Fundamentals of Surface Engineering: Mechanisms, Processes and Characterizations

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Lecture-34
Surface Modification Techniques: Nitriding

Hello I welcome you all in this presentation related with the subject fundamentals of surface engineering and we are talking about the surface modification techniques and under the surface modification techniques using the surface composition modification for improving the surface properties. We have talked about the 2 approaches 1 was like the carburizing where carbon content is increased at the surface or near surface layers.

So that after the required post carburizing heat treatment suitable combination of the properties can be realised and the second process was the cyaniding where both carbon and nitrogen addition is used for improving surface properties . But in the cyaniding the role of the nitrogen is much bigger in improvement of the surface properties than the carbon. In both the cases we need the post heat treatment, post carburizing, post cyaniding or cyaniding heat treatments.

So that the required phrases and compounds can be formed, so that the expected improvement in surface properties can be achieved. Now will be talking about the third process and this category where are primarily diffusion is used for surface composition modification. So carburizing also uses the diffusion, cyaniding also uses the diffusion and nitriding also uses the diffusion for modifying the chemical composition of the surface and near surface layers.

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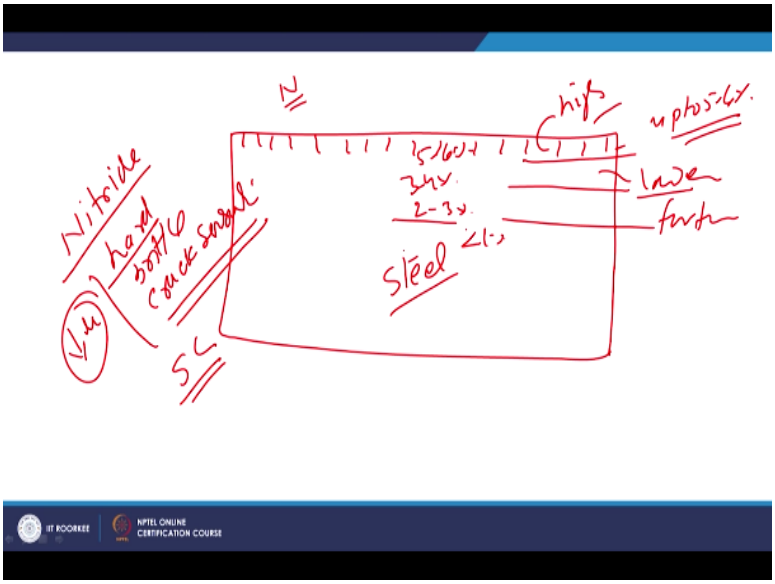

So that the required improvement in surface properties can be achieved. So as the name appears in nitriding basically the objective is to form the nitrides at the surface and near surface layers and all types of the nitrites may not be good especially nitrides of iron, chromium, aluminium, vanadium, molybdenum, titanium. Those nitrides whose which are stable, which are hard.

And of course they are accompanied with the increase of specific volume, this is not the target but increase in the hardness is the prime objective but when it occurs with the increase of the specific volume we get the benefit of both increased surface hardness and developed the residual compressive stresses and both these properties help in improving the tensile strength, fatigue strength as well as wear resistance of the material.

And that is why nitriding helps to improve the wear resistance at the same time the mechanical performance of the component. So what is the basic procedure for this. So for the nitriding purpose the steel component which is subjected to the nitriding process basically the nitrogen content of the surface and near-surface layers is enhanced it can vary like say up to 5-6% and when the nitriding is carried out.

The objective is to form the nitrites which are hard and stable and at the same time they do not enhance the brittleness and increase the cracking tendency. So when the nitriding is performed will see that the nitrogen concentration like carburizing is higher nitrogen concentration is high at the surface, then somewhat lower at the subsurface layer and then for the lower at that in the further deeper zones away from the surface.

At the surface we may have like a 5 to 6%, then 3 to 4% in the subsurface layers then 2 to 3% may be less than 1% as well in the subsurface zone. So accordingly the different types of the nitrides are formed at the surface and these nitrites which are formed at the surface which are extremely hard very brittle and they are crack sensitive. All the hardness and brittleness reduces where the friction coefficient.

But increase the sensitivity for cracking, increases the chances for the fracture through the growth of crack. So once the cracks are developed then this will be acting as a stress concentration exercises and thereby degrading the mechanical performance of the component. So if we see if we try to plot the variation in the nitrogen concentration with the increase of the depth.

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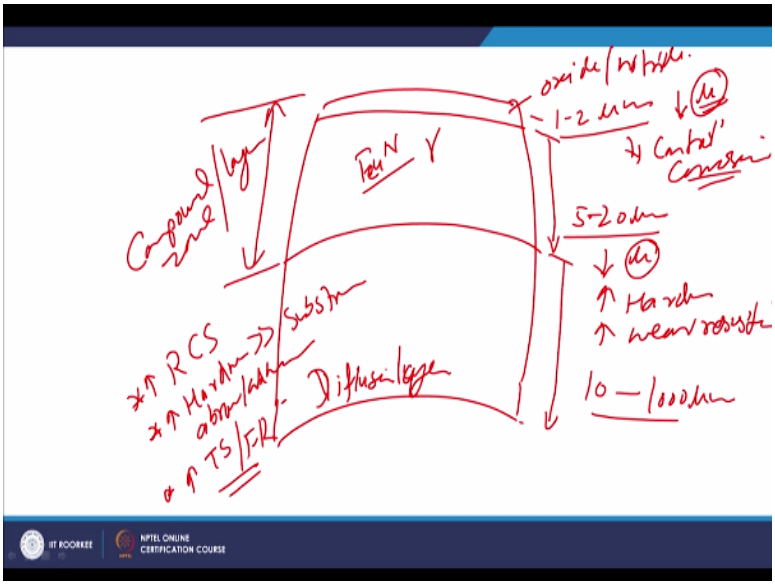

And the kind of compounds which are formed at the surface, so just systematic understanding if we make a very top surface layer this has oxides and very high nitrogen nitrides is of 1-2 micrometre thickness and this because of high hardness it helps to reduce the friction coefficient that is the new or the friction coefficient is reduced and it also helps to control, it also helps in like controlling the corrosion.

This corrosion resistance is improved because of the presence of this, then another layer which is like a formation of depth Fe4N the gamma nitride, this can be of the size range like 5 to 20 micrometer, this very effectively reduces the friction coefficient it increases the

hardness and it increases the wear resistance. But only problem is that it also increases the cracking tendency.

And both these 2 layers are called the compound zone formation or diffusion compound layer where the compounds are being formed and in the further lower zones will have the for the lower concentration of the nitrogen and this will be the diffusion layer and the width of this or depth of the diffusion layer can vary as per the kind of material and the conditions 10 to 1000 micrometre.

So this is extremely good from the properties point of view it helps to enhance the residual compressive stresses, it also helps to enhance the hardness greater than the substrate, hardness is greater than of this layer is greater than the substrate. So there by it will be improving the abrasive and adhesive wear resistance and because of the residual compressive stresses it also increases the tensile strength and the fatigue resistance of the material.

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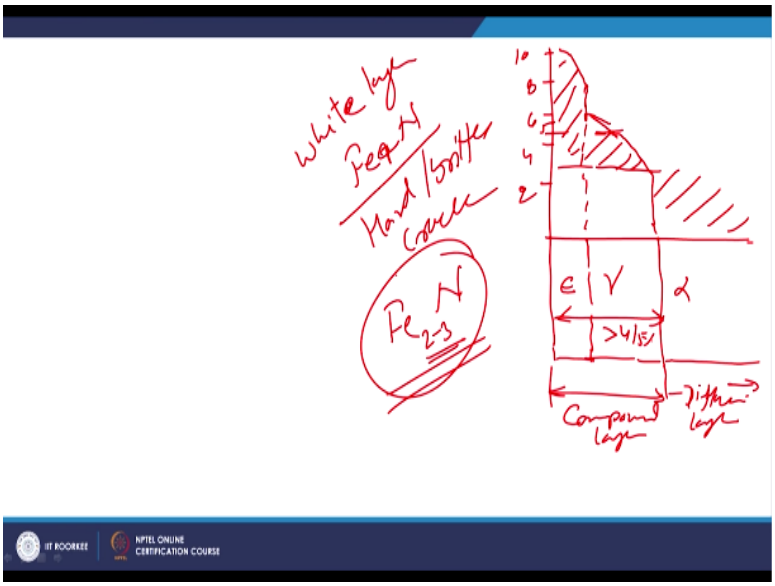

So this is how the different zones are being formed due to the varying concentration of the nitrogen in the surface layers and if we try to plot the concentration verses the different zones which are formed. So very top surface layers will have the 1 type of the nitride layer then are there will be another nitride layer in the subsurface zones and the further subsurface zones there will be diffusion zone.

So if we if you plot this is the compound layer zone and this is the defused diffusion layer zone. So here are the gamma kind of the nitride is formed is a kind of and here there after that

will have alpha nitrites where iron nitrogen will be defused state with the iron to form the iron nitride and if we see the variation in the nitrogen concentration like 10, 8, 6, 4 and 2.

Then the variation will be like this is decreasing from 10 to somewhat 8%, this is one you have corresponding to this and then this comes out how to this zone then will have the another zone and then this zone is a little bit wider and will have third zone. So this second zone actually corresponds to this is start somewhere 5% and then like this also here these are the compound a layer zones will have the higher nitrogen concentration which is greater than 4 or 5% of the nitrogen.

And below that will have the low nitrogen content in case of the nitrogen is diffused state in the ferrite. So this zone corresponds to the very high nitrogen concentration than the second zone somewhat lower nitrogen concentration for the lower nitrogen concentration is this alpha where iron nitrate is form and the 2 kinds of the nitrides which are commonly form like one is a found in form of the white layer where very Fe4N kind of the nitride is formed which is extremely hard and brittle and craft sensitive.

This is formed at the surface and in the diffused zone we may get like 2-3 range of the like F2-3 is the range and then and so this is the iron nitrate which is found in case of the diffused layer zone . Now if we want to see when where are so in this case we have primary talked about the iron nitrate formation of marinated which is hard and brittle specially which is formed at the surface.

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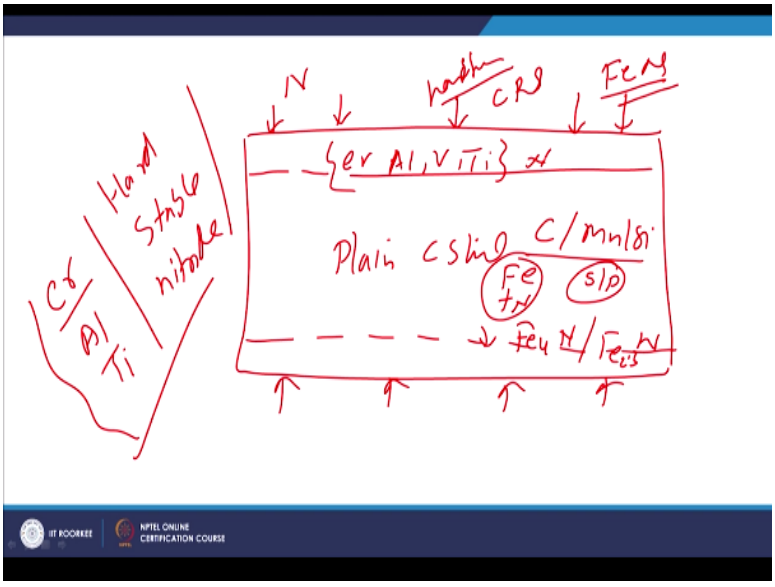

In order to since in this process we are enhanced in the nitrogen concentration at the surface through the enrichment of nitrogen in the steel component. So if the steel is like plain carbon steel where primary carbon Magnus and silicon are present and Sulphur and phosphorus are alike impurities. So balance is the iron because of the higher affinity with the nitrogen it will be primarily forming the Fe4N or Fe2-3 nitrogen for property enhancement.

But these steels are not that effective for improvement in the hardness and the compressive residual stress, because iron nitride is not that effective with regard to the property in improvement and their other nitrites like chromium nitride, aluminium nitride, titanium nitride. These are the elements from very effective very hard, very stable nitrides. So if the steel whose properties are to be modified by the nitriding if these is steels are having some amount of the chromium, aluminium or nitride.

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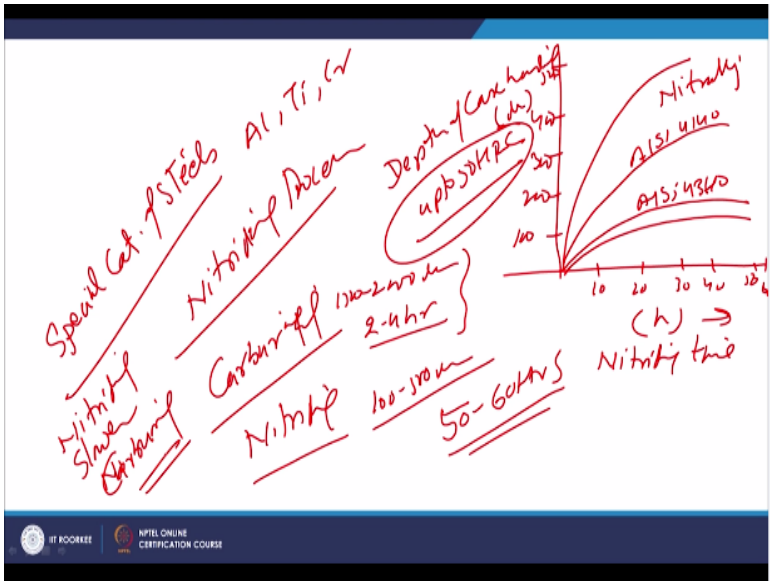

Then the effectiveness of the process will be much better. So in that case if the steel is a design to have the chromium, aluminium vanadium, titanium etc. in the formation of their nitrites will be causing the much better improvement in properties. So we can say there are special category of steels is steels having the aluminium, titanium, chromium. So that they can respond in much better way during the nitriding process.

So with regard to this if we try to see the effectiveness of the methods, then effectiveness of methods will be going like this where in if we perform the nitriding for longer period like 10, 20, 30, 40, 50, 60 like this in which is hours nitriding time in hours and the depth which is a

realised depth of case hardening realise after nitriding in of course micrometre of 2 reference level of the hardness increasing hardness 50HRC.

So the depth up to 50HRC hardness is realize to the nitriding process that the depth vary with the nitriding time but the variation is different for the different steels like if we take up Ai, SI 4340 is one steel which is having chromium as well as controlled content of the carbon then if we use instead of the Ai, Si 4340 if we use a AiSi 4140 steel then the depth which will be produced up to the required hardness that will be much better.

In case of 4140 as compared to the 4340 steel and this is activated to the presence of the different kind of nitride forming elements which are much better as compared to the case of the simple 4340 steel and maybe for plain carbon steel the it will be like this. So what were the another (()) (16:54) having this will be responding in much faster rate for increase the harden depth up to the required hardness during the nitriding.

And if you see this depth of to which the hardening is being plotted here it will be like this, so 100 micrometre 200, 300, 400 and 500 as compared to the carburizing which was taken like time of 2-4 hours to get the hardness set is hard and the depth of 2000 like 150 to 2000 micrometre. In case of the nitriding the case hard and depth is like ranging from 100 to 500 micrometre and while it is taking time very long time like 50 to 60 hours.

So all this variation is different for the different category of the steel, but if we compare the two processes directly the nitriding is slower process, nitriding is a slower process as compared to that of the carburizing. So now will see the conditions under which the nitriding is performed and how it is facilitated. So as far as the conditions and the reactions which are required to perform for nitriding say there is enclosed chamber like this.

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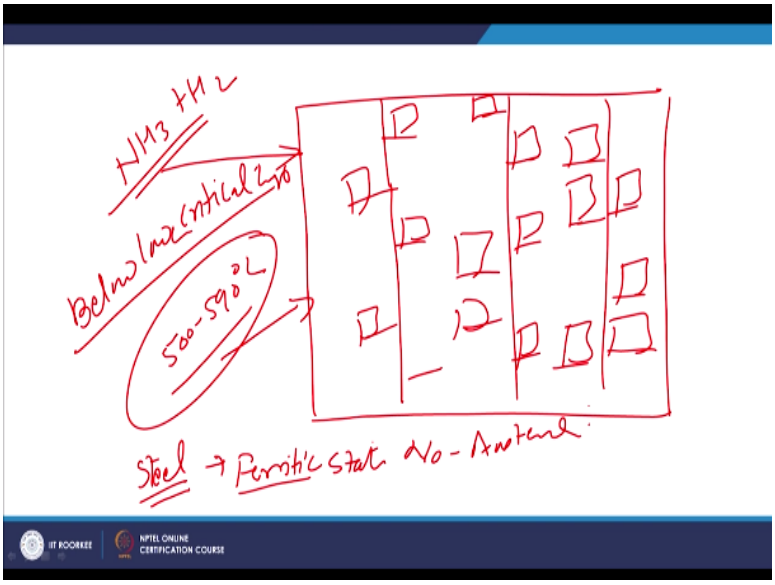

Where the components to be subjected to the nitriding will be placed this like these are the stacks and here the components to be processed will be kept and this entire enclosure is subjected to the high temperature through the external heating. So this chamber is heated in the range of likes a 500 to 590 degree centigrade and we know that and then we feed the gas mixture which primary consists the ammonia.

And sometimes the hydrogen mixture, so these are the gas mixture and the temperature conditions which are used for the nitriding purpose, if we see this temperature range carefully this is the temperature range below the lower critical temperature in the iron carbon diagram. So if it is the steel then the steels in when they are heated 500 to590 degree centigrade they remain in the ferritic state.

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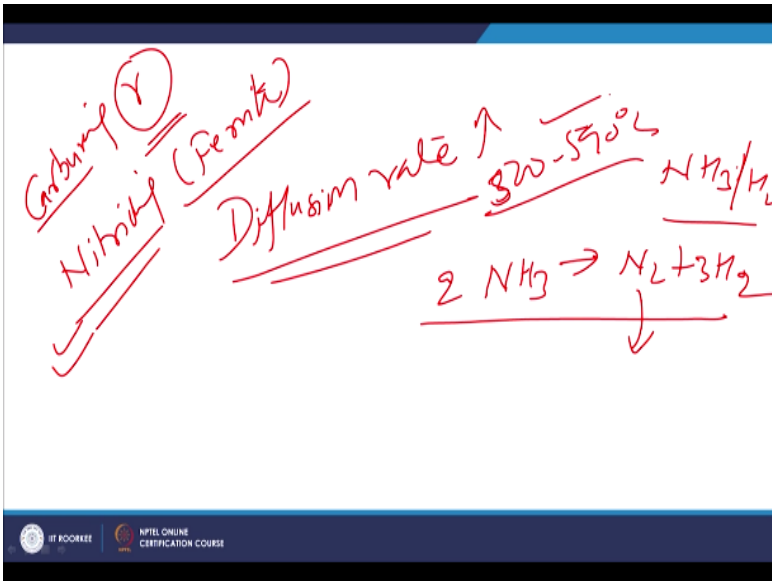

And no transformation is observed under these conditions primarily which means carburizing is performed in the austenitic state while nitriding is performed in the ferritic conditions. So this steel which even during the nitriding will remain the will be in the ferritic condition and reason for this is that when the nitriding is performed in the ferric state or the diffusion rate is quite good.

So to exploit this benefit under to take to avoid the unnecessary high temperature heating the nitriding is performed in this temperature range of 500 to 590 degree centigrade. So we get the much better diffusion rate in the ferritic condition and when this carbon and when at this temperature of like 500 to 590 degree centigrade in this gas mixture is passed in the chamber then it will be leading to certain kind of the reactions like NH3 it will be decomposing into the nitrogen+hydrogen.

And so this is 1 reaction so it will you making the nitrogen available all around the component which is to be processed through the nitriding, now this is an example of the gaseous mixture is fed in the chamber which is heated in this temperature in so that all the components are processed to the nitriding process.

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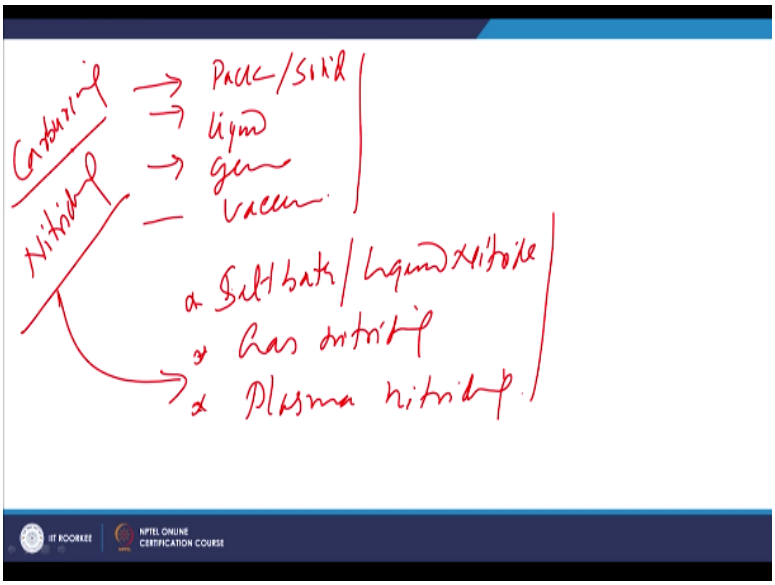

The nitriding can be available in 3 different variants like carburizing we have seen was available in form of like say the pack carburizing or solid carburizing, liquid carburizing, gas carburizing and the vacuum carburizing. Similarly the nitriding is also used in the form of the 2 variants or 3 variants 1 is like salt or the liquid nitriding. The second one is gas nitriding.

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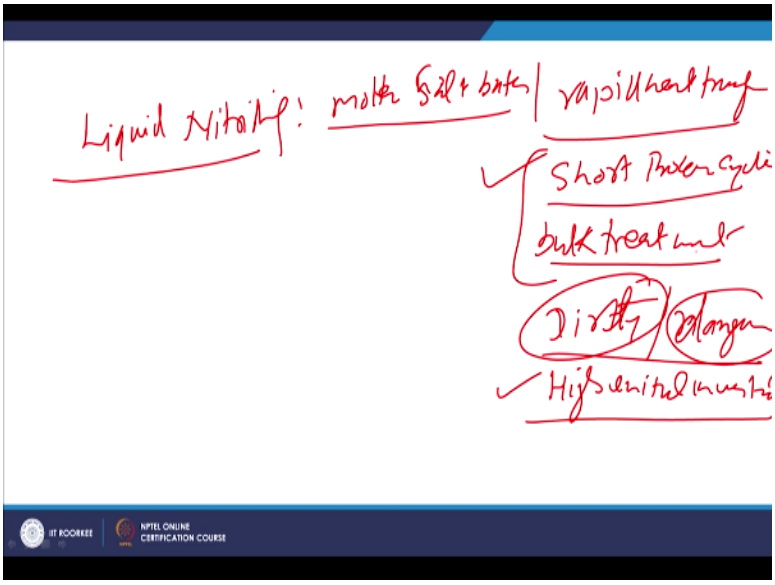

And third is the plasma nitriding. So these are the three different variants as for as nitriding concern and this 3 variants differ significantly with each other with regard to their process characteristics. So starting with the liquid nitriding, liquid nitriding like we have seen in the case of the liquid carburizing we use the molten salt bath. So here also molten salt bath is used.

So the components will be dipped in the salt bath and because of this we get the benefit of the rapid heat transfer. So this shortens the process cycle short process cycle**.** So this processes fast this is one aspect and we use the bulk of number of the components can be subjected to the nitriding in one go. So it is good for the bulk treatment when number of small components needs to be treated.

But there are issues like whatever waste is generated that will be making the process dirty and it will be making the processor dangerous also because of the use of the molten bath and at the same time this process uses the high initial investment. So the process initial the fixed cost is the initial cost is high, the processes is dirty and it is dangerous use of the molten salt bath but it is quick the process cycle is quick because of the faster heat transfer and it can be carried out on the number of components at a time.

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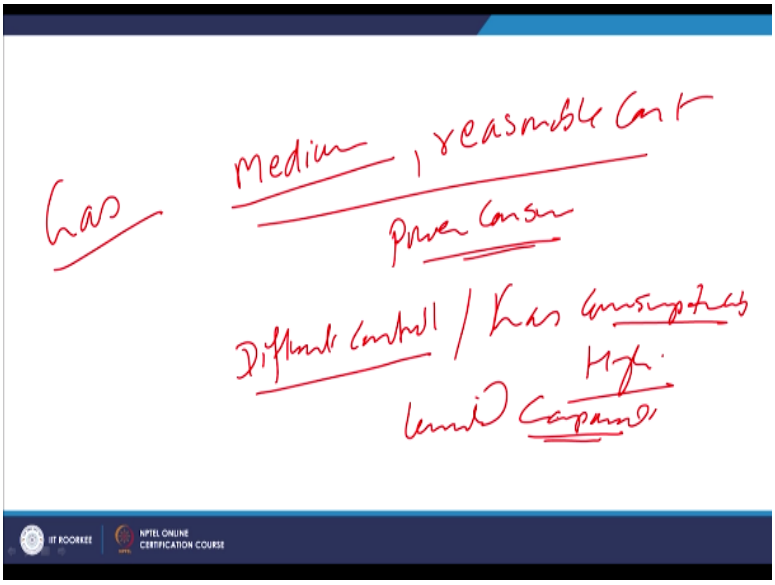

On the other hand if the gas variant of the nitriding process the process cycle is medium, medium process cycle and the cost wise it is reasonable cost and it consumes and the power consumption is also moderate related with this a process but the negative sides of this process is like the difficult control of this process gas consumption is high. So the process control is difficult gas consumption is high.

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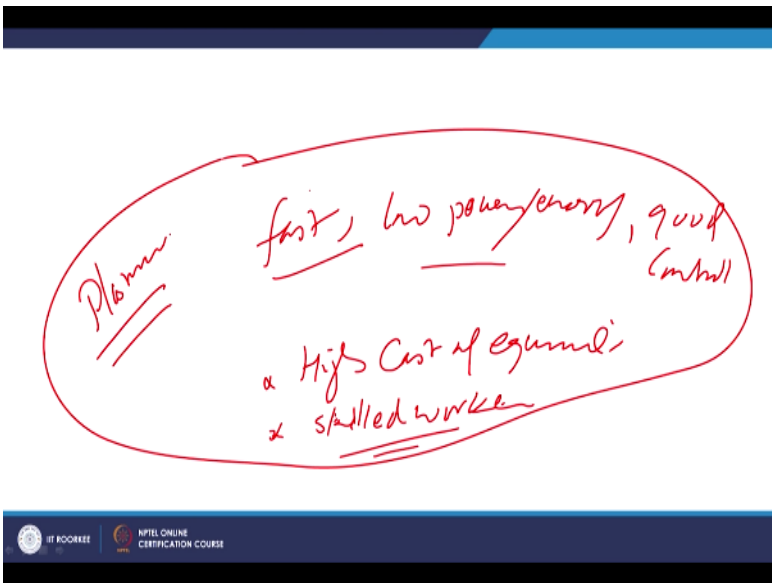

And it can be applied on the limited components, so this application of this process are very limited. On the other hand the plasma variant of the process the plasma process it is very effective process, it is very fast and low power energy consumption and but the equipment cost is high. So low energy and the good control over the process this is first low power consumption but initial high cost of equipment is one aspect.

It needs the skilled worker or train people for performing the plasma nitriding. So these are the different variants only but the basic underlying principle of the nitriding process is say what we have talked in detail that are nitrogen content at the surface layers is to be improved. So that we can form the required or nitride or nitrides of the other elements for improving the surface properties.

Now I will summarize this presentation, in this presentation basically have talked about the underlying principle of the nitriding process and what are the chemical reactions, what are the conditions required for the nitriding process and there are few special category of the steel which will perform or which will respond very effective to the nitriding process for improvement in the surface properties, thank you for your attention.