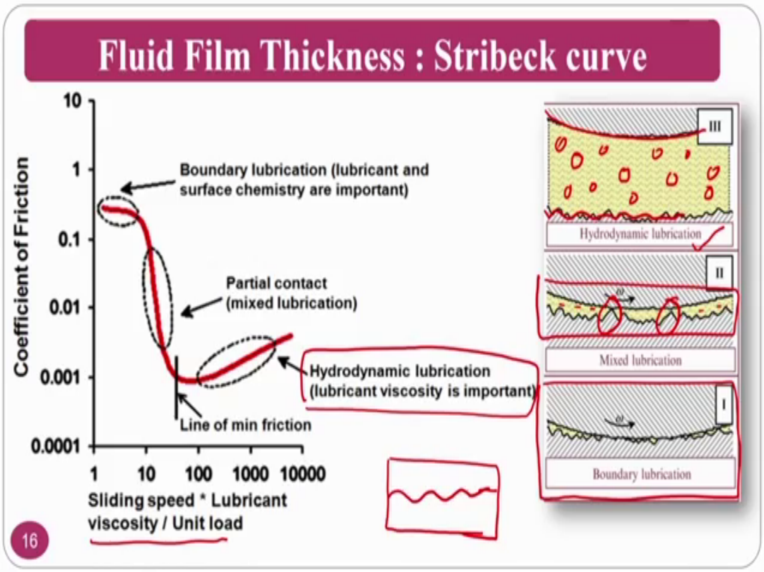

So, if you see the basics of Stribeck curve and other things, you can easily understand what is a boundary lubrication, what is the mixed lubrication and hydrodynamic lubrication. If you plot between the sliding speed versus coefficient of friction, the first one is about the lubrication. Boundary lubrication means if you see here this particular image is shows the boundary lubrication that means that it will have physical contact with respect to both surfaces.

Assume that if you having a abrasive grinding wheel at the same time you are having the workpiece. So, the contact region between the abrasive particle and the workpiece that is nothing but the boundary lubrication, that means that your abrasive particle is completely in contact with respect to the workpiece.

So, for example, to for better understanding is chip-tool interface, what will happen is the sticking region and the sliding region is there, the sticking region is a boundary lubrication, where you have a chip as well as your cutting tool both are in contact that is nothing but the your boundary lubrication, where metal to metal contact or tool to chip contact will be there.

In the mixed lubrication, that means the sliding zone where you will have partial cutting fluid also will fall or that mean that you have the tool at the same time chip, but in between you have a cutting fluid. The film is very, very fine, that means that some of the locations you will have the lubricant some of the locations it has a pure contact between the two metallic surfaces or I am assuming that HSS versus the mild steel, so that is why I am telling about metal to metal contact or something ok.

This is called sliding region, you can say some of the locations you will have contact and some of the locations you will have fluid. In the hydrodynamic lubrication that is nothing but where you do not have contact no contact, that means, that elastic emission machining work is in the hydrodynamic lubrication region, where your workpiece is at the bottom and your tool is at the top, you do not have any contact, wherein you will place the abrasive particles ok. So, these are the abrasive particles along with a carrier fluid. This is hydrodynamic lubrication zone is what you are going to use in terms of elastic emission machining.

Because of your rotational effect of your tool as well as the normal load because of which what will happen your abrasive particles are guided at the same time chemically reacted with the workpiece, and it will forms a layer and the material removal will takes place.

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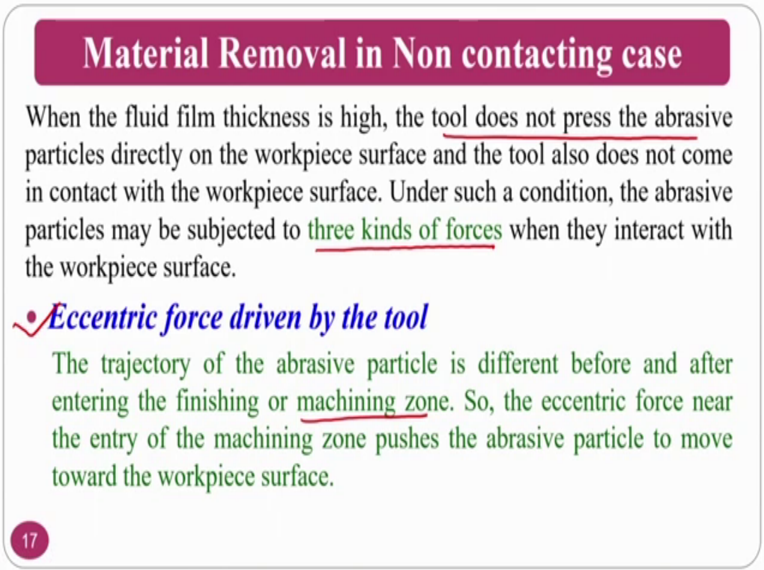

So, how the material removal will takes place in the hydrodynamic lubrication region or the non-contact region? When the fluid film thickness is high, the tool does not press the abrasive particles directly on the workpiece surface and tool also does not come in contact with respect to workpiece surface. Under such conditions, the abrasive particles maybe subjected to three kinds of forces ok.

What are the forces? As I said in the previous slide you have a gap microns gap between your tool as well as your work piece. In that circumstances what are the three kinds of forces are generated which is nothing but eccentric forces driven by the tool that mean that the trajectory of abrasive particle is different before and after entering the finishing and the machining region, so that the eccentric forces near the entry of the machining zone pushes the abrasive particles to move towards the work surface ok. This is one type of the forces that will pressurize the fluid towards the workpiece.

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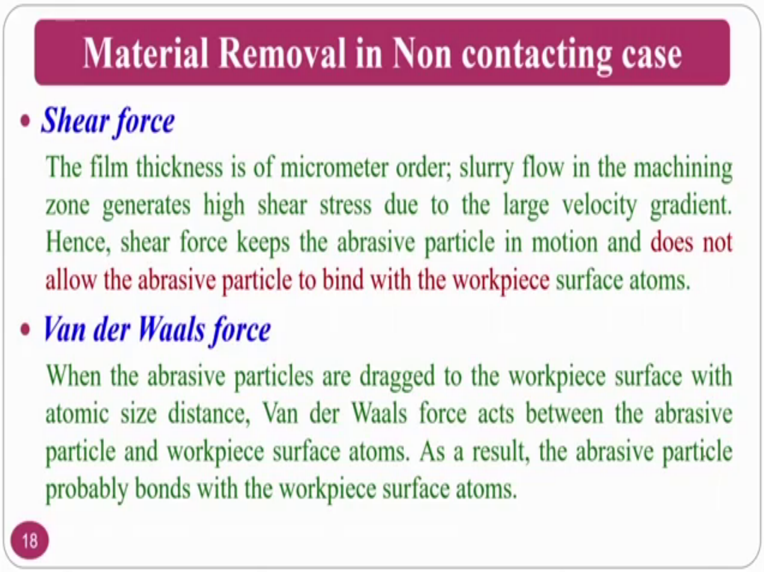

The second one is shear force. The film thickness of micrometre order slurry flow in the machining zone generate the high shear stresses due to which large velocity gradient will be there, hence the shear force keeps the abrasive particle in motion does not allow the abrasive particles to bind with the workpiece that means that whenever you are giving a rotational motion to the sphere, what will happen my abrasive particle having a chemical reaction with respect to the workpiece at particular location.

It should not be stagnant at that particular position. If it is stagnant what will happen the material removal may not takes place ok. For that purpose it should be in a continuous dynamic motion, for that what will happen your sphere is rotating these rotating these rotating sphere what will it will gives out the dynamics shear force to the abrasive particle, so that it will take away the material by forming OH-OH bonding and water will be released, and O which is get the atom of the workpiece material will get some shear force, so that it will be removed ok, that is nothing but the shear force.

The Van der Waal forces, when the abrasive particles are dragged to the workpiece surface with atomic size distance, Van der Waals force act between the abrasive particle and the workpiece surface atoms. As a result of abrasive particle probably bonds with the workpiece surface atoms, normally this will help the abrasive particles to bond between the particles bond with respect to the workpiece, and the shearing force will help in removing that bonding of that O with respect to the atom of the workpiece material, so that the material removal takes place by atom by atom.

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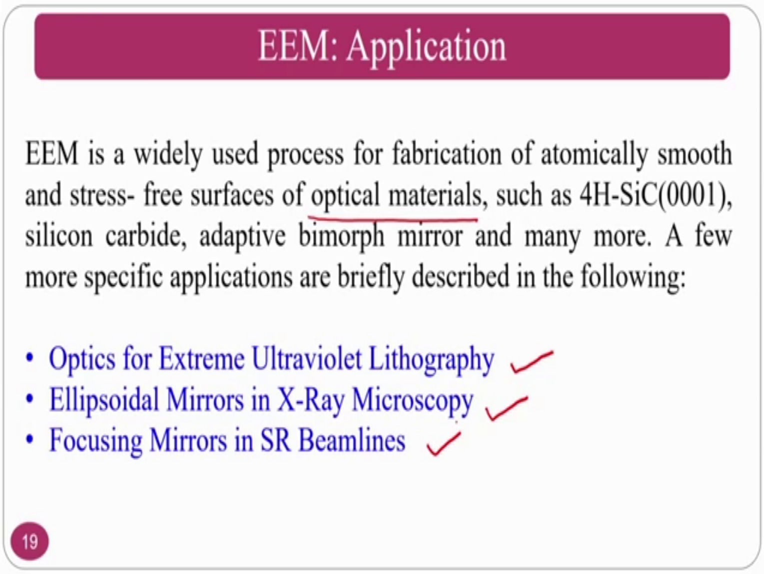

If you see the applications of elastic emission machining, the as in the first slide I said elastic emission is widely used process for fabrication of smooth stress free surfaces in the optical materials such as 4H-SiC silicon carbide adaptive bimorph mirrors many more a few specific applications are optics for extreme ultraviolet lithography this is one of the application; ellipsoidal mirrors for X-ray microscopy; at the same time focusing mirrors in the SR beamlines ok. These are the major applications of this particular elastic emission machining process.

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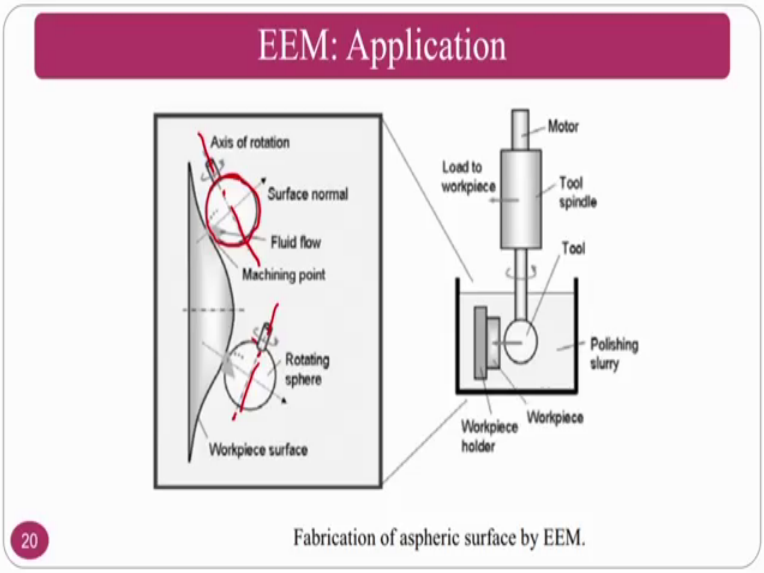

You can see here you have a lens with respect to the convex surface and you have to use your particular sphere that is nothing but polyurethane sphere in different angles. So, you have a x, y, z motion, swelling action and other things, normally you might have seen the three axes machines, five axes machines and other machines. So, you can use this type of motions to the spherical ball, then you can do at a different, different positions, different, different axeses will be maintained.

Here this is a axis, and this is another axis, where you are maintaining at that different axeses ok. When you can get the smooth surface, you should have always a perpendicular direction ok, a sphere will have always the perpendicular direction if you can orient properly ok. This is how you can do the aspheric surfaces by elastic emission machining process.

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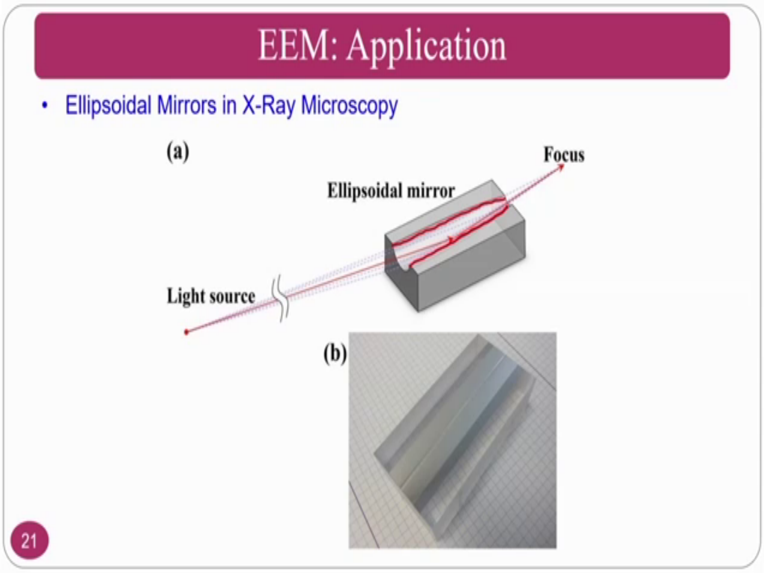

Ellipsoidal mirrors in X-ray microscopy you can do the finishing operation. We can see there will be a gradual change in the curvature, and this curvature can be machined by the elastic emission machining process.

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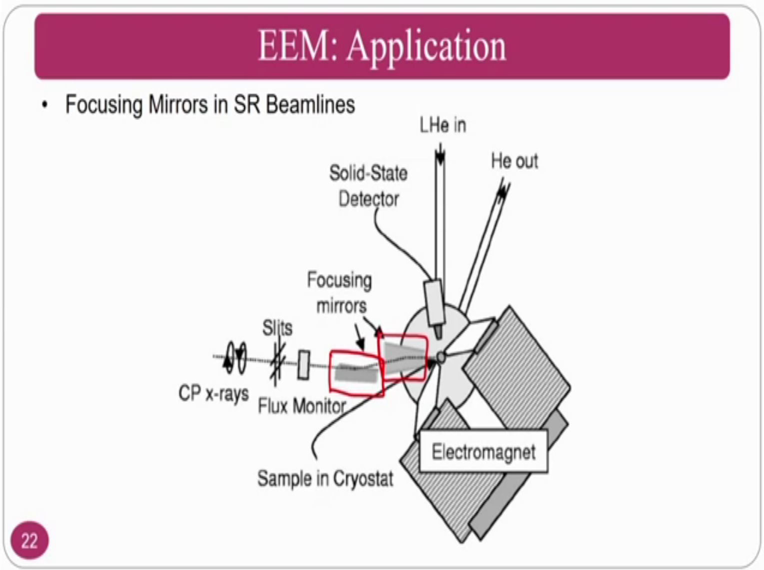

And the SR beamlines also if you see these are SR beamlines, these are the mirrors focussing mirrors are machined by elastic emission machining process ok.

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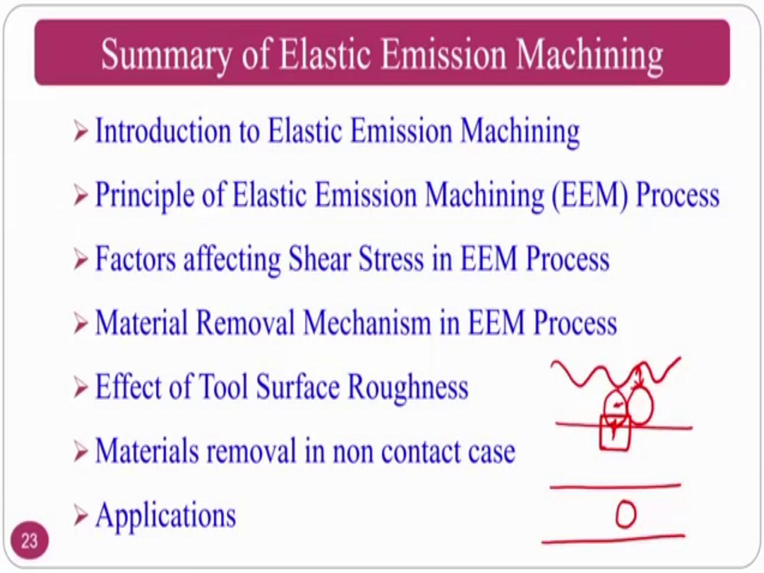

So, we will see the summary of this particular class. So, we have done introduction to elastic emission machining, then we have seen the principle, what are the factors affecting, what are the tool factors, what are the input parameters, what are the workpiece parameters, what are the slurry characteristics, these are all we have seen how the material removal is taking place.

We have seen that abrasive particles come near to the workpiece, but it would not touch the workpiece. And the OH bonds on the abrasive particles, OH bonds on the workpiece will interact and H 2 O will release the remaining oxygen will bind to the workpiece material and it will take away the atom, so that is how the material removal mechanism atom by atom will takes place without contacting the workpiece because of which you do not get any feed marks that normally you will achieve in terms of the mechanical processes.

So, effect of tool surface roughness if the surface roughness of the tool is very high, what will happen assume that this is my workpiece surface if roughness is like this, always you should maintain the abrasive particle gap should be more than abrasive particle size. If this is abrasive particle, what will happen at this particular location it may not touch, but if you come to this position what will happen it will touch. So, what will happen, it should always have a smooth surface. If you have a smooth surface like this and like this, if we have a particle size like there would not be any interaction. For that purpose the surface roughness of the tool plays a major role in determining surface roughness of the workpiece. If your surface roughness is poor what will happen some of the places it can scratch the surface. This particular location it will scratch the surface. So, you may get lines or the scratch marks on the surface. So, material removal in non contact type you have seen the three modes of material removal in the non contact case. And applications you have seen the lot of beamlines, lenses and other things and other places you will use this elastic emission machining process ok.

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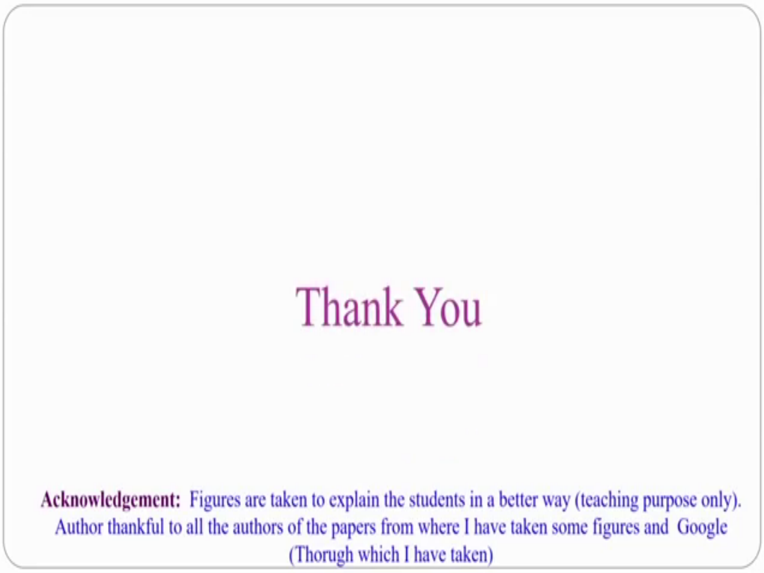

I am very thankful for your kind attention. And you should note that not only a mechanical processes can do the machining and finishing, you should also look into these type of advanced machining processes where the abrasive particles are not in contact with respect to the workpieces, but it can remove the materials. And the beauty about this particular process is you do not get a single scratch on the surface or single feed marks on the surface, because there is known depth of indentation as because of the abrasive particles are slightly ahead or the above the contact of the workpiece. Because of this non-contactness, there would not be any mechanical action, only the chemical action will be there.

Thank you.