Welding Metallurgy
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Lecture – 19
Case Hardening Methods

Welcome to the lecture on case hardening methods, so far we have talked about different types of heat treatment and there we have discussed you know how to harden you know, what are the different methods of hardening but they were the bulk you know hardening methods, we were talking about the hardening throughout the material, so they are known as bulk hardening heat treatment processes.

Whereas many a times, we require that the heat treatments will be done in such a manner that the surface should be wear resistant or hard and the coarse would be still soft because the material is expected to be under the impact loading and the course would be sufficiently ductile or tough to take those you know impact type of loads. Typical examples are the gears like in the case of gear; you require the surface to be extremely hard and wear resistant.

Because the gear teeth is meeting with each other and they are you know rubbing against each other also and in that case you know the abrasion resistance has to be quite high whereas, you know the gear is also subjected to the impact loads in that case, it has to you know sustain those impact loads, so for that the core part of the gear needs to be tough. So we; so, in one sense what we feel that we need both hardness and toughness.

Although both is very contrary but we need hardness in the outer region and we need toughness in the inner region, it means we are trying to you know basically limit the depth of hardness which we are going to achieve using the hardening processes.

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Case Hardening

- In this process, surface is made hard and wear resistant while the core has to remain soft and tough.
- In steels with more than 0.35%C, the surface can be hardened by heat treatment.
- For lower carbon content (0.15-0.2%), chemistry of surface is changed by adding carbon or nitrogen.
- Different case hardening methods are Induction hardening, flame hardening, carburizing, cyaniding, nitriding etc.

So for that you know normally what we see is that in those cases, so we have to have the core to remain soft and tough and make the surface hard now, we have two categories of you know if you talk about these steels, so when you have steel with more than 0.35% carbon, so the surface can be hardened by heat treatment as you know that you know, we know that the as the carbon percentage is becoming more and more, steel is becoming more hardenable.

So, carbon percentage is becoming more by quenching you can have the formation of martensite, so for these cases where the carbon percentage is more than 0.35%, your surface can be hardened you know by the suitable heat treatment processes because you know hardness of martensite will be a function of the carbon content that we have already you know understood.

Now, there will be another category of material of especially, steel that is low carbon content and we know that these low carbon content materials they have; they are having less hardenability, so there is less chance of having formation of martensite in usual circumstances because the stability of martensite you know is more at with higher amount of carbon.

So, in those cases your surface chemistry is to be changed by adding carbon or nitrogen, so what we do in those cases; we try to you know induce, we try to diffuse basically, the carbon and nitrogen into the surface itself because that is the only way by which you can make the surface hard because if it is low carbon content material, it will be anyway tough you know all the throughout.

But then the surface can be made hard by inducing the elements like carbon or nitrogen on the surface, so we will talking about the two types of you know treatments which are you know given for the two categories of materials and for that you have different type of case hardening methods are basically advised and if you go talk about the first category, then in that case we talk about the you know methods like induction hardening, flame hardening so that basically will be dealt with for the materials when you have 0.3; carbon more than 0.35% you know.

And if you have you know the or even the laser hardening and if you have the second you know type of material; second category of material in those case, we try to adopt methods like carburizing, cyaniding, you know nitriding, carbonitriding, these are the methods which are used for; so in the that case basically you have to put them in such a manner that the surface at the surface basically, they react with these carbon or nitrogen.

And then they form the hard you know surfaces you know, the surface will have the martensitic structure, so we will talk one by one about you know these methods. So, if you talk about the method for the first category where the carbon is more than 0.35%.

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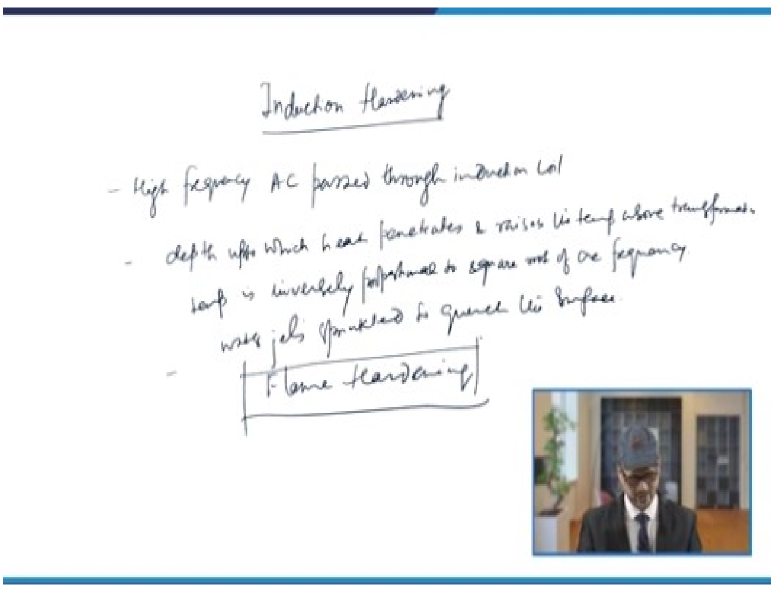

So, first is your induction hardening, so in this induction hardening process you know the high frequency you know, alternating current so that will be passed through the induction coils, so high frequency AC current, so that will be passed through induction coil, so that will be in closing that steel component which is to be heat treated so basically, the induced EMF that will be generating the heat you know and this you know, so that heat will be; heating that sample and you know the depth up to which they; so the depth up to which this heat will be penetrating, so depth up to which heat penetrates and resists temperature.

That is basically inversely proportional to the square root of AC frequencies, so that will be you know the depth up to which the heat penetrates and raises you know the temperature above transformation temperature, so that is inversely proportional to square root of AC frequency. So basically, you can control by controlling the frequency, you can control the depth up to which this temperature is raising above A_{C3} temperature or so.

And then after that you know, once you do that so, only in few seconds this hardening will be taking place and after that you are sprinkling the water jets, so you know that up to what depth this temperature has increased and if you sprinkle the water jet, then you are likely to have the martensitic structure. So basically, you know water jets are activated, sprinkled to quench surface.

So, once the water jets are you know activated then that will basically form the martensite on the surface immediately and the surface will be quite hard and wear resistant, so since it uses the you know, induction principle for heating the material and then further you are quenching it by sprinkling the water or by using the water, so we are using this, we are calling it as induction hardening process normally, we use it for the articles of uniform cross section.

Because you have to have these you know, you have to use these induction coils and all that so, you must have some material of uniform cross section, so that is normally in the case of induction hardening. Now, another process which is used for the material of first category that will be your flame hardening so, if you go to the flame hardening process now, as the name indicates; now, in this case you use the flame basically to increase the temperature in the in certain zone.

So, like for larger you know cast specimen or many a times you do not have the material of uniform cross section you have complex geometry where you can you know not use these induction hardening methods in those cases, we use these flame hardening because flame with flame with the oxy flame, you can always use, you can heat at any point, so you can use the flame, you ignite using you know torch.

And then you can you know subject these flames to respective places, so that the temperature is increased, so normally we use the oxyacetylene torch type of thing you know to do it and then once the temperature is increased you know to the required value, then we are further quenching so normally, it is suitable for very large objects or maybe many a times for the you know, somewhat complex you know, type of you know cross sections where normally we; it is very difficult to use the induction hardening you know method.

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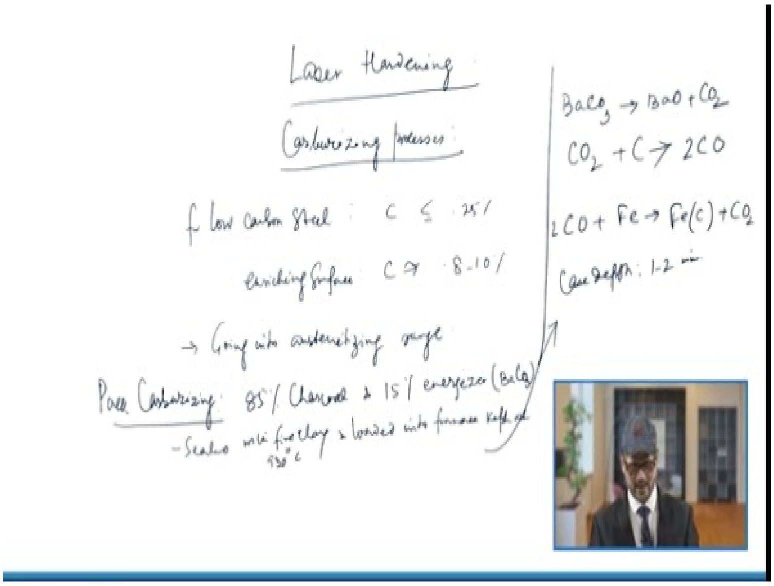

So, we go with these you know, flame hardening methods; the third method which is used is the laser hardening and as the name indicates here too, we do the heating with the help of laser, so as you know that the you know laser, so with that you can have so that is a very good heat source may be because you know with they will be; there will be beams of very high intensity.

And you know, we are basically using the lens to reduce the intensity of those beams and also we can have the deep focus spot, so we can have the deep focus spot of certain sizes, ranges because it will be focused to a very narrow region, then there it can go and it can melt also but if you are you know having in a certain you know ranges of size may be varying from 1 to or 0.5 to let us say 25 mm size in that area, it can be deep focused.

So that way it will increase the temperature, it will try to see that it does not melt, so you will have to adopt you know the proper controlling measures, so that it does not melt. Now what is does is that in this case, you increase the temperature and then you leave so, in this case you do not need to go for quenching you know because it is because of the mass of the unheated.

Because you are going into a very small region, so when you stop basically the focusing the beam you know or projecting the beam, then since the mass of the material all around is quite high, so anyway the heat transfer rate will be quite high from that localized region, so without the in fact, without the use of quenching setup, you get the hardening process you know done in this case, in the case of laser hardening.

The disadvantage with the case of laser hardening is that the hardening is shallower as compared to the either you can take the example of induction hardening or the you know the flame hardening, so with respect to these two, it is somewhat shallower. Now, we will come to the next you know category of you know, the process of case hardening that is carburizing processes.

So that these are for the materials especially steels when your carbon content is less may be 0.15 to 0.3% or so, so in those cases that the hardenability is quite less and for the steels maybe so typically, we normally go for you know for low carbon steels, so normally carbon is less than 0.25 you know percent and you know, so we are basically enriching this in this case the surface with carbon percentages of may be, so enriching surface with you know carbon percentage of the order of 0.8 to 1%.

So that is known as carburizing process because in this case, we try to you know give the carbon at the surface diffuse carbon into the surface and so that once the carbon goes, then it will make the surface hardenable and you will have the formation of martensite once you or basically by going the carbon into it, you will have the hardness achieved. Now, how to put this carbon for that; we use some sources.

So that we can have; so we have to have the source of carbon and this source of carbon may be either in the form of solid or liquid or gas, so we can have the solid that is known as the pack carburizing, so because you have the powder of charcoal and mixed with, so that will discuss, then we have also liquid may be you may have liquid you know medium or you may have the gaseous medium also to have you know this formation; this heat treatment process.

So, normally what we do is in this case, we are heating to temperature above the or austenitizing temperature, we are normally going to the temperature range of 920 to 950 ^{0}C and then we are doing this treatment because if you do you know at lower temperature, then the solubility of carbon in ferrite is less you know, when there is ferrite.

And in that case the cementite you know a large amount of cementite will be formed and massive cementite particles formation will further pose difficulty in heat treating the material, so normally we go to a temperature which is higher than the 920 temperature or so we will go to the range of 920 to 950 ^{0}C , so basically we are going into the austenitizing range.

So, going into austenitizing range, so we are always doing the carburizing when we are in the austenitic state. Now, so talking about the variety of the carburizing method; one is the pack carburizing, now in this pack carburizing as we discussed you have you know the materials which are packed in a box and you know, so you have a powdery mixture you have 85% charcoal and we have 15% of energizer.

So, energizer will be something like you will have $BaCO_3$, now this box basically is sealed you know with fire clay and load into the furnace, so sealed with fire clay and loaded into furnace, so that will be loaded into the furnace which will be you know kept at 930 ^{0}C. So, you know see so what happens the residual air which is there inside the box that will be combining that will be forming first you know the; that will be reacting you know.

And ultimate aim is to have the you know gaseous product that is carbon monoxide, this carbon monoxide will talk with; will be reacting with carbon and it will be forming though, so iron will be having you know, iron will be enriched with the carbon, so the reaction follows you know in the following manner so basically, the reaction will proceed like you will have $BaCO_3$ basically converted to $BaO + CO_2$.

And then this CO_2 will be further reacting with the carbon because you have limiting amount of oxygen, so you will have the formation of carbon monoxide now, this carbon monoxide from here the carbon will enter into the steel, so the carbon monoxide will react with iron so, it will be having you know iron with carbon and also you will have the CO_2, so you will have; so, this way typically, the reaction takes place in the case of pack carburizing where you have charcoal which is there reacting with CO_2 which is the product of this reaction.

And then, you will have the iron that is picking up this carbon and making it you know harder so, the typical carburizing time will be normally from 6 to 8 hours and the case depth which is hardened, so that is about 1 to 2 mm, so in this case you will have case depth of 1 to 2 mm and hardening time will be so, the carburizing time will be about 6 to 8 hours.

Now, what we do is; many a times if you are putting inside the pack, then you need you may also need to see that certain part is not you know is not required, I mean in those parts we do not require hardening, so they are basically sometimes we use either the electroplating of copper, plating with copper so that can be done you know up to certain thickness you know so that way you can have avoidance of the carbon pick up into that zone.

Or we may have also the refractory you know paste that is fire clay mixed with asbestos that is also you know kept on that surface, so that there is no hardening in that region taking place. Now, this we are going to the next kind of carburizing that is use of the gas.

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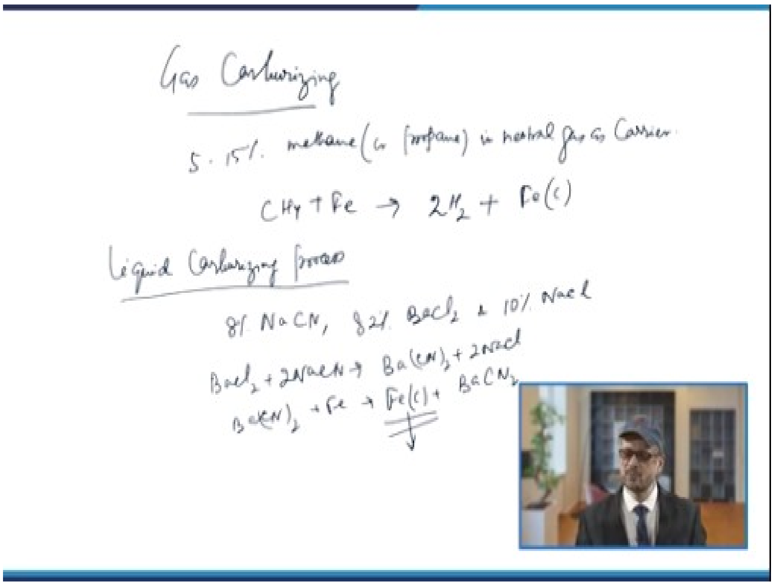

And we can go for the gas carburizing, we use some gases like methane so, in this case we use 5 to 15% of methane or propane and in neutral gas as carrier, so carrier will be some neutral gas, so what will happen; this methane will decompose and methane will be decomposed and then after that it will react with, so iron, so you are getting iron and carbon, so that way your carbon you know, will so this iron will be having be picking this carbon and it will be giving you the better hardness in such cases.

Then you have also the liquid carburizing method now, it is you know it is somewhat like the cyaniding process which we will discuss later so, in the case of liquid carburizing you know processes you have a bath which is composition of 8% you know NaCN and then you have 82% $BaCl_2$ and 10% NaCl, so you have a bath composition is there and then in that bath you are keeping you know the material.

So, your reaction will take place, so $BaCl_2$ will react with NaCN that will be giving you barium cyanide and then you will have NaCl and this $BaCN_2$, this will be reacting with iron, so you will a pick-up of iron with carbon and then barium CN_2, so in this case you are getting this pick up of you know the carbon by the iron and you have hardening taking place and in this case, the advantage is that you have a rapid heat transfer.

Because liquid will have you know this is a better medium to conduct the heat transfer to the to the specimen so, you will have the temperature control is also more in the case of liquid bath and also you have the heat transfer rate at a quite high value so, this is the gas carburizing method. Apart from that you know but one more thing is what is required in the case of carburizing is that after carburizing; we go for some heat treatment methods.

So, what we do is; normally when we do the you know carburizing then we do the heated but in two stages; first is that we are going into the temperature above the A_3 line and then cooling below and then we are going to; we are further heating to just above A_3 and then you know further going to the room temperature in the second stage we are going to just above A_1 and then we are further cooling.

So, this is just to have you know the fine structure of the material, we go for these post carburizing heat treatment you know processes now, we will talk about the different other you know heat treatment process; case hardening method.

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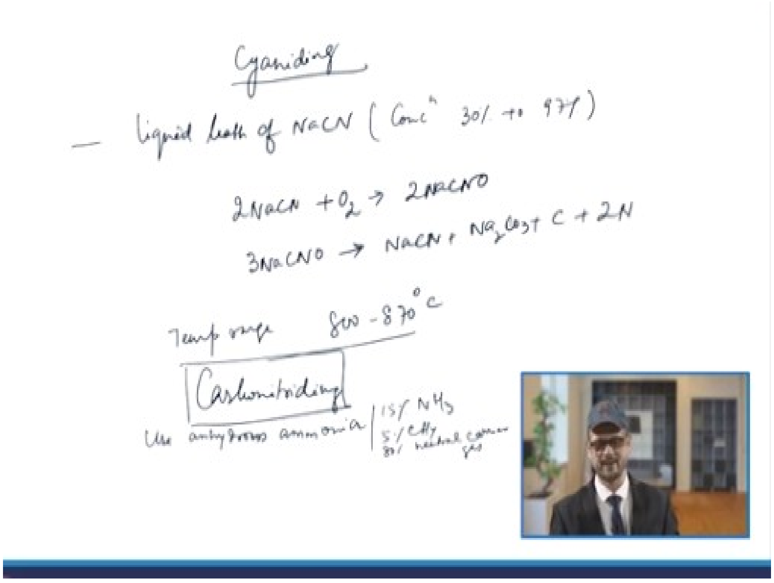

One is you know cyaniding, so in the case of cyaniding, you have; so we do the you know heat treatment in the liquid you know bath of NaCN, so you use liquid bath of NaCN, so the concentration will be varying from 30 to 90%, so what happens in this case, both carbon and nitrogen they diffuse into the surface, so they were enter into the steel and then you will be; that will be followed by a certain reaction like you have NaCN, so that will be reacting with oxygen and give you NaCNO.

And this NaCNO that will be you know forming NaCN + Na_2CO_3 + carbon + 2 nitrogen now, this carbon as well as the nitrogen, these are free for; so they will be you know reacting they will be going into you know, so they will be combined with carbon and they will be giving the hard surface you know by so, by the pick-up of this carbon and nitrogen.

Now, in this case the temperature range is somewhat lower than that of carburizing, so temperature range will be somewhat close to 800 to 870 ^{0}C grade and you know in this case, the time of cyaniding is normally smaller, it is 0.5 to 3 hours and for basically, the having the skin depth of or a case depth of 0/25 mm or less you require lesser time so that is how the cyaniding process is defined.

Now, there is another you know process that is a carbonitriding process, so this is also known as dry cyaniding or gas cyaniding process, this carbonitriding process now, in this case you know it is basically the gas carburizing process and you have the addition of anhydrous ammonia and this ammonia that will decompose and it will give you nitrogen and which will be entering in the steel along with carbon.

So basically, you use anhydrous ammonia, so you know so typical gas mixture which is used is normally 15% you know NH_3, so your gas mixture will be 15% NH_3, then you have CH_4 that is you know 5% of CH_4 and you know 80% of will be your neutral gas; neutral carrier gas, so that we have already you know we seen while we talk about the liquid carburizing you know when we are talking about the liquid carburizing method that time we discussed, so that is normally used.

Temperature used will be about 750 to 900 ^{0}C and you know if you increase the temperature, then large amount of you know the carbon will be entering into the steel so that is your nitrogen now that is carbonitriding.

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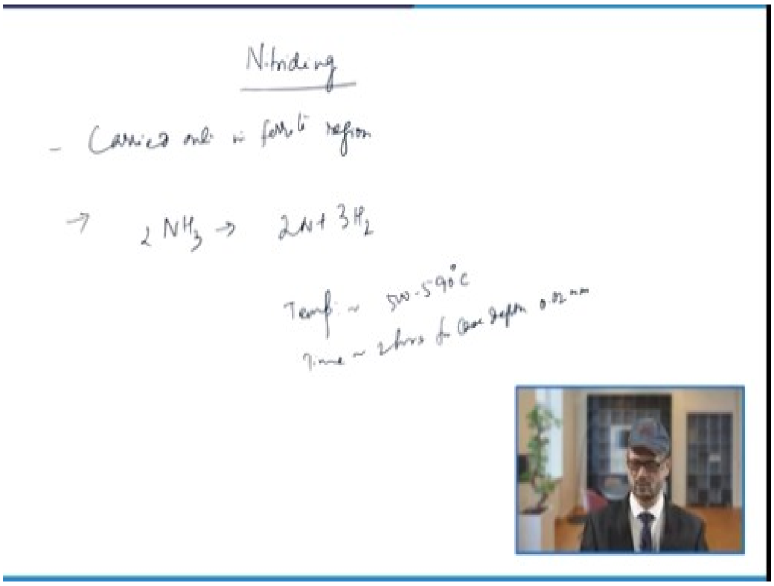

Now the we will also discuss about the another important you know case hardening process that is nitriding now, you know in contrast to the you know other processes which we discussed, this nitriding is carried out in the ferrite region, so carried out ferrite region, so basically you will have no phase change occurring because it is you know carried out in the case of in the ferrite region.

And you know this the part so, in this case you use the pure ammonia now, so this would have the cool; this should have; this should possess the required cool properties before you know nitriding and if necessary you have to have the prior heat treatment given to develop these properties. Now, in this case what we do is; we use take pure ammonia which will be decomposing.

So, your ammonia which we take it will be decomposing to you know $2N + 3H_2$, so the solubility of nitrogen basically you know in ferrite is very, very small so, what happens that you know the iron will react and it will form the you know hard nitrites basically, you know the concept of having carbon or nitrogen normally is that you will have the information of carbides or nitrites, so in this case this nitrogen will form the nitride.

And basically typically, the Fe_3N will be formed and you know the typical nitriding steel that will be containing alloying elements like you will have 1% of aluminium and 1.5% chromium and 0.2% you know molybdenum. So, in that case you are; so these aluminium, copper and molybdenum they form a very hard you know and wear resistant you know nitrites.

So, these alloying elements are typically required, so that you can do the nitriding you know treatment and you get the good surface hardness for these materials now, in the case of nitriding, the temperature will be of the order of about 500 to 590 ^{0}C and the time will be about 2 hours for case depth of you know something like 0.02 mm, so this way you get quite 1000 to 2000 time value of VP and hardness you are getting in such cases or close to maybe more than 60 that will see you are getting for these you know in the case of nitriding.

So, we discussed about all these different types of surface hardening processes which basically affect you know the surface characteristics of the steels and that can be applied to other you know allowing you know materials also, alloys also and this when we can; you can further you are advised to go through the other literature on the different you know heat treatment methods.

Because we must have the concept that how the hardening is taking place, how it affects the surface properties and what will be its effect on the mechanical properties, so this is about the different type of case hardening methods, thank you very much.