Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-30
Surface Modification Techniques: Changing Surface Composition

Hello I welcome you all in this presentation related with the subject fundamentals of surface engineering and so for we have talked about the various mechanisms that leads to the wear of the material from the functional surfaces. And then various properties which are important from the controlling wear as well as the, what are the materials which can be used for improving the uh wear resistance, also we have talked about the one category of the surface modification techniques.

So, where in only the surface metallurgy is changed for improving the surface properties. So, that the wear resistance can be enhanced. So, what we have seen that how just by changing this surface metallurgy using the application of the heat or application of the localized stresses.

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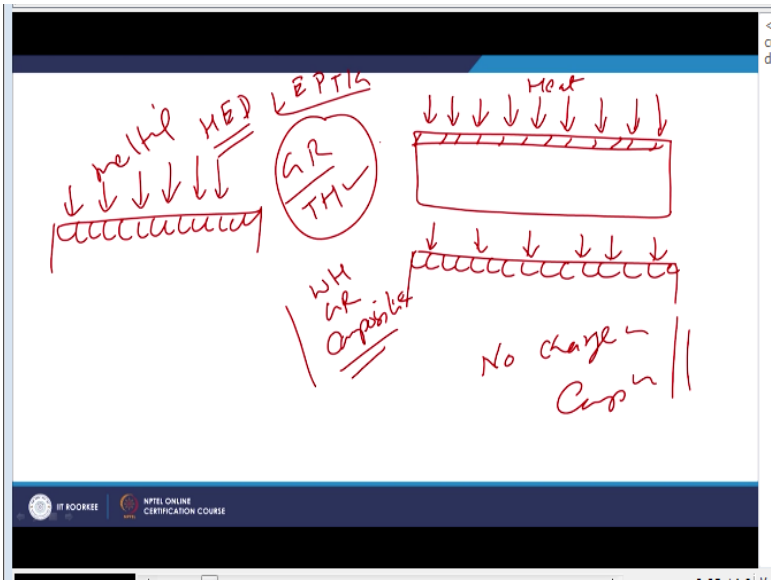

We can change the surface metallurgy for developing the wear resistance surfaces so, in one of the category where we have applied heat for changing the required micro structure in form of the Grain refinement or inform of the transformation hardening. And in another category what we

have seen that application of the localized stresses at the surface leads to the surface layer control surface layer deformation.

And which in turn increases the hardness and the wear resistance through the work hardening approach through the grain refinement and sometimes even by developing the composites using the reinforcement reinforcing agent at the surface. So in both these techniques there is no change in chemical composition and in one more category what we have seen that controlled melting of the surface layers helps to refined the grain structure as well as it also helps to refine the sometimes it helps to achieve the transformation hardening through the melting based approach.

So in these in all these cases I means especially in this particular approach we use the high energy density source like laser like electron beam, like plasma or even or can be used for control surface layer melting. So, that by high cooling rate the Grain refinement is achieved and in some of the cases as per the hardening ability of the material transformation hardening is achieved.

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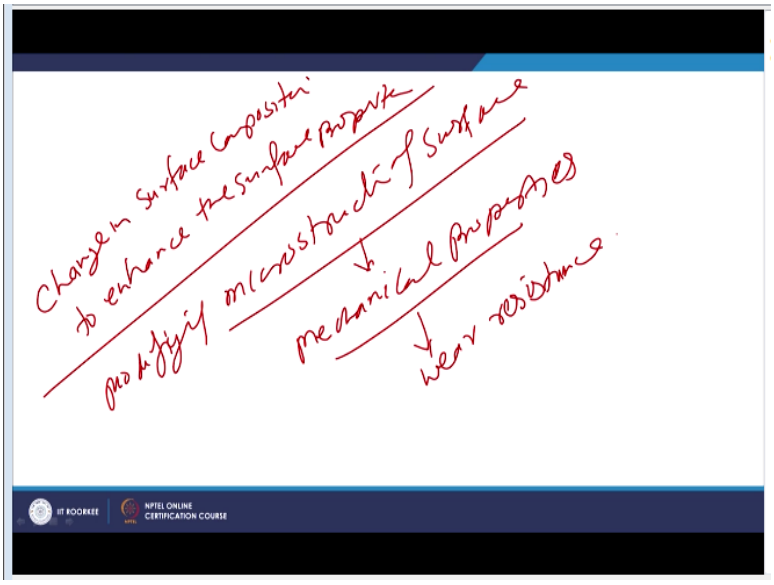

Now we will be talking about the another category of the surface modifications techniques, where in change in surface composition is used to enhance the surface properties. And this change in composition helps in modifying basically it helps in modifying the microstructure of the surface layers in very controlled ways. So, this is structural modification basically helps in

achieving the required combination of the mechanical properties. And once this combination of the mechanical properties is achieved this in turn will help in improving the wear resistance of the material.

So, this is the kind of the logical sequence so, as per the case there can be variety of purposes of changing the chemistry for surface modification.

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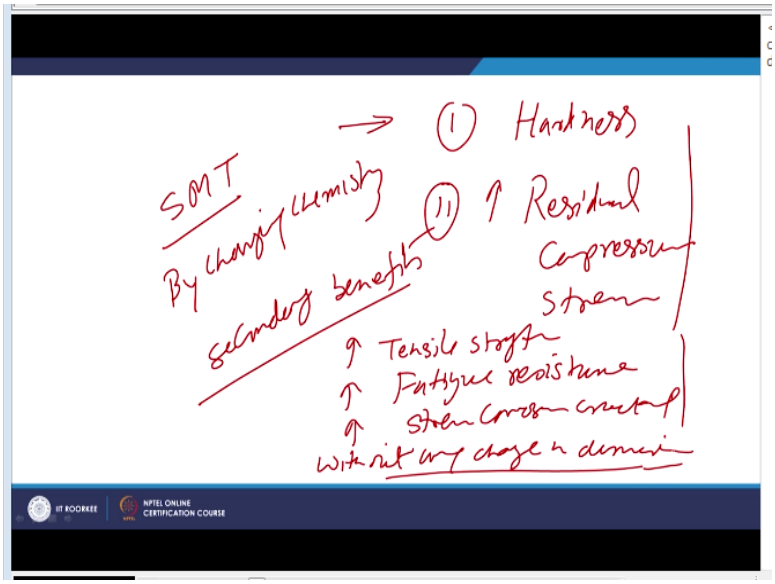

But there are two main objectives of the surface modification by changing chemistry and this is a one out of this is increasing the surface hardness and the second one is to induce the residual compressive stresses. And when these two objectives are realized we get many other you can say the secondary associated benefits after the improvement in these two types of the characteristics of the surface which has been modified through the change in chemical composition.

So, there are many secondary benefits which may be in terms of like increase in tensile strength of the material increase in the fatigue resistance of the material. So, it will be able to carry the fluctuating loads more effectively and it may also increase the resistance to the stress corrosion cracking. And all these things are realized through the compositional modification without any change in the dimensions when this kind of the approach of modifying the chemical composition, modifying the surfaces through the change in chemical composition is applied.

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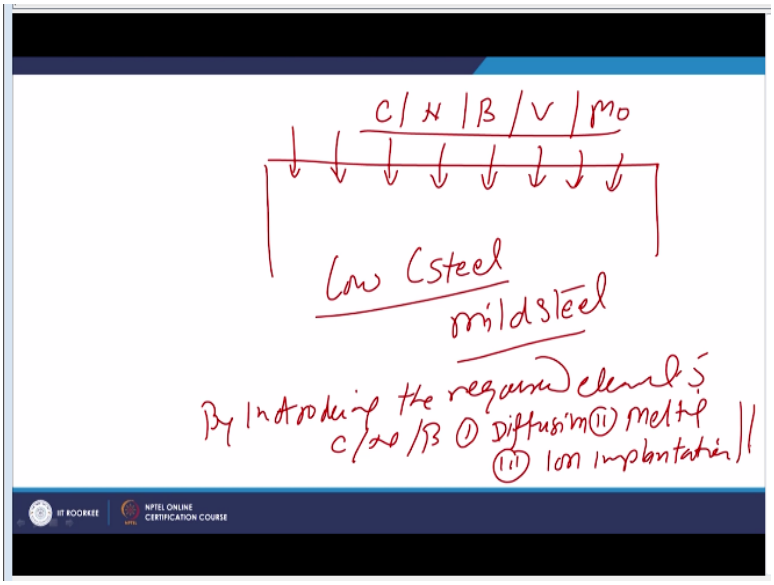

Now this change in composition is normally realized in certain category of the metal systems wherever we find that edition of the certain elements will be beneficial for improving the properties. For example in case of the simple low carbon steels or the mild steels where carbon content is very low addition of the some of the elements or the presence of the some of the elements which are missing in these category of the steels have to improve the surface properties.

So, addition of these elements may be in form of like carbon, nitrogen, boron, vanadium, molybdenum etc. So, as per the case what we want to incorporate for enhancement of the surface properties we will try to introduce these elements at the surfaces. So, the change in composition by introducing the required elements at the surface it may be inform of carbon, nitrogen, boron etc.

This change in composition is realized to certain mechanisms, certain approach is and these approach include one of the primary one is the diffusion. Second is where in melting is achieved and third one where ion implantation is used to modify the surface chemistry and modify the so, that the structural modification in the material surface is realized for achieving the require set of the properties at the surfaces for improving the wear resistance of the material. So, accordingly the kind of elements which are to be introduced there can be various methods which are used for this purpose.

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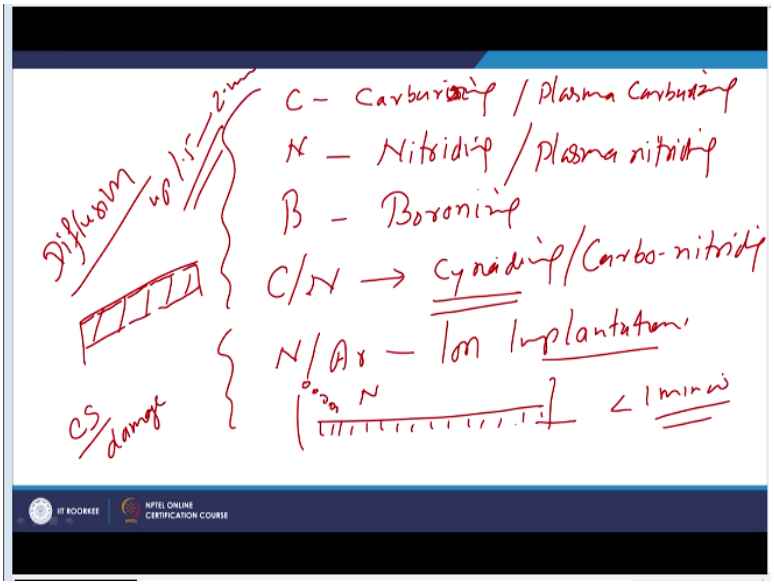

If like say if the carbon is to be introduced then basically we use carburizing or there is another more effective method plasma assisted carburizing and if the nitrogen is to be introduced and the surface of the steel then it will be termed as the process termed as nitriding or it can be plasma nitriding. Then for introducing the boron and the surface of the steel it is called boronizing, both these combination of the carbon and nitrogen both are introduced in case of the cyaniding or carbo-nitriding.

In both these processes carbon and nitrogen is introduced, in case of the carbo-nitriding carbon concentrate concentration is more than the nitrogen. And in case of the cyaniding, nitrogen concentration is more than carbon. So these are the various combination of the processes and ions of the various elements like nitrogen or organ are introduced in the surface through the process like ion implantation.

So, in these case basically the diffusion is the mechanism through which these elements are introduced and composition is modified accordingly while in another case the crystal structure of the material is damaged through the impingement or impact of the ions directed on to the surface, at the same proper mixing of the organ or nitrogen and at the surface is also facilitated like ion beam is directed on to the surface in the environment of the nitrogen or nitrogen ions.

So, they will be damaging the crystal structure up to the certain depths all the, these depths are very, very small even less than 1 micrometer. So, very thin layer is modified using the ion implantation kind of techniques. While some what the thicker layer, thicker modified layer is produced using the carburizing nitriding kind of the techniques where in modified thickness can range say up to 1.5 to 2 mm.

So, these are very great thicknesses up to which modification in surface properties through the compositional changes is realized. So, processes like ion implantation the this thickness modified thickness is very less. While in other cases like carburizing and nitriding this is very thick up to 1.5 up to 2 mm. So, depending upon the application for which the surface modification is to be done the different thickness of the modified surface layers will be used.

And accordingly will be trying to control the modified surface layers or the depth up to which modification is to be achieved that is controlled using the suitable combination of the process parameters. So, that the modified surface layers of the required set of the properties can be realized. Now if we try to see the kind of properties that we normally have with respect to the hardness which we get from the various processes.

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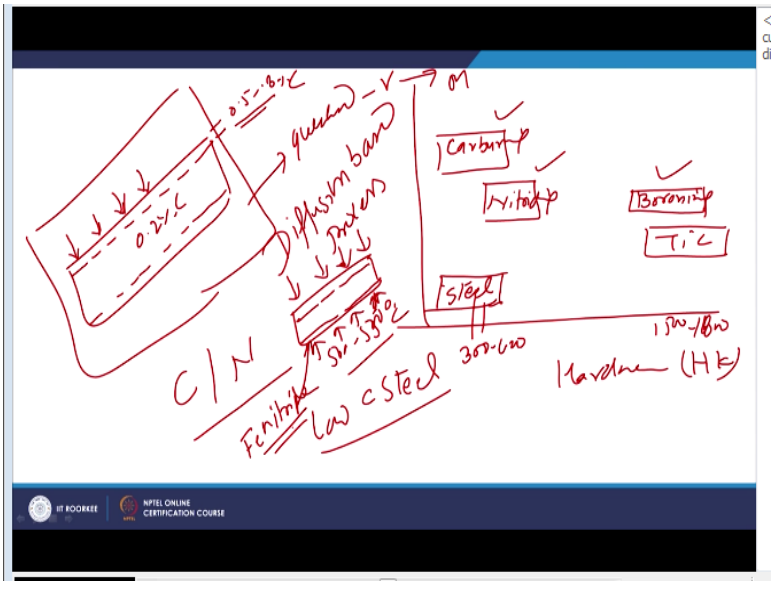

So, in y-axis, basically if we have the various diffusion based processes, and in x-axis, if we have the hardness in knoop hardness Hk then say for the steel hardness is very less then boronizing

offers maximum increase in hardness and then here is the hardness of the titanium carbide which is too hard. So, if we compare them then boronizing results significant increase in the hardness.

On the other hand nitriding process results in this level of the hardness, and the carburizing will be leading to the somewhat lower hardness like this carburizing. So, what it indicates that here the hardness level may be 300 to 600 levels here it is 1500 to 1800 levels of the knoop hardness. So, we get the two high hardness in case of the boronizing, somewhat higher hardness in case of the carburizing and nitriding as compared to the simple low carbon steels.

Low carbon steels will be offering very low level of the hardness. So, the basic objective behind these compositional modifications, so the carbon and nitrogen is what that low carbon steel components the in these components basically the carbon content is enriched increased up to the required depth. So, if the steel head like say 0.2% carbon content. So, the carburizing or through carbo-nitriding will try to increase the carbon content in the high carbon steel range.

So, that it is in a range of 0.5 to 0.8 so, such high carbon concentration once the component is enriched with the carbon entire component from the ascetic state having the higher carbon content it is quenched. So, there can be 2 step processes or there can be 1 step process for achieving the required set of properties. So, quenching will be leading to the transformation of high carbon austenite into the martensite side to achieve the required hardness and improvement in the wear resistance of the material.

Now likewise there is another element which is also commonly added in the steel surfaces to enhance the properties is nitrogen. So, nitrogen is at normally at the temperature like 500 to 550 degree centigrade and this temperature is primarily used to diffuse the carbon, diffuse the nitrogen in the steel surface at in the ferritic zone. So, that sufficient diffusion is achieved while this steel remains in the ferritic state.

So, the nitrogen is a diffused up to the required depth and this kind of the nitrogen diffused in the steel surface forms the iron nitrides of the different kind. And this formation of the iron nitrides

leads to the increase in the hardness and which in turn develops the residual compressive stresses as well as increases the wear resistance through the increase in hardness.

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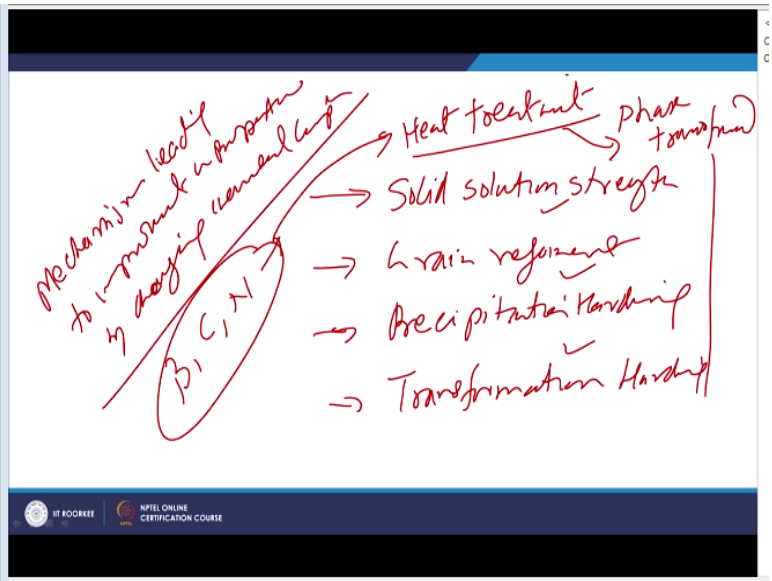

So, various mechanisms which leads to the improvement mechanisms leading to the improvement in properties by changing chemical composition the certain mechanisms which work in for improvement in properties these mechanisms include the solid solution strengthening, second mechanism is the grain refinement, third is the precipitation hardening and fourth is the transformation hardening.

So, at a time either one or combination of these mechanisms can help to enhance the properties of the surfaces when the chemistry of the surface is modified. So, we can choose boron, carbon, nitrogen to get introduced in the steel surfaces. And when these are introduced it can lead to the improvement in properties through the solid solution strengthening grain refinement precipitation hardening or the transformation hardening.

So, for this purpose this kind of improvement through this mechanisms can be achieved directly or it may required like heat treatment after the compositional modification to facilitate the required phase transformation. So, that the change in properties can be achieved. So, it can simply chemistry modification or after chemistry modification we need the heat treatment. So,

that the required micro structural changes in terms of the grain size or the phases can be achieved for improving the surface properties.

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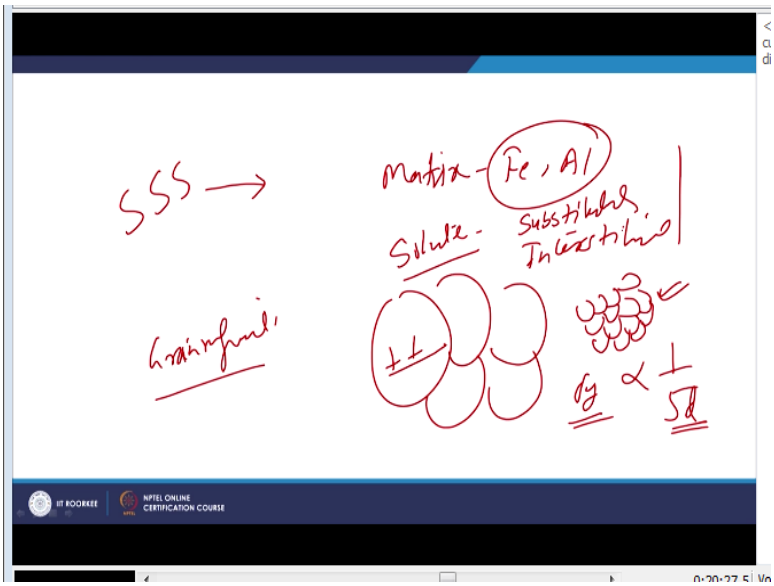

So, I hope most of the candidates are aware of these mechanisms but in brief I will tell you how these strengthening mechanisms work. So, in solid solution strengthening basically the solvent which is the matrix materials may be in form of a like iron or aluminium when we add the solute it forms the solid solution. So, addition of some of the solutes in the matrix leading to the formation of the solid solution in form of the substitutional solid solution or interstitial solid solutions. In both these cases there is a whenever the solute is a dissolved in the matrix.

There is increase in the hardness and strength of the material and which in turn leads to the improvement in the properties. On the other hand the grain refinement mechanism when the grains are course we get the poor mechanical properties, poor hardness because of easy movement of the dislocations under the influence of external stresses. But when the grains are fine the movement of the dislocations is very restricted.

And this in turn leads to the increased resistance to the deformation increased hardness and therefore and there is also direct relationship between the yield strength which is inversely proportional to the square root of the diameter. So, finer the grains greater will be the yield strength of the material. So, in general whenever efforts are made to refined the grain structure it

leads to the improvement in mechanical low properties in terms of the hardness yield strength and the ductilative.

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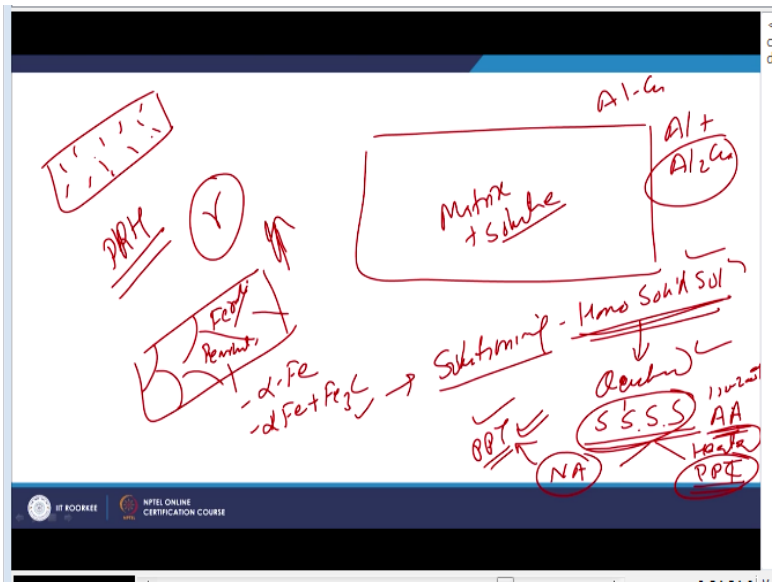

There is another mechanism which is called precipitation hardening, in case of the precipitation hardening, hardening one simple approach is used like matrix having the solutes whose solubility changes as a function of temperature. So, what we do first we try to solutionize all these elements in the matrix. So, that all the elements, all the solutes present in the matrix get dissolve properly and so, that homogeneous solid solution is achieved.

Once the homogeneous solid solution is achieved we quench the material. So, after quenching we get the super saturated solid solution especially in the situations when the solute atom or the element present in the matrix is more than the solubility limit at room temperature. So, it may be present in other form like compounds or the carbide or the other phases. For example like in steels we have ferrite and perlite under the room temperature.

So, ferrite is basically alpha iron and the perlite is mixture of the alpha iron and iron carbide. So, when such kind of system is heated to the high temperature everything will get dissolve and form the solid solution all these iron carbide or the ferrite all these will get dissolve. And they will from the actinide if the actinide has to be should be of the uniform in terms of the structure and the chemical composition.

So, that is the state of the homogeneous solid solution similarly in case of like aluminium copper alloys there will be aluminium matrix+Cu Al2 so, when we heat it Cl2 get dissolve in the aluminium matrix and forms the homogeneous solid solution. Similarly when it is quenched it forms the super saturated solid solution and thereafter under the room temperature condition it the super saturated solution may start getting precipitate in form of the fine precipitates the leading to the natural ageing.

So, by the natural ageing this super saturated solid solution will start forming the precipitate for the strengthening purpose and if the super saturated solid solution is heated to high temperature then it will be leading to the formation of other as formation of the precipitates also. But at much faster rate and this will be the situation of the artificial ageing. So for the precipitation hardening purpose we have to solutionize the material to be hardened then after solutionizing will be getting the homogeneous sold solution.

Thereafter homogeneous solid solution will be quenched to get the super saturated solid solution and thereafter it can be aged naturally at room temperature to get the precipitates or it can be heated at high temperature like 150 to 200 degree centigrade. So again we get the precipitates but this is the shorter process it is a fast and it takes long time and all the alloys or not sensitive for natural ageing.

So, they may be required to perform it may be required to perform the artificial ageing to get the precipitates and once we get the precipitates uniformly distributed in the matrix. It will be leading to the increase in the hardness and it is strength and improvement in properties.

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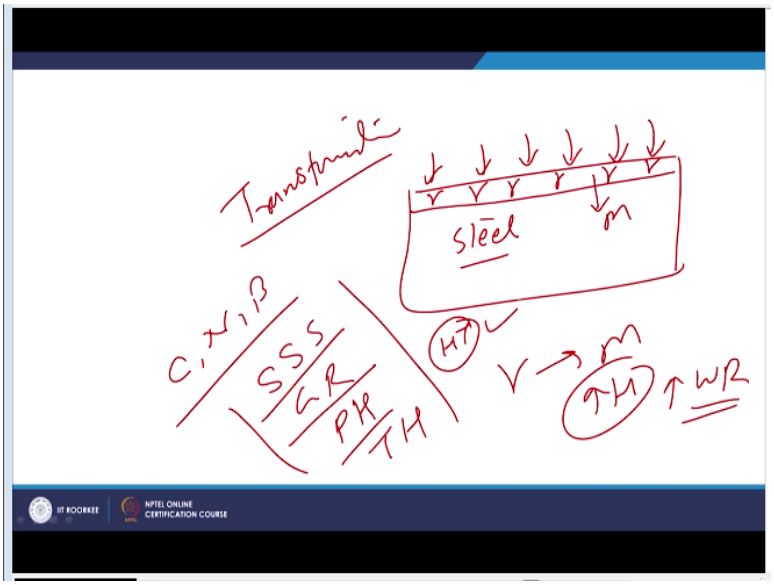

And about the transformation hardening I have already talked earlier in the transformation hardening we try to heat the surfaces. So, that the unstable phases are formed followed by the rapid cooling leads to the formation of the phases which will make the surfaces hard. So, this is an example for this kind of the hardening is the simple hardenably steels where heating leads to the formation of arsenate followed by the rapid cooling either by the water jet or the self cooling.

This will be leading to the transformation of arsenide into the martensite and once this kind of transformation takes place. We get the increase in hardness, we get the improvement in wear resistance. So these this is how the different hardening mechanisms will be working as I have said in case of whenever the change in chemical composition is realized through the addition of carbon, nitrogen, boron.

One of these mechanisms will be working like solid solution is strengthening grain refinement precipitation hardening or transformation hardening. And this may be achieved directly or it may require the heat treatment. So, just by changing chemical compositions some of these mechanisms work to enhance the properties and sometimes after changing chemical composition. We may require the heat treatment for achieving the required change in the wear resistance required improvement in the wear resistance.

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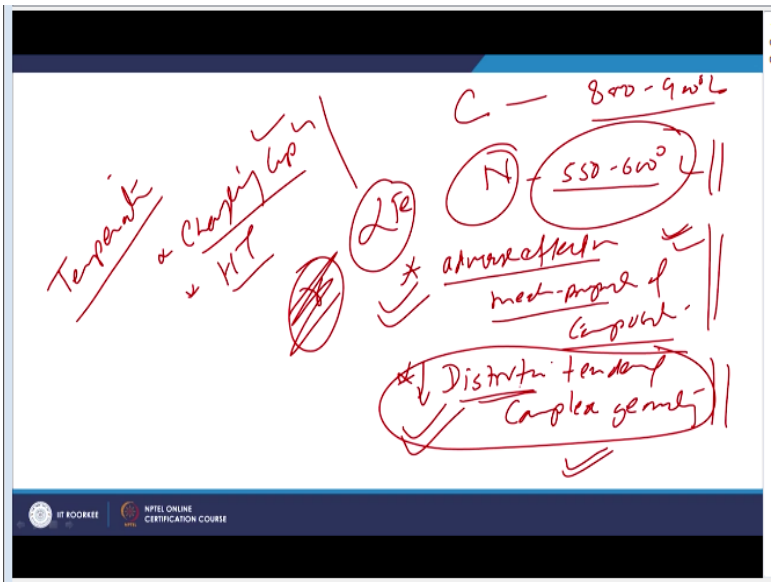

Now if we see we always want that the temperature conditions which are required for changing the chemical composition or for changing the microstructure through the heat treatment, for both these cases. If the temperature required is as less as possible then will be preferring it because increase in temperature increases the chances for the adverse effect on the mechanical properties of the component which is being heated either for the changing chemical composition or for the heat treatment.

This is one point and if any process where the maximum rise in temperature is reduced then it will be beneficial from this aspect like adverse effect on the mechanical properties of the component will be reduced. And another benefit which will be realizes through the control of the temperature is that distortion tendency is reduced and if the distortion tendency is reduced this is especially important in case of the complex geometries.

So, the geometries complex are the size of the component is being where in very large means significant heating is carried out for longer time. Thereafter cooling is done, then there will be increased chances for the distortion and increased adverse effect on the mechanical properties. So, if we compare like carburizing and nitriding, carburizing needs the temperature of like say 800 to and 900 degree centigrade for austenitizing.

While nitriding is carried out in the range of temperature 550 to say 600 degree centigrade. So, this temperature is somewhat lower and that is why it is favorable from these point of which as if the nitriding is carried out nitriding will be carried out in the ferritic zone not in the arsenatic zone. So, if the ferritic zone nitride means nitrogen is introduced in the steel where it is in the ferritic state.

Then it will not be leading to the metallurgical transformation but it will be simply causing the change in chemical composition and thereafter it will be leading to the formation of the iron nitride. But alpha iron that is ferrite it will not be transforming into the unstable phase like arsenite. So, this is one effect that extent of adverse effect on the mechanical low particles will limited.

When the nitriding is carried out because it is performed in the ferritic state and the limited temperature will also be having the lower tendency for the distortion especially when the geometry of the component is complex. So, these are the 2 important benefits related with the processes where in the maximum rise in temperature is limited, if the rise in temperature is too high.

Then it will have tendency to adversely affect the mechanical properties of the component as well as it will have the tendency to distort the component. Now here I will summarize this presentation. In this presentation basically I have talked about the principle of a changing the surface properties by modifying the surface composition through the various approaches. So, basically the carbon, nitrogen, boron or nitrogen irons are introduced in the surface of the steel component.

So, that the required change in the surface properties can be achieved, so I have also talked about the various mechanisms so, which will be working behind for the improvement in mechanical properties as well as wear resistance of the component modified through the change in chemical composition, thank you for your attention.