Technology of Surface Coating
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Lecture 29
Mechanical, Chemical and Ion-Assisted Method

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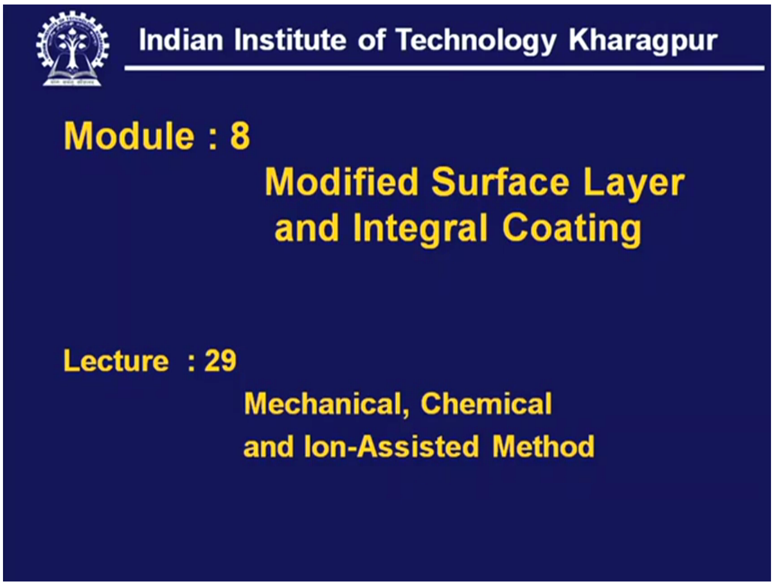

Modified surface layer and integral coating and in this what we mean that this modified surface layer in actual practice this is actually a change in mechanical characteristic of the surface layer which is mechanically functional and this is in particular important to the parts which are mechanically functional. So in this case emphasis is given on how to improve or increase and enhance the surface properties of this mechanically functional part?

That means the surface of this mechanically functional part, so this is modified surface layer the purpose just we have mentioned and integral coating. Now integral coating means it is not like the conventional coating what we mean? Conventional coating means that it is a separated layer well, it is very clear to reveal this thing and it is separate layer which can be deposited by various coating techniques and most of the materials are supplied from an outside source.

So in this case when we call it integral layer in that case actually there is no sharp demarcation line or separation line between the coating and the substrate rather this coating becomes an integral part and it is not that easy to distinguish it from the basic substrate, so this is exactly what we mean by modified layer and integral coating. Now this can be done, this surface modification or making developing one integral layer that can be done either by mechanical means or by chemical means or even by assistance of ion.

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So we shall go through this and try to understand various advantages demerits and the scope of, use of those processes. So number 1, what we can see? That here we give special emphasis to mechanically functional component, in fact in mechanically functional component on the surface we expect certain properties and characteristics and these are namely resistance to wear, resistance to indentation, resistance to scratching, resistance to oxidation, corrosion and so on.

A mechanically functional part it service like maybe affected by any of these 3 stated modes and life will be shortened and last but not the least for a mechanically functional component what is very important? The fatigue life, so it is submitted to some reversal stress or alternating stress and these components are processed by various mechanical processing technology and as an outcome of that in certain cases we find that the surface is not free of certain flaws and limitations and as a result of that this surface as a short fatigue life.

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So we understand actually in this case that this mechanical characteristics are mechanical property should be elevated or enhance by some process and here we can find out some of the process, so mechanically modified surface layer. How the surface layer can be modified?

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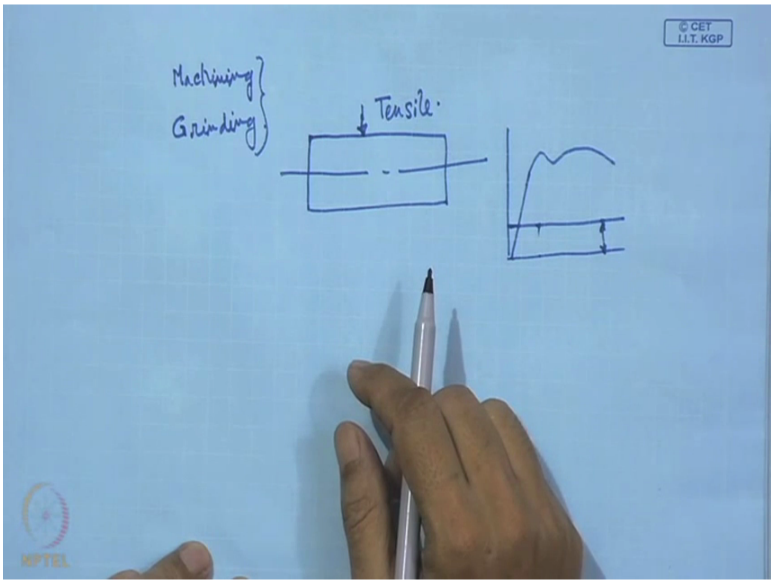

In fact what happens on a surface which is actually formed by machining or by grinding there are some grinding Mark or machining Mark, feed Mark this is number 1 and number 2 is that there can be also high residual stress because of the unequal cooling between the top surface and that of the core area that means high temperature gradient and as a result of that on the surface whether it is cylindrical or flat in that case on this surface, this is actually the functional surface, on this surface the residual stress is tensile, tensile stress.

Now if this thing is allowed to move and spin at the very high-speed, there will be reversal of stresses because of the external loading but because of this residual tensile stress on this graph what we can find out? On this graph we have already some stress is already stored, so the base line is shifted here. So this is a loss of strength of the material, now it is our objective to conserve this strength of the material that's why there must be some process of neutralising the tensile stress and also to induce some compressive stress.

So this is number 1 how we can do? Number 2 is that, if we have some cold working on this surface then there can be some strain hardening and as a result of this strain hardening surface hardness will increase this is number 2 and number 3 is that by this plastic flow of the material we can have a smoother surface and all sort of tear, cracks that can be suppressed by this plastic flow.

So we can summarize induction of compressive stress, suppression of the scratches or flaws by this plastic flow of the material then by this strength hardening we can also increase the hardness of the material and getting a smooth shining surface we can reduce the roughness and also the frictional characteristics. At least one can apply this concept to improve the surface property of this mechanically functional.

Now this can be a ground component or it can be a turn component it can be even a flat surface, a milled part or even a surface ground apart but the basic thing remains there that store it is actually the frozen tensile stress on the top surface which cools at a faster rate and compared to the core area and how to neutralise this stress which is tensile in nature and to make the situation favourable for application of this particular component.

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So one can look into this process shot Peening, actually in Shot Peening, what is done? On this surface with a nozzle this glass ball or steel balls or similar material having a size ranging from few fraction of a millimetre to few millimetres that is actually impinges on this surface. So here what is going to happen? That year we have this SOD stand-off distance number 1 then size of the ball, material of the ball, velocity with which it is striking the surface and also these incidents angle.

So all these will finally decide upon, what is the final outcome on the surface? So on this surface the first thing what we like to have? That improvement in the stress situation, so by this impingement or bombardment this surface will undergo some kind of plastic deformation and with this plastic deformation this compressive stress will be induced there can be some plastic flow of the material and as a result all this thing which were originally the shortcoming of a ground or a machine part those can be little bit neutralised and as a result of this Shot Peening we can get a favourable surface property over this.

So here these velocity materials, size of the ball, incidents angle that means the energy of impact all these things will decide what is the quality? And here the quality means actually to what depth we can have the surface modification? And it can be few millimetre to a fraction of a millimetre and this, one has to also control depending upon the application and so naturally precise control of this process parameter is also extremely important in this case.

So this can be done on either a cylindrical surface or on a flat surface and this process can be made useful for this improving the property, mechanical property of that machined the ground surface, so this is Shot Peening.

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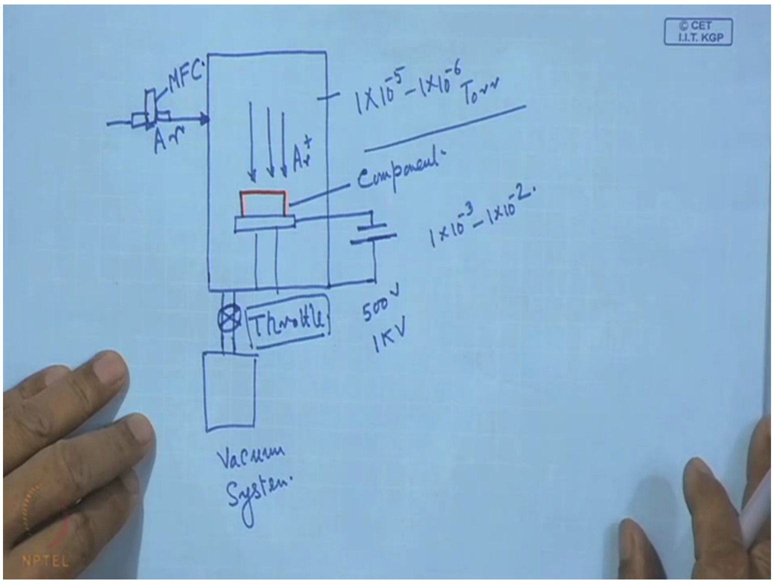

Now this Shot Peening can be also done in a plasma environment. So here we don’t use any ball of glass or steel, cast steel or glass, sometimes sand particles are also used but in this case the process is actually refined. This refinement means actually in this case we must have a vacuum chamber, this is an evacuation chamber and there we have the table and this table is for supporting the specimen which must undergo such kind of treatment and here what we have?

We have a vacuum system for evacuating, what we need to have further to this? That means here we need polarisation of this sample that means this will be connected to this negative polarity and the body can act as an anode or we can have one anode plate on the top also. So if we use this body as anode then what is going to happen?

And then what we have here? Entry of Argon, so what are the parameters which are very important in this case? That this Argon will be admitted and between this wall or a separate anode plate and this cathode there will be a gas discharge and that will be ignited and during and at the time of ignition what is going to happen? This negatively biased this actually component that will be bombarded by this Argon ion.

So this Argon ion will impinge on this surface and this will be accelerated by this negative polarity and this way it is possible also to have neutralisation of the stress it is much refined, we can control the depth of that deform layer, the thickness of the deform layer we can also have some dent formation on this surface. Sometimes it is also necessary to use this as the pocket for fluid for lubrication.

So there are various way of using this process but most importantly of is that first of all you have to evacuate with a pressure of 10 to the power of minus 5 to10 to the power minus 6 or that means it is free of oxidation, the sample is well protected then it will be backfilled with Argon to a pressure of 1 into 10 to the power minus 3 to 1 into 10 to the power minus 2 and there will be a DC excitation, it can be between say 5 volt to1 KV and with that it is possible to have this impingement of Argon ion over the surface.

Obviously here the process pressure, what are those things should be looked in? That means the flow rate of Argon which is controlled by one mass flow controller from this side, this is going to be a mass flow controller for Argon and in this side we have fine tuning of the pressure by this throttle valve.

So these are the peripheral elements around this vacuum chamber. So we have incoming Argon, properly controlled flow rate with MFC. We have here the throttle valve to control the pressure and what we have? A DC excitation and then this job is properly done. So this is a refined way of doing the thing, just by pinning in plasma environment or by the assistance of Argon ion this thing can be done.

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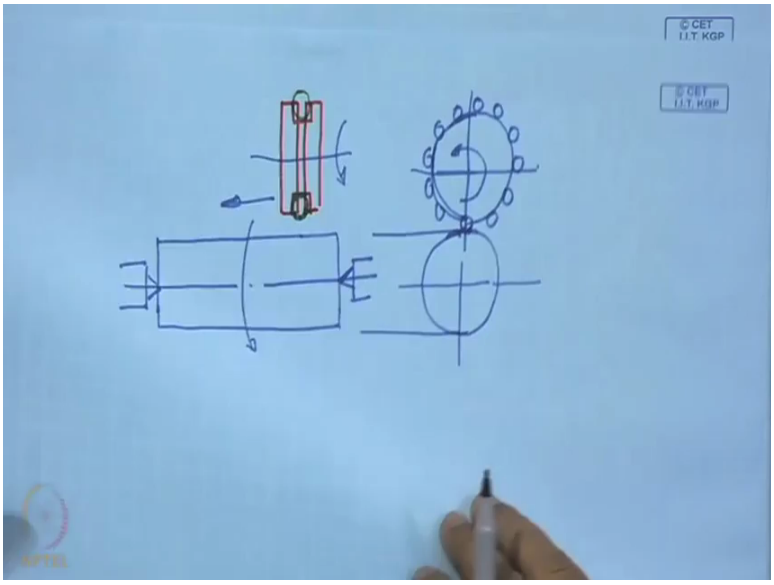

Now comes word mechanical process of ball burnishing, ball burnishing means here suppose if we have a cylindrical piece and on which we need to improve the property or the quality of this surface and then what we can do? Now this surface can be ground in a central in a cylindrical grinder this surface can be ground and after grinding we have to replace that grinding wheel with another wheel in the same spindle and this wheel has a different shape is actually looks like a disc.

So here what we have? We have a disc it is almost like a cage and over this, what we have? On these 2 sides that is the place where we can show the balls. So these are the balls, so if we see the in view then we can also have this projectional will view. So this is the end view and over that what we can see? This is actually a ball and this is going to be a disc and here the balls are retained in a cage.

So in that slot the walls are retained and they should not fall out, so this will have a rotation this is also having some rotation and at the same time translation. Now what happens? It is also, it rotates at that high-speed and this ball is pressed against this surface. Now while pressing against this surface it can do the necessary plastic deformation over the entire surface and that pressure is created by this centrifugal action because of this there is little clearance in that slot.

However during this high-speed rotation they will be thrown out by this centrifugal force and they will be held against this surface and as it moves on this side, this ball having this rotational motion and at the same time a translator emotion and with that it is continuously doing this mechanical work over the surface and this is basically a plastic deformation. So with this plastic deformation what we get?

It is almost getting a very smooth finish over this surface and at the same time by this plastic flow we can get a better finish those grinding marks can be totally suppressed through this deformation and more importantly in grinding the greatest problem of grinding it is actually the residual stress and that residual stress part can be well handled by this ball burnishing process and we can also achieve a compressive residual stress over this surface.

And obviously for this reason this shaft which is going to be a mechanical component in any application as a shaft as a rotating element having the alternating stress during one particular cycle of rotation and in that case the material property which is little bit gets deteriorated by this grinding action that can be recovered by this ball burnishing action through this plastic deformation and this inducing some of the compressive stress. So this can be done in the grinding machine itself.

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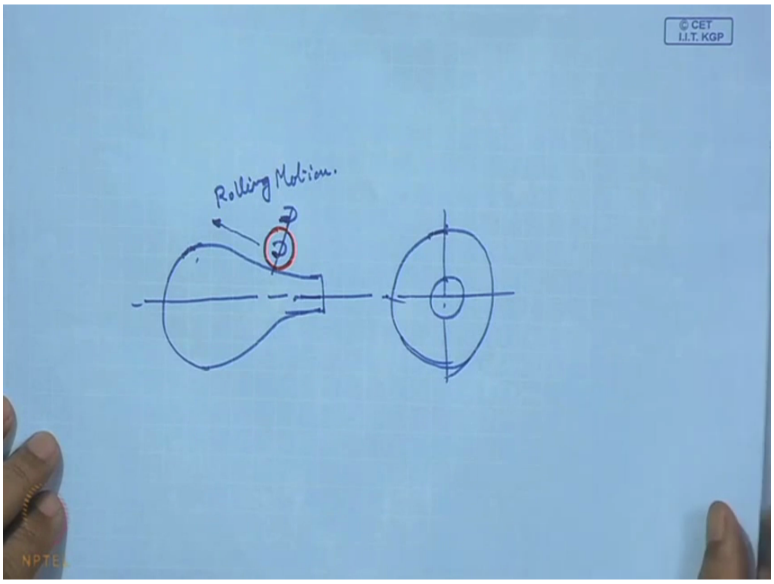

Now this ball burnishing can be also extended for improving the property of contoured surface, say for example we have a contoured surface with certain axis of symmetry and this is going to be in axis, so this is just like a symmetrical about this axis and here what we can conveniently put? And this surface can be contoured in a machine, in milling or in a turning whatever may be the case.

Now this surface need some kind of attention and modification, modification means in clear terms it is augmentation or improvement in the mechanical property like hardness removal of tear torn area scratches in and then regaining the hardness then wear resistance and smoothness and last but not the least a good stress situation on this surface.

So here we can also put one ball, so this is going to be a ball and this ball will follow this contour that means this ball has a rolling action that means this is actually a surface of revolution. So from this side what we can see? It is actually a large circle and also here we have a small circle and ball is somewhere positioned here.

It is a curvature; it is a continuous curvature and the ball is positioned here. So what it will have? It will have a rolling motion that means a rolling motion following this contour. So a rolling motion, rolling motion following this contour for this ball and at the same time it must also have another rolling motion over this Periphery. So it has to rolling motion one about the axis following one particular diameter and at the same time it is having another rolling motion over this following this contour.

So it has 2 rolling motion one is about this axis and another is about this axis. So with that we can also have perfect ball burnishing over a contoured surface and which is going to be at 3-D contour surface.

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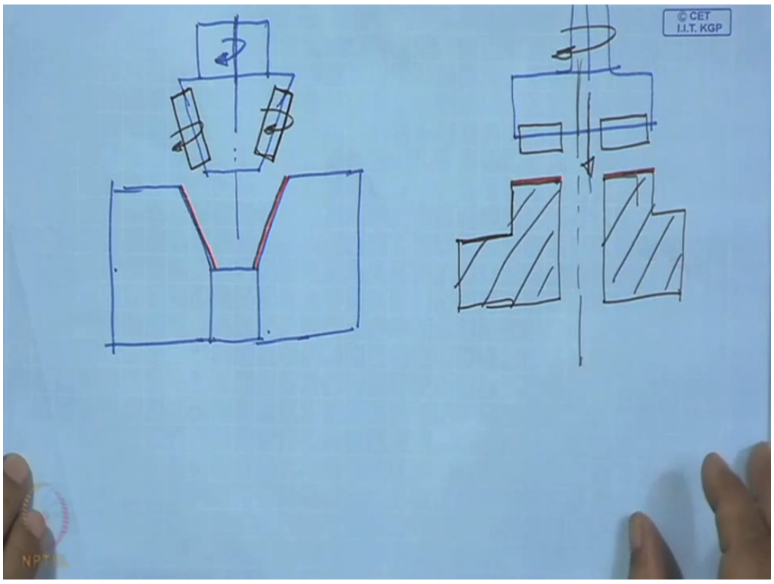

Now comes roll burnishing, now in roll burnishing the rollers are used and what we have seen? The use of the ball and in roll burnishing actually what can be its application? We can see here say we have the internal conical surface, it can be the valve seat, this is actually the valve seat and here what is important? One has to, so the valve will come over here and sit.

So these surfaces are the valve seat, now here during locking and opening that will be stress reversal, so these surfaces will have change of stress that means they will be submitted to some alternating stress and that means it is going to be a fatigue, so how to improve its fatigue life that is one consideration? And this can be well handled by one ball burnishing tool and it can be placed here something like this.

So this is like a spindle which is spinning at a very high speed and now we have here the rollers. So this, it is a taper surface, so that will geometrically they must match and fit properly, so this roller will spin and this is also going to spin and in that case we have roller burnishing over this entire conical surface, the whole idea here is to improve the fatigue character or the resistance to fatigue that elevation of that resistance to fatigue that can be remarkably improved by this roller burnishing action.

Say for example, another example this is also another valve seat, it is not conical but it is going to be a flat one. So this is going to be a flat one and in this case also we can see that a burnishing tool can be very effective. So here the surface of interest is these surfaces, these are the surfaces where the valve will simply rest and blocking the path and this way what we can see?

That this surface will be subjected to some change in the stress situation, what we have seen here? This is the surface of interest where we need some mechanical surface modification that means we have to deform this surface to change the stress situation to improve hardness by work hardening removal all those machining Mark and improving the oxidation resistance, corrosion resistance all those things.

So similarly here, what we can do? Rather conveniently using one such roller and this roller will have it is something like this, so this is one disc it is provided with roller and this roller can be put here. So it should cover these surfaces and this will keep on spinning over this and then by pressing in this direction, so these 2 surfaces immediately will be worked by this roll burnishing action and in that case we can remarkably improve the surface property of this particular zone of this machine component. So these are the 2 examples of roll burnishing.

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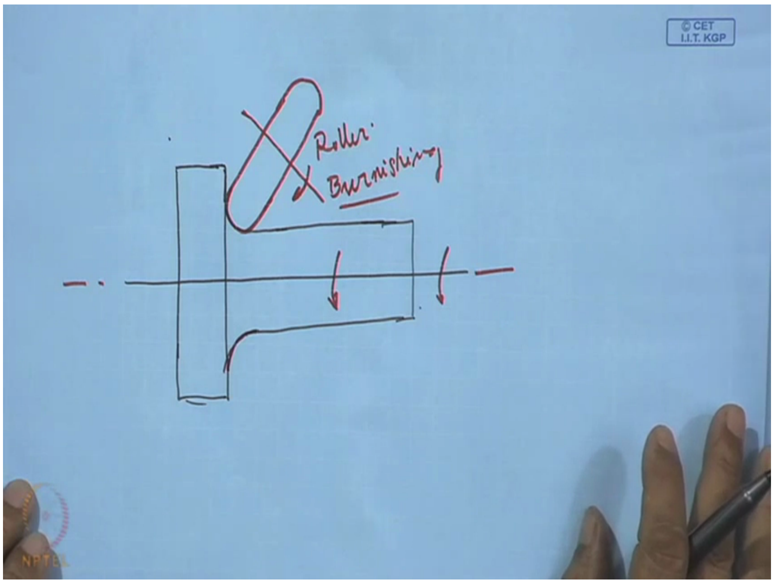

Another one also we can also highlight highlighting the importance of roll burnishing. Suppose we have one disc, it's like a collar it is a shaft with a collar at this end and here we must have filleting to avoid this stress concentration. However there is still scope of using this roller in this zone and this can be just here matching this curvature. So we can have one roller using this type of roller, of course it's geometry this thing should match with the fillet radius and this roller can spin and the job is also rotating, this way also these are the zone these are the very delicate area in the whole body because it is going to spin and in that case what we see?

That by this roller which is burnishing, by this roller burnishing process we can improve the situation here and making the part very safe and reliable that is one of the prime objective that means to improve the property, to augment the property in such a manner that the part becomes safe and reliable and have a longer fatigue life.

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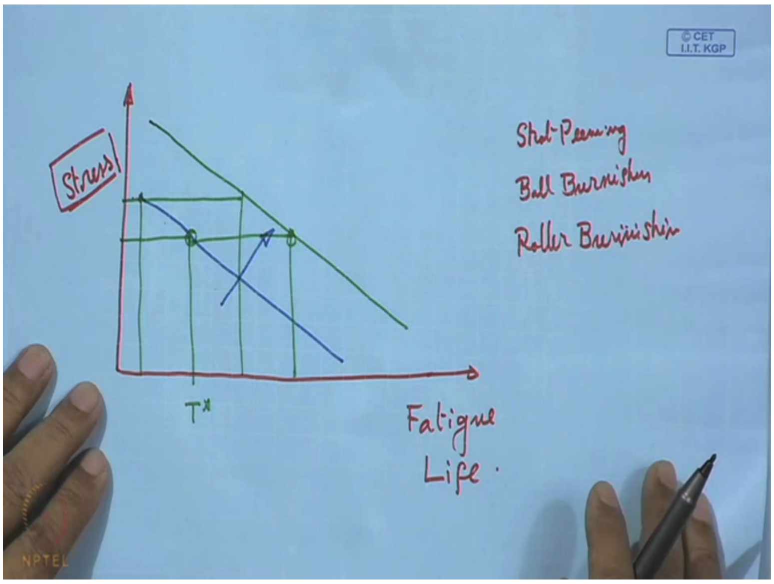

Now this thing can be well illustrated by one diagram. If we follow one diagram that means say on this side we have the stress, alternating stress which is not a steady one and on this side it is the fatigue life. So in proper scale log log plot just to give an impression that what we can do? We can get series of curve more or less following this nature, okay. So these are the curves, now what is our objective?

Why we do all sort of these mechanical working whether it is short spinning, roll burnishing or ball burnishing, the whole idea here is to shift this curve in this direction. In one sentence we can say that this is our sole objective, so what we can see? When we just mill or turn or grind a sample and maybe this one situation but when this process is followed by say Shot Peening or ball burnishing or roller burnishing the whole idea here we like to see that this curve shaped in this direction and that is a whole idea.

That means we can shift this curve, so by this shift what we mean? That we get not only a prolongation of the fatigue life but also higher stress, so if we limit our stress level here then we can have say for this, this is the life and now we have this life. Now for this fatigue life with this blue line this is the fatigue life and with this improve situation with this ball burnishing or roller burnishing or Shot Peening we can get a point here and that is actual elongation.

Or with the same life we can also increase the stress level which may we may encounter during mechanical application of this component which may be subjected to some alternating stress. So the basic idea here is to apart from all quality good surface finish, resistance to indentation, improvement in hardness through strength hardening, polishing of the surface that means corrosion resistance, corrosion oxidation resistance all these things we can achieve.

But what will be more important in this case? Is to improve the stress situation that means the unfortunate tensile frozen stress which develop on this surface that should be neutralised or if possible we can have a compressive stress over this surface just by either Shot Peening, ball burnishing or roller burnishing or if we like to have refinement of the process we can also use ion impingement, ion bombardment inside a restricted environment within by getting a plasma and with by immersing the sample in the plasma volume the Argon ion and we also brought in and we can get an effective result.

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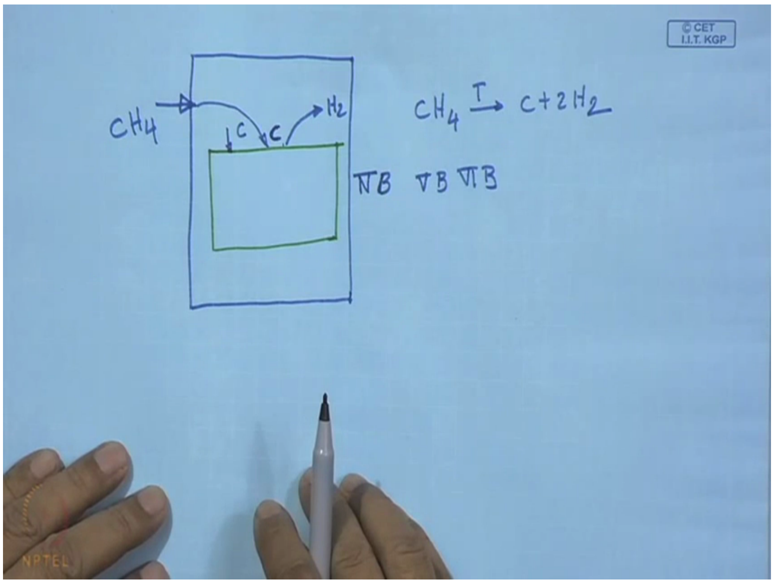

Now we go to this integral coating and here we have at least Carburizing and nitriding, these are the 2 well-known processes and the whole idea here is to have a surface and this surface should be enriched with carbon, this should be enriched with Carbon or Nitrogen. Now here in most cases steel, it will be that dissolution of Carbon in iron and once that gets saturated, what is going to happen?

If this steel have some material say which are Carbide former which are known for their property say group 4B, 5B and 6B all this Titanium, Vanadium, Chromium, Tungsten, Molybdenum, Niobium and so on, all these materials are known for their great tendency to form Carbide. So if those materials are present inside within the body then this Carburizing process will be one affective process to enhance the surface property and this is actually what we mean by carburising, so that is the whole idea.

Now in case of conventional Carburizing what is necessary? It is actually a thermally activated process, so thermally activated process means we must have one furnace and then reasonably we can put inside CH4, a stream of CH4 which will be thermally activated on this surface and depositing Carbon and leaving Hydrogen, so it is going to be a thermal decomposition and this will require certain temperature and also tendency of this elements which are present inside this sample, inside the specimen which has certain affinity to form this Carbide of that particular element.

Say it can be Molybdenum Carbide, Tungsten Carbide, Vanadium carbide it can be even Titanium Carbide or Chromium Carbide and they are known for their all elevated properties like hardness wear resistance. So on the surface reasonably we can get an coating which we cannot in that sense distinguish it from the substrate but it is almost like a transition and it is a part of the substrate just on the top surface the surface property different from that of the core.

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So this needs actually temperature, since it is heavily activated we need a temperature for Carbide formation and this may be 1000, 900 or 1100 depending upon the free energy of formation of any reaction. So Carbon Titanium, Carbon Chromium, Carbon Vanadium like that, so we have to look into those free energy data and from there we can find out what is the best temperature for this? So this is actually traditional Carburizing for conventional carburizing.

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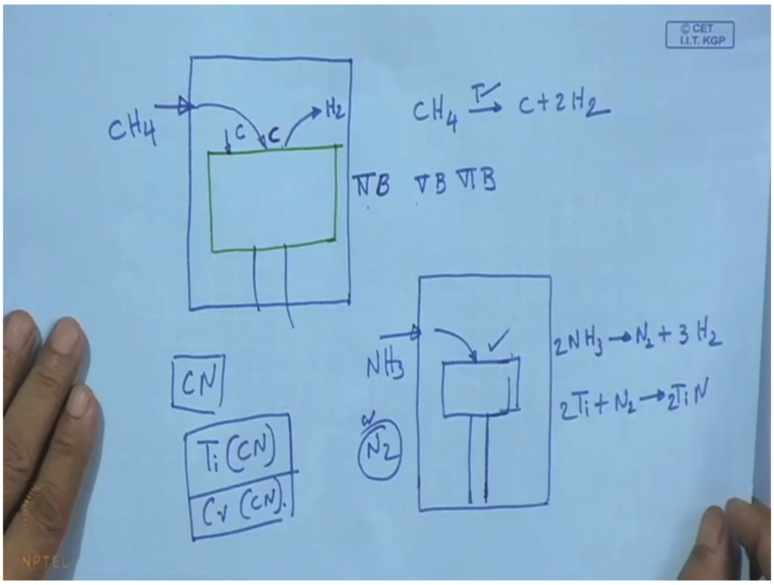

Now what we see here in this case? We can also have Nitriding, now in Nitriding what we see? That instead of this Methane what we can have? We can have say either Nitrogen or Ammonia or Nitrogen but it is also revealed that with NH3 the requirement of temperature can be brought down around 600 whereas when it is just Nitrogen it can be as high as 900 degree centigrade.

Again it is the same principle that when this materials have certain nitride former which are from group 4B, 5B and 6B transition elements from there we can also have this and NH3. So here also NH3 that will split into Nitrogen and also to 3H2 and this Nitrogen with Titanium definitely but is going to make one Titanium nitride. So in all these cases we have to look in that the temperature requirement it can be done also with Nitrogen alone but in the temperature will be quite high.

Whatever may be the case, what we need here? High-temperature, this is thermally activated. However this is carburising, this is nitriding but we can also have Carbonitriding the reason is as follows that in this case we need to take the advantage of both Carbon and Nitrogen, as we know from our understanding say for example if we consider say Titanium as the metal, as the metal donor then we can have Titanium Carbide or Titanium nitride or Titanium Carbon nitride in that.

So carbides are known for their hardness whereas the nitrides are more important in terms of anti-welding property or chemical stability and if we like to have some balance in between there we can also have a Carbon nitride coating. So in that case it is called Cabonitriding, only we have to have control quantity admittance of Methane and Nitrogen within this and maintaining certain pressure it can be in atmosphere or it can be below atmosphere. So with that we can we can also hope to get a coating of say Titanium carbonitride or Chromium carbonitride and so on.

So in this case the whole idea is to have a balance between Carbon and Nitrogen, so that we have an optimum mixture of both metal Carbide and metal nitride which can give some of the best performance in very specific application. So these are actually conventional Carburizing and conventional Carbonitriding.

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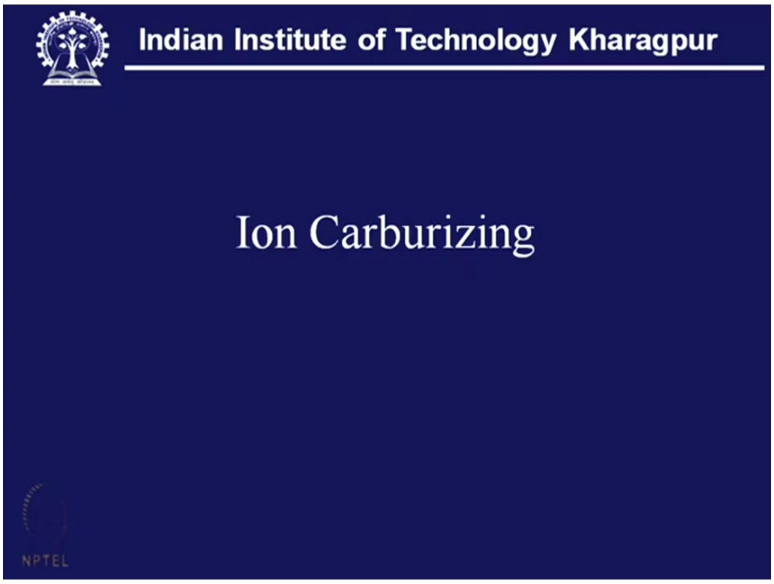

Now this is actually ion carburising. So we call it ion assisted carburising, now what we have seen so far that it is not the question of carburising, it is a question of high temperature. Now when it is a high-temperature many of the (()) (44:19) may undergo some kind of thermal deformation or even distortion geometrical distortion and certification also becomes a problem.

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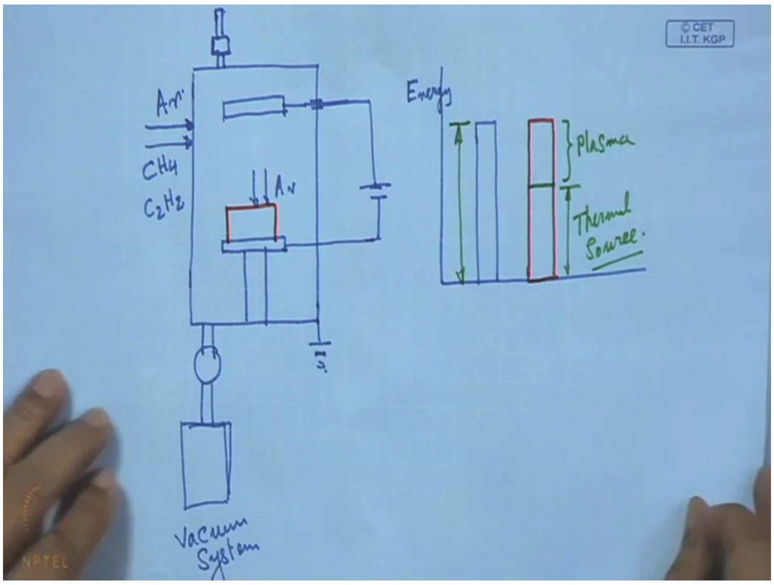

So naturally how to get rid of such limitation and for that it is ion assisted Carburizing that means the whole operation has to be performed in a closed in a restricted atmosphere and restricted atmosphere means here what we see it is actually a vacuum chamber? So in the vacuum chamber we have the table for supporting the substrate, this is a substrate material and what we have here?

Flow of Methane or flow of, it is a source of Carbon and then what we need? We have a vacuum system with all sort of peripheral supports, vacuum system we have also one pressure sensor here which can be monitored and then it is a close metering and what we have in addition to that? We can have one anode plate here or the valve can be anode but if we can put it in the ground and then we can put this thing, it is isolated and this is actually the anode and this is the cathode, it is a floating anode it has nothing to do with this chamber which is already grounded.

Now what we are going to have in this place? We have ionisation of this Methane and in that case what is going to happen? First of all we have to evacuate the whole system, first of all we have to evacuate and then if we like to have some cleaning of the sample and that is the greatest advantage we can also have a discharge of Argon and by that with this negative polarity we can have also Argon, incoming Argon with that we can clean this substrate followed by admittance of Methane and then with this discharge of Methane what is going to happen?

On the surface this will split and then Carbon will be deposited and Hydrogen will be released as neutral finally and since this is plasma supported, plasma enhanced or assisted we can reduce this temperature. So this we can illustrate it, illustrate here by this diagram, this is the total energy requirement. Now to conduct some process this is the total energy requirement and this we can show in another way that means this is another bar diagram.

So here we can show one borderline, so what we are showing here? That in this case the whole thing is plasma activated and it is the temperature through this particular temperature at a level we supply the internal energy requirement is met. So this is normal Carburizing process but here plasma activated. So we can understand that this comes from this plasma and this is actually thermal source.

So with this, what we get? That we can reduce the requirement of the temperature and it is actually basically the principle what we use? The system, what we using sputtering that same apparatus can be used in a very intelligent manner and what we can have here? That just by reducing the requirement of this temperature the whole process can be conducted in the range of 200 to 300 degrees centigrade and with all new power supply devices it is possible to hold the temperature in a range where this component which are made of steel they will not undergo any distortion.

And it can be taken just as a finished product and that can straightforward undergo this carburising, ion assisted Carburizing process without having any metallurgical damage or any mechanical damage, mechanical property, metallurgical damage, geometrical distortion, residual stress problem all the things are taking care of by this process.

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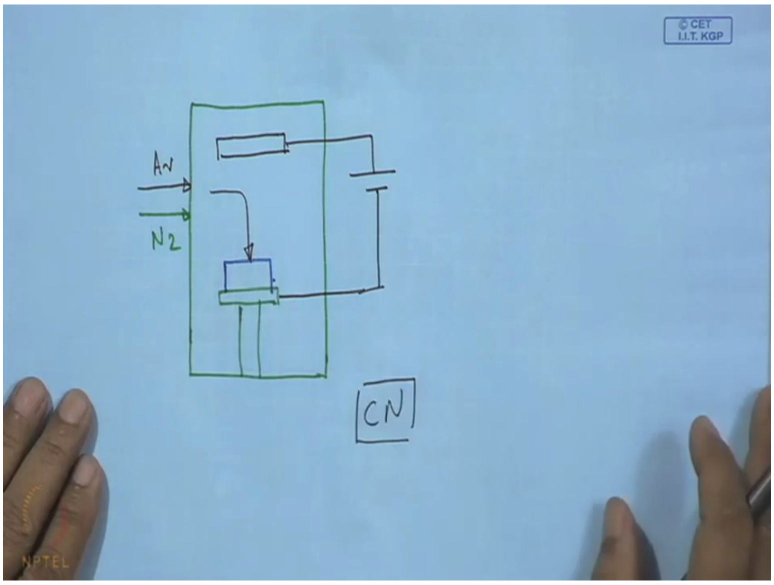

So similarly following this we can also have what we call what we call plasma nitriding and in plasma nitriding we have here just in place of CH_4 we have N_2 this is going to be the substrate holder that means the sample, here we have the sample and then we have here one anode plate maybe placed and this body and these are constitutes, this cathode, this is cathode and this is anode and what is going to happen?

As usual we can put also Argon and then Nitrogen, so with Argon all these cleaning can be done and with Nitrogen actually the nitriding that will be conducted and in this case it is also possible to hold the temperature in the range of 200 to 300 degrees centigrade and without having any problem of metallurgical damage, deterioration of the property or even any surface flaws generation.

So it is going to be a process which can be applied on any finished product and after this process, no further treatment no further finishing that is necessary and this is one convenient way of using this process particularly for those materials which are sensitive to temperature and this temperature is very critical in that, in normal nitriding or Carburizing processes this temperature becomes very critical and we may not go to the temperature and the process is limited to very specific or some of the not so precision samples or precision parts but with this advent of ion nitriding and ion Carburizing it is possible to improve the surface property of various components which are temperature sensitive.

Now with this nitriding and Carburizing it is obvious that with this processes we can also have carburising, Carbonitriding of the substrate that means CN we can also produce. So it is actually plasma enhanced process and in this case the plasma actually supplies the energy and thereby reducing the requirement of that high-temperature. So with this, what we can say? We have covered ion nitriding.

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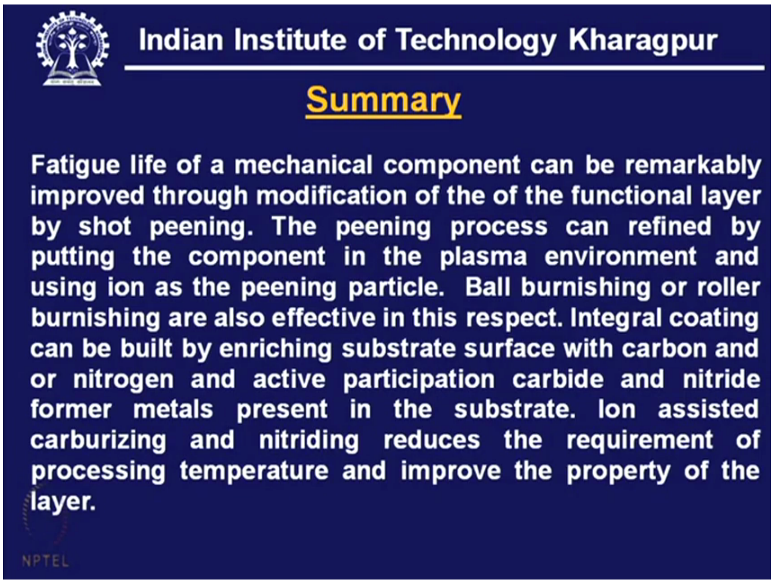

So what we can summarize here that particular information you component can be remarkably improved through modification of the functional layer which Shot Peening. Now this is actually the most important focal point because it is the fatigue life one would be interested but apart from resistance to indentation, resistance to wear then good surface finish, resistance to oxidation, resistance to corrosion those are also achieved but we give special emphasis to this fatigue life.

Now this Peening process can be verified by of Argon inside a plasma environment and it is very closely controlled, so naturally a layering within few microns that can be also possible. Now ball burnishing or roller burnishing are quite effective and these are used in mass production, this can be used in mass scale production of mechanical components and integral coating can be built by enriching the surface with Carbon or Nitrogen and in this case of course active participation of those Carbide or nitride forming elements are essential.

Now when this Carburizing or nitriding processes are ion assisted we can reduce the requirement of the processing temperature than the use of consumption of the gases can be also low, cycle time will be also low and last but not the least because of this low-temperature and because of this ion impingement we can make a good surface layer with a close control and within few microns as if it is necessary and with all the required property in an improved manner.