Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations
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Lecture-28
Surface Modification Techniques: Controlling Surface Metallurgy III

Hello, I welcome you all in this presentation related with the subject fundamentals of surface engineering and you know we are talking about the different surface modification techniques which are used for improving the surface properties. So, that they are wear resistance and the performance in terms of the mechanical properties can be enhanced and as you know that there are 3 broad categories of the surface modification techniques.

One is where only the surface metrologies modified the second one where the chemical composition of the surface layer is modified and third one where the liquid where the metal of the required properties is applied or the materials of the required properties is applied on the surface of the component whose properties are to be improved. So among these 3 headings we are talking about the first approach where primarily the surface metrology is modified through the application of the force or through the application of the heat.

So, that the required structural modification can be achieved in order to have the required set of the mechanical properties which in turn can help to improve the mechanical performance and under this approach we have talked about the few techniques like induction hardening, laser hardening, flame hardening

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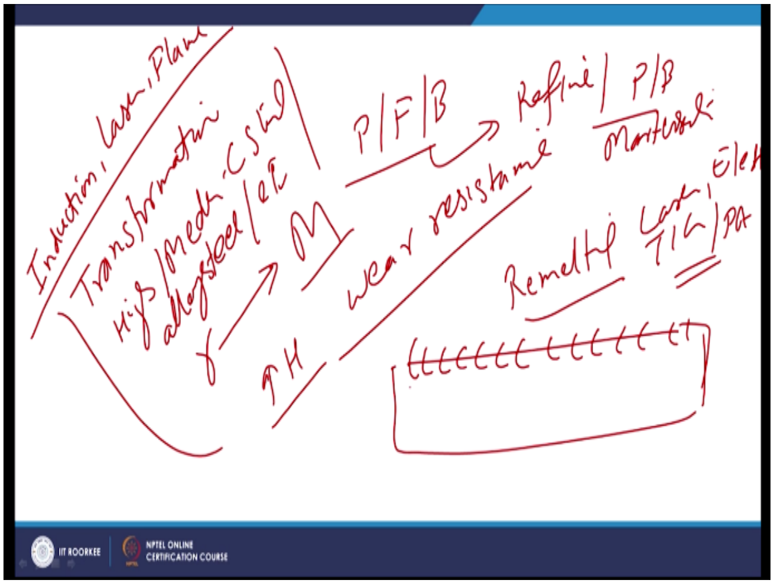

And likewise we can use a TIG hardening or the plasma hardening. But the basic principle in all these hardening processes is based on the transformation hardening wherein high or medium carbon steel or alloy steel or cast irons are subjected to the localised heating of the near surface layers. So that required transformation for austenite to the martensite can be achieved.

In order to have the better improve the hardness and so the required wear resistance can be enhanced this and in this case no change in chemical composition is achieved only the surface structure is modified from the soft phases like ferritic, pearlitic or benedict to the like refined pearlitic or benedict or the martensitic. So, these structural transformations help in improving the hardness and which in turn helps to improve the wear resistance.

There was another category of the methods where the melting is used surface layers are brought to the molten state followed by the rapid cooling due to the self quenching leads to the refined grain structure and this kind of method was like re-melting of the surface layers. And this primarily achieved through the use of the laser or electron beam or we can use TIG ark or the plasma ark also.

So, in these cases the primary purpose is to melt up to the required depth which maybe like 1mm or 0.5mm or 1.5mm as per requirement followed by the rapid cooling of the molten metal results in the both grain refinement as well as the transformation hardening. So, these were the 2 category of the methods about which we have talked.

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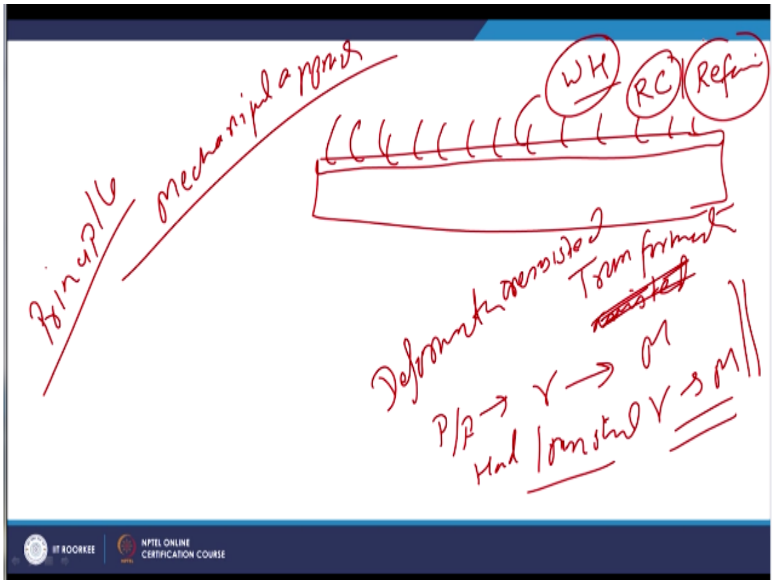

In addition to this we have also talked about the principle of the surface modification using the mechanical approach wherein the surface layers are subjected to the localised application of the forces at the surface. So, that the near surface layers are deformed plastically and this plastic deformation at the surface layers causes the work hardening, sometimes re-crystallisation of the grain growth, grain refinement, refinement of the grain.

And then deformation assisted transformation is achieved and in this case primarily whenever the deformation happensm whenever the material is deformed in very localised manner. The soft phases like perlite or ferrite they transform due to the heat generation in the austenite and followed by it transforms into the martensitic. And sometimes even like in had field steel or high manganese steels wherein the austenite transforms into the martensite.

So, there can be the deformation assisted transformation in some of the category of the steels. So, in case of the mechanical based approach where localised plastic deformation is use to enhance the surface properties, work hardening, re-crystallisation, grain refinement and sometimes even the transformation hardening also helps to improve the properties and under this category we have 3 methods.

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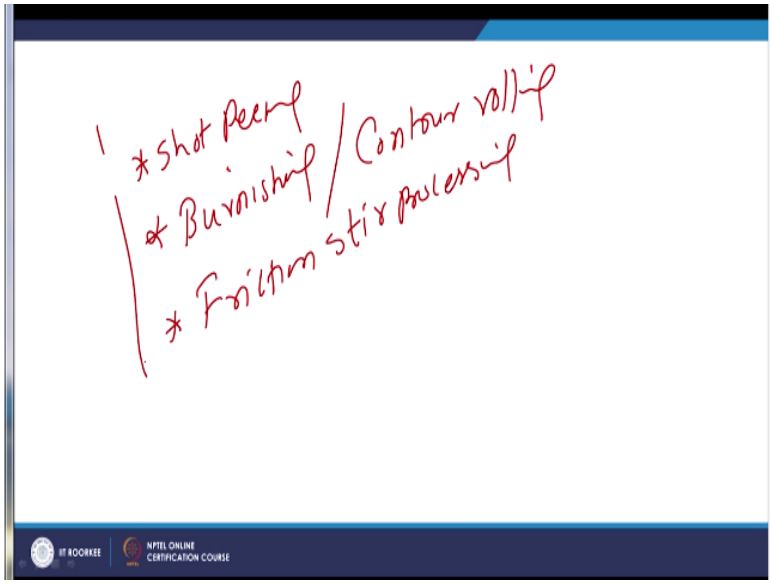

There is one method which is called shot peening, second method is burnishing and similar kind of the method is also contour rolling both methods work are of the similar kind and third method is the friction stir processing. In all these 3 methods controlled surface layer deformation is achieved.

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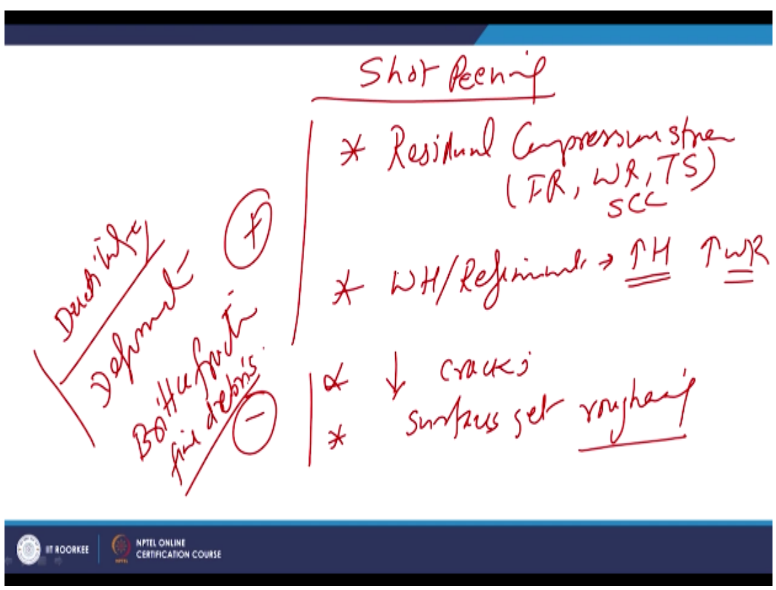

So, now one by one I will be talking about all these methods, the first one is the shot peening, so shot peening the main objective of this approach is to develop the residual compressive stresses at the surface. So, that the fatigue resistance, wear resistance and the tensile properties in terms of tensile strength can be enhanced, this also helps to enhance the stress corrosion cracking resistance. So, this is one of the main objectives.

At the same time whenever the shot peening is performed near surface layers get deform. So, they will so apart from the work hardening due to the surface layer deformation, sometimes the grain refinement helps to increase the hardness of the surface layers and this improves the wear resistance. So, these are the 2 main objectives, but sometimes apart from these 2 favourable effects, we may find unfavourable effect with regard to the development of cracks.

If the material is having the limited ductility and subjected to the severe shot peening or so these cracks can cause the premature fracture, if they are not taking care of properly and there can be another unfavourable situation where surface may get roughened, surfaces after the shot peening may get roughened. So, roughening of the surface can take place, so that also needs to be taken care of.

So, these are the positive effects and these 2 are the negative effects, so we must be careful with regard to the negative effects also whenever the efforts are made to enhance the surface properties for improves mechanical as well as wear performance through the shot peening and it cannot be applied to all category of the methods especially the materials which show some kind of the ductility and the deformation tendency at the surface only those are subjected to the shot peening.

If the material is having very limited ductility like 1%,, 2% in that case shot peening will be causing the brittle fracture onto the surface. And removal of the material in form of the fine debris through the development of fine cracks and their propagation will be leading to the removal of the material in form of fine debris. So, impact wear may occur in that case if the material is having very limited ductility. So, this may not solve any purpose, how it is performed.
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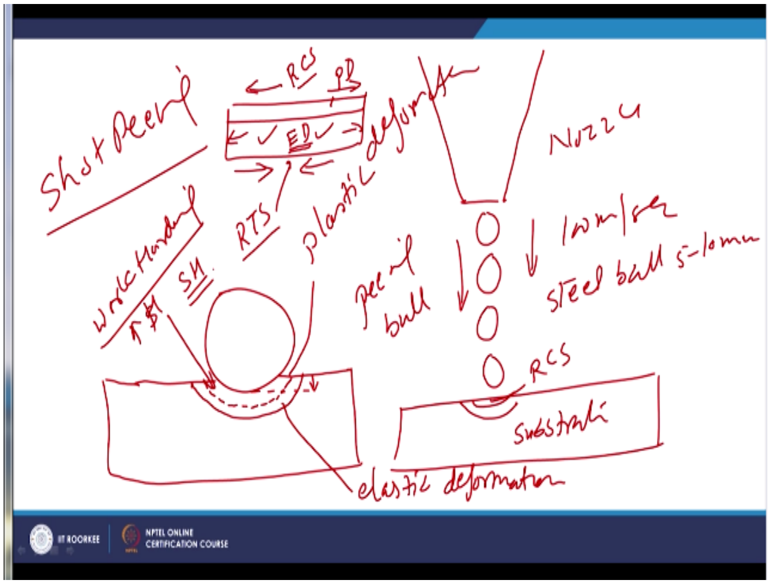

So, for shot peening basically we use nozzle through which the steel balls are accelerated at high speed like say up to 100 meter/second, the steel balls of 5 to 10mm in diameter are accelerated to the high speed and they are directed towards the surface for impingement. So, the impact of these balls with the surface causes the surface layer deformation like say this is the substrate, this is the shot peening nozzle.

And these are the shot peening balls which are being directed, whenever these balls impact onto the surface of the substrate we will see that the plastic deformation of surface layer is taking place, if the material is showing enough ductility. So, whenever there is impact there will be indentation up to this much depth, at the same time surface layers up to certain depth will be subjected to the plastic deformation.

So, this zone, first zone is the plastic deformation just below the surface which will be experiencing the plastic deformation and below that there will be another region which will be under the effect of the elastic deformation. So, once the ball impacts to the substrate plastic deformation takes place and coupled with that the near surface layers near sub surface are also subjected to the plastic deformation.

So, the 2 type of surfaces are generated like this, the top surface will be under the influence of the plastic deformation and below that it will be under the elastic deformation. So, plastic deformation which has been elongated under the effect of impact and while the one which is under the elastic deformation will also be strain. But the layer which is further below the surface that will which and under the elastic deformation, this will try to regain it is dimension once the impact is over.

So, this sub surface layers will try to this sub surface layer which is under the elastic deformation will tend to come back. And this come back will be resisted by the plastically deformed material and therefore the surface layers comes under the residual compressive stresses while the 1 which is under the elastic deformation because it is come back is not a permitted as it is metrological connected and join with the surface layers which are under the plastic deformation state.

So, the sub surface layers which were under the elastic deformation condition, they will be under the tensile residual stress condition, it is always favourable to have the residual compressive stresses as compare to the residual tensile stresses even if the residual tensile stresses are present. But if they are below the surface the not much of the damage that they will be able to cause.

So, adverse effect will be limited, if the residual tensile stresses are present in the sub surface zone. So, this is how the shot preened components will be able to have the residual compressive stresses at the surface. Since these kinds of stresses are being developed due to the plastic deformation of the near surface layers, so whatever layers are being deformed plastically they will be strain hardened or work hardened.

So, this kind of work hardening will be leading to the increase in the hardness due to the strain hardening effect. So, greater the plastic deformation, greater will be the number of dislocations which will be generated at the surface which in turn will be making the deformation of the material further difficult and that is why we say that there is a increase in the surface layer hardness.

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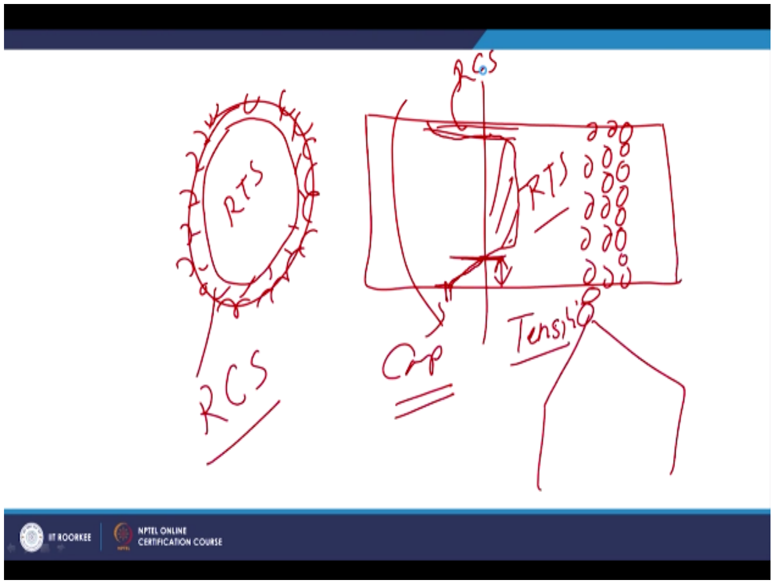

So, these 2 things which will be happening when the shot peening of the surface components is performed, let us say when a cylindrical shaft subjected to the shot peening like this with the help of suitable nozzle. So, the component which is rotating and the balls are being shot onto the component or in the substrate at regular interval, so the entire surface from all around will be subjected to the shot peening like this.

And accordingly the impressions onto the surface will be formed, so if we will see all around the circumference the shot peening will be done. And in this scenario if we will try to see any section for it is a residual stress present then the surface layers all around the periphery like this surface layers all around the periphery wherever the shot peening has been done this will be under the residual compressive stress effect, while below that it will be under the residual tensile stress.

And if this distribution will try to plot in the front view, in the cross section because this is side view showing the circular cross section, in the front view it will be simply rectangular shape for the cylindrical shape. And if the residual stress distribution in this case is seen, then we will see the residual stresses are maximum of the surface of compressive nature, then it is magnitude will keep on decreasing below the surface.

And then it will become tensile then it will remain tensile up to certain depth then again it will start becoming compressive as soon as it approaches to the surface like this. So, residual compressive stress magnitude will be maximum at the surface and gradually it will keep on decreasing and up to certain depth. So, this is the zone which will be under the effect of the residual compressive stresses, this zone is corresponding to the compressive stresses.

And this zone is corresponding to the tensile stress, so the core of the component of a shaft will be under the residual tensile stress and the surface layers will be under the residual compressive stress which is favourable from the mechanical performance point of view.

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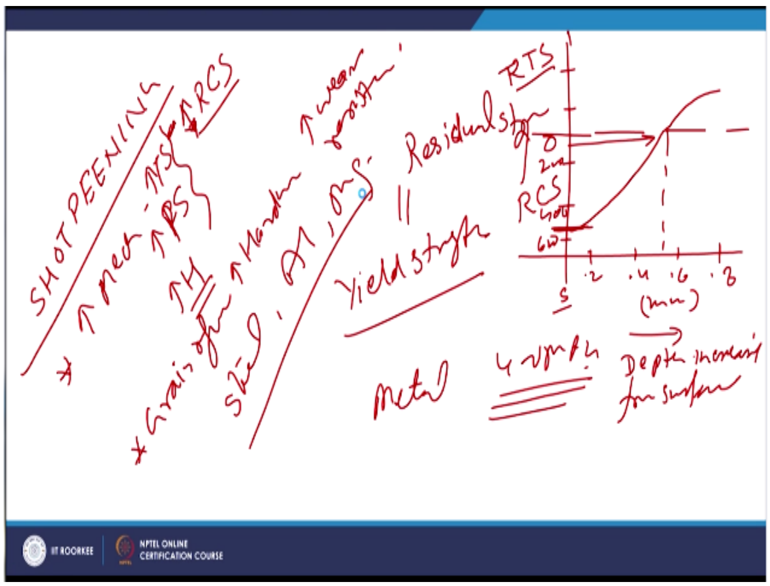

And if we try to see the depth up to which the kind of stresses as for typical example then the depth up to which the residual stress magnitude is affected residual stress. We know the residual stress magnitude can be maximum equal to the value of the yield strength of the metal. So, if the metal for metal yield strength is 400MPA then this will be the maximum magnitude of the residual stress which can be generated.

If the residual stress magnitude is greater than this and the plastic deformation will happen and the residual stress will be relieved or will be eased out. So, the residual stress magnitude in any case will not be more than the yield strength of the material. So, depending upon the kind of the material which is being considered will see like 0.2, 0.4, 0.6, 0.8mm increasing distance this is the surface in increasing depth.

So, depth increasing from the surface and this y-axis is showing the residual stress magnitude. So, this is the 0 reference level because at the surface will have compressive residual stress and below the surface will have the tensile residual stresses in case of the shot peened components. So, if that is what size try to see then the 0 at the level where transition from the compressive to the tensile residual stresses, residual stresses taking place.

So, this side will have the residual tensile stresses and this side residual compressive stresses. So, if we have like 200, 400, 600 as per the material which is being shot peened whether it is yield strength is 400MPA, 200MPA or 600MPA and accordingly the residual stress magnitude at the surface will be vary and this is how residual stress magnitude will be changing.

So, maximum residual stress magnitude occurs at the surface then it will keep on decreasing below the surface and up to certain depth it will remain compressive. So, this is the depth in this particular case say depth up to which the residual stress magnitude is compressive, residual stress nature is compressive and beyond that it is tensile in nature. So, further below if we will be going then it will be tensile in terms of the nature of the residual stress which is being generated.

So, this is how we can see that the shot peening, shot peening helps to improve the mechanical performance in terms of the tensile strength by developing the residual compressive stresses at the surface. And this in turn helps to increase the greater tensile load and the greater fatigue resistance, this helps in improving the tensile strength as well as the fatigue strength.

Surface layer deformation also increases the hardness of the material, on the other hand the associated grain refinement increase in hardness both these help to increase the wear resistance of the material. So, whether the material is of the steel or the aluminium, magnesium most of the components when they are subjected to the shot peening will find the improvement in mechanical properties and the improvement in wear resistance.

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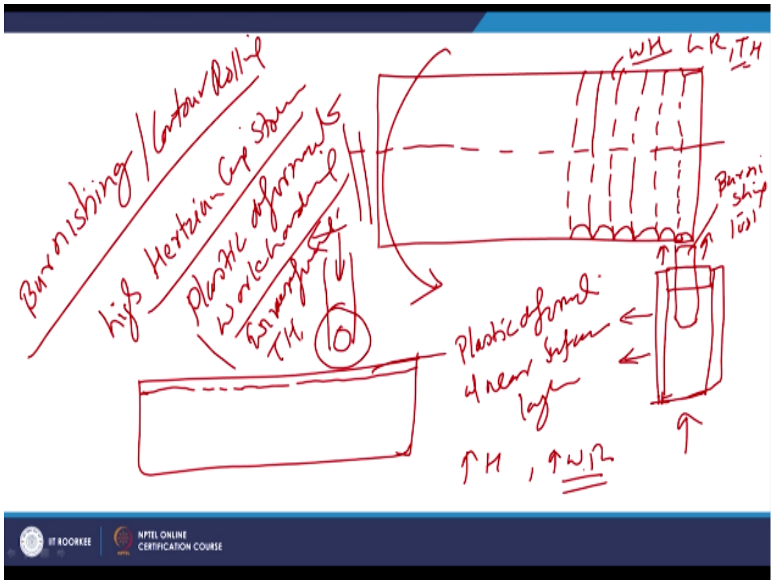

Now we will take up the another mechanical deformation or the mechanical approach of the surface modification which is like burnishing or contour rolling. Burnishing and contour rolling both processes work by and large in the similar manner like for burnishing purpose the component subjected to the like say this component is to be modified using the burnishing process.

So, the component is say mounted on the lath sack and then it is rotated then we use a burnishing tool like this burnishing tool this manner and this is rotated when it comes in contact with the substrate or the workpiece and then this is connected with some holder like this. So, this entire assembly is pressed towards the substrate, so the burnishing tool this is burnishing tool, burnishing tool is pressed against the rotating workpiece.

So, it deforms all around the periphery of the rotating work piece, so all this area will be subjected to the surface layer deformation, by pressing the burnishing tool against the rotating substrate or the work piece. There can be another way wherein the roller like this under pressure is moved over the surface of the substrate. So, substrate surface is flat and this burnishing tool is moved over the flat surface.

So, that it causes the localised plastic deformation of the near surface layers. So, basically idea is to have the plastic deformation of near surface layers with the help of this simple rounded tool which simply causes the surface layer deformation by applying the localised stresses. So, likewise the burnishing tool once it is pressed against the rotating workpiece or the substrate then it is moved longitudinally parallel to the axis of the rotating workpiece.

So, that entire length of the workpiece or the substrate can be burnished, so when since in this case of the burnishing localised surface layer deformation of surface layers is achieved by pressing the burnishing tool against the substrate. So, that the required effect of the work hardening and the grain refinement and it if at all any transformation is taking place then the transformation hardening benefits can be exploited for enhancement of the surface properties.

So, now we will see schematically what happens whenever the burnishing tool is pressed against the rotating workpiece or on the flat surface of the workpiece. So, under the load when burnishing tool is pressed against the sub surface of the workpiece high hertzian compressive stresses are generated at the surface and this in turn causes the surface plastic deformation.

And this plastic deformation leads to the work hardening of the material as well as sometimes even the grain refinement and transformation hardening is also observed. If the material is having the tendency for the deformation assisted hardening and these factors in turn will increase the hardness will increase the wear resistance of the material.

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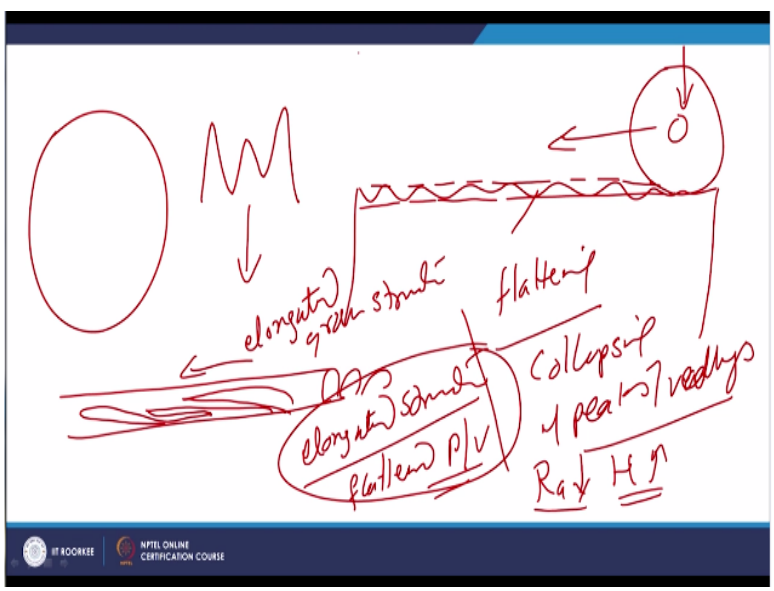

Now we will see like how does it work if we are having the all surfaces will have peaks and valleys like this and a burnishing wheel will be moved under pressure over the substrate. So, whenever the tool moves over the surface all these peaks and valleys are flattened and they will collapsed. So, flattening and collapsing of all these peaks and valleys is ensured by the burnishing tool.

And once the flattening and collapsing of these peaks and valleys take place, so all these peaks and valleys which were like this after the burnishing they will get flattened like this. So, all the peaks and valleys and the near surface layers will have the grain structure which was equated like this will be elongated grain structure in direction of the burnishing.

And this is also the sign of the plastic deformation which is taking place. So, as a result of this at the surface we get the elongated structure and also we get the flattened peaks and valleys. And because of these 2 what we notice that surface roughness has been reduced and the hardness has been increased. So, these are the 2 main effects which are observed when burnishing using the large diameter the burnishing tool or the contour rolling is applied both will have the similar kind of the effects.

So, now here I will summarise this presentation in this presentation basically I have talked about the techniques where in the mechanical stresses are used in very localised way for ensuring the surface layer deformation. So, that the improvement in surface hardness and the surface properties can be achieved for enhanced tribological life, thank you for your attention.