Principles of Physical Mertallurgy
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Lecture No. # 37
Surface Hardening

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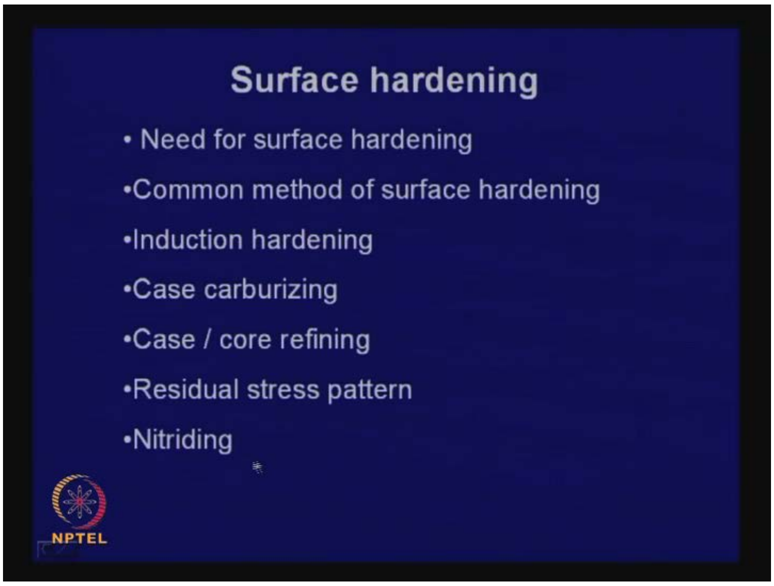

Surface hardening

- Need for surface hardening
- Common method of surface hardening
- Induction hardening
- Case carburizing
- Case / core refining
- Residual stress pattern
- Nitriding

Good morning, last six classes, we talked about the heat treatment of steel. And today we begin a new chapter, new topic, we look at surface hardening. Now under this, we will try and see why we need surface hardening. And one of the reason we may say it is quite evident when we talked about heat treatment of steel. So, if we want to harden it, often it is not possible to get uniform properties from surface to the core, because of the limitation of the cooling rate that we adopt. Even if we quench, if the dimension is large, the core will may cool depending on the dimension of the job, the core may cool very slowly you may have a totally different structure and properties of the core whereas you may have extremely hard structure at the surface. And in surface hardening, we actually try to exploit this feature.

And we will see why do we need? What are the types of components where we need surface hardening? Some we look at some common methods of surface hardening, we will talk about induction hardening, we will talk about that the carburization process, case carburizing, we will talk about post carburization heat treatment, case and core refining. We will also look at the residual stress pattern that is likely to develop as a result of surface hardening, we will see whether it is when it is beneficial, when it is harmful, and we will also talk about another process of surface hardening called nitriding.

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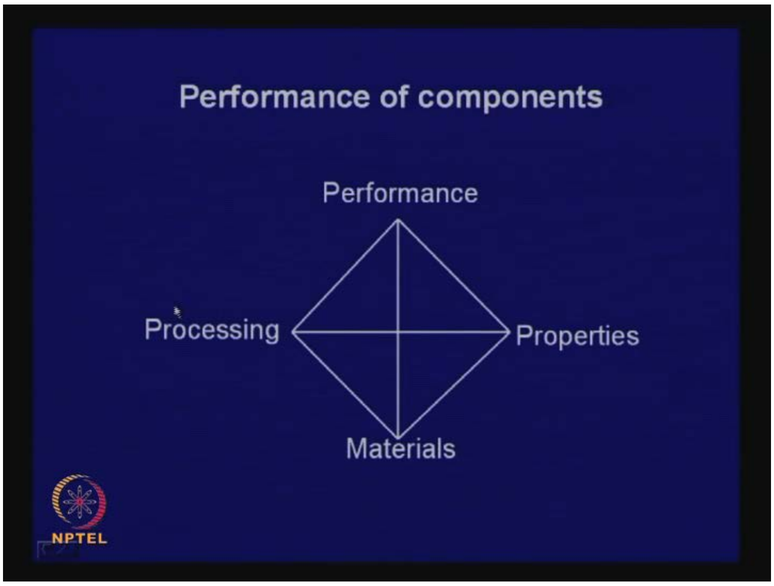

Performance of components

Performance

Processing

Properties

Materials

Now main purpose of this particular course is to correlate the material and the processing technique which is adopted. The material means basically we see that the composition of the material. What the material consists of whether it is a pure metal, or it is an alloy, what are the alloying elements added. And how do we process; whether it is cold rolled, or whether is annealed or whether it is cold rolled and recrystallized structure, or whether it has been given some special heat treatment, or some thermo mechanical processing that will affect this properties. And whenever we select a material, it has it posse's specific properties it has to perform well in surface.

Now these performance criteria will vary from component to component, for certain component we will look at certain specific properties. So, suppose if we are selecting a material for cutting tool or axe. What we will look for? Whether the material is extremely hard, can be hardened so that it can cut most material so in that case obvious choice will be say suppose we see that plain carbon steel because (( )) is quite thin. You can quench a plain carbon steel so having a high carbon content, and you can get filled in martens tic structure give it a low temperature tempering, and it will have a very high hardness close to Rc64, and with this we will be able to cut most metallic materials and many other non metallic material as well. So, here the performance you know the processing is actually apart from the making the sheet of the I mean thin sheets from which by thermo mechanical processing from which (( )) will be made. And another important processing is heat treatment.

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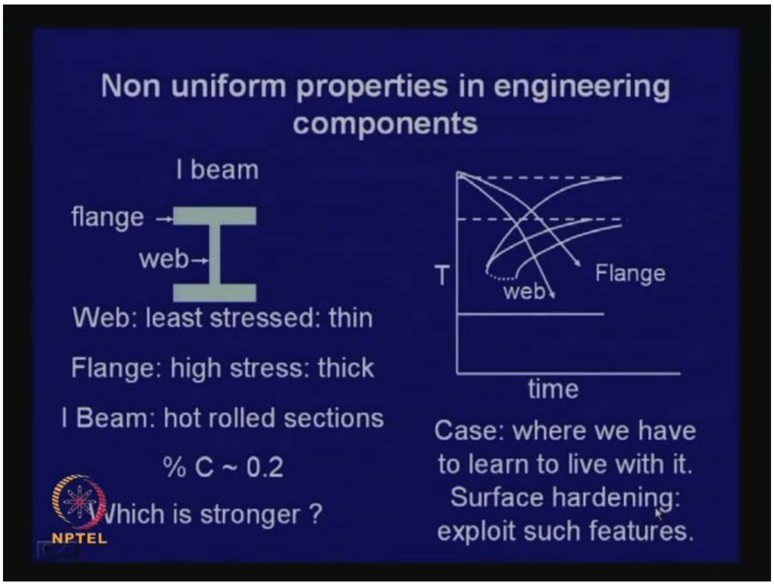

Non uniform properties in engineering components

I beam

Web: least stressed: thin

Flange: high stress: thick

I Beam: hot rolled sections

% C ~ 0.2

Which is stronger ?

Case: where we have to learn to live with it. Surface hardening: exploit such features.

Now we will see some examples, also as we go through this lecture. And infect when if we look at a real component it will always a particular dimension and very often, this dimensions are quite large. So, one of the common structural components that you may have seen is I beams. So, it is used in bridges; it is used in multi storage construction of multi storage buildings; and there you will find the section has different dimensions and different zones. This I beam, this is the flange part, actually and this is the web part, and this is the top flange, this is the bottom flange, this dimension are same and this is way this relatively thin, and these are named by section rolling or hot rolling. And this is rolling is done at high temperature a steel has made around 1200 to1100 1200 to 1100 degree centigrade it is rolled into this section and after that it is here cooled.

Now since the section size here is small, when it is air cooled you may find that the flange will cool the materials in the flange will cooled relatively slower compare to the web. So, therefore what you expect that the web will have finer paralytic structure, it will be stronger whereas, the flange will cool slower it will have more amount of (( )) fluoride, it will have relatively coarse paralytic structure. Therefore, this strength will be low and this part will have a higher strength and usually we find that normal processing you will find that this will have a high strength and this has an associated arm along with ductility may be relatively low compare to this.

Now the point is this is obviously so he real though you know that design in specific properties this turned away that actual that most critically stress region is the flange so that is why it is made thicker. So, this is where you know we learn to live with it and in surface hardening so this is not intentional. This is because of the size limitation, you get different properties and whatever and whenever you design a I beam, you always see that this is the least stress so make it thin, this is the high stress region so you make it thicker. So, that the stress is a much lower than the permissible level of stress for this particular material.

Now we try to develop in other similar properties when shear in case of surface hardening, we try to exploits such a feature. Say if different regions are cooled differently, you can get different properties if you cool surface very fast then you will get very hard structure and the surface and many applications we do need such material.

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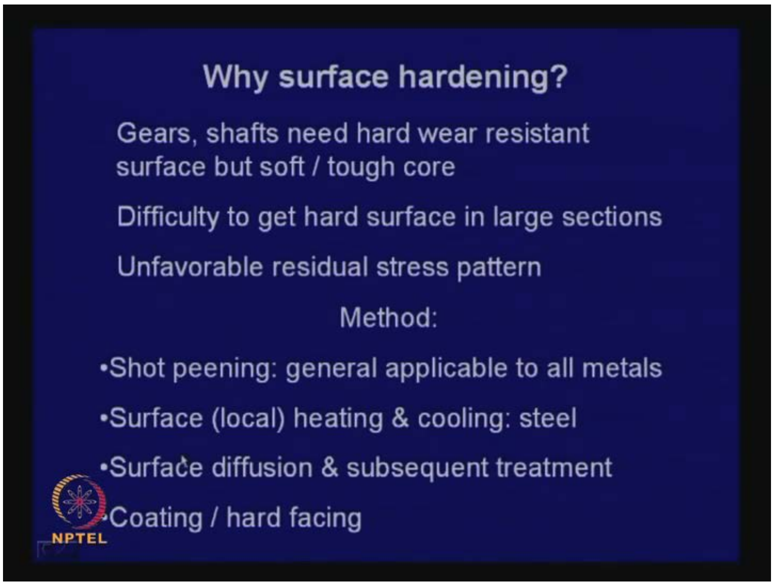

Why surface hardening?

Gears, shafts need hard wear resistant surface but soft / tough core

Difficulty to get hard surface in large sections

Unfavorable residual stress pattern

Method:

- Shot peening: general applicable to all metals
- Surface (local) heating & cooling: steel
- Surface diffusion & subsequent treatment
- Coating / hard facing

So here you can see we have listed, why surface hardening is necessary? So they are several components like gears, shafts some of this drive shafts will be huge very large. Particularly say steam turbine for power generation. They are extremely large. I mean the diameter itself may be often it diameter and the length also may be quite long, may be 10,15meters long and such a material is to be given and it rotates many of these components they rotate at very high speed. So that therefore, the surface is highly stressed. And it is also the steam passes through it is also suppose to have good resistance. So, materials like to this gear, shafts they need high wear resistance surface.

And it must an at the same time it must have soft core but core discussed is not very high but if therefore, it is better to have a soft and tough core. So, that you know even if a crack initiates at the surface is does not propagate to leading to failure. Now problem is difficult to get hard surface in large sections, so like gear some of these gears the sections size is quite large shafts are indeed a very thick components. So, here it will be impossible virtually impossible to get full hardness like quenching that whole component. Not only that when you quench a very large component that thermal gradient will be so high that it will be thermal stresses will be very high. Along with it the there will be super impose transformation stress. And that can result in cracking, during because of thermal soft as well as for the transformation stresses and you get unfavorable residual stress pattern, if you try to harden such thick components.

Now how can we do surface hardening? So there are several methods we will not go all of these, and I am told there is a separate course on surface engineering. So, therefore we will talk some of these which are relative to steam say some of these which are listed is a shot preening. It is a general approx method it is applicable to all metals. Like steel we have seen it can be it is amenable to a large number of spatial heat retreatment processes, because it can undergoes allotropic transformation. It has certain special that phase diagram has certain very specific features which allow makes it amenable to a large number of different heat treatment processes, which may not be show in many other matters, but shot preening where you try to see some harden poles.

They are allowed to they are at a moving at very high speed it is allowed to strike this surface and the surface get cooled, what there is a local hardening which results increasing strength of this surface. Now there is another way of doing it that is heat that is local heating heat only the surface and then cool at fast. So, this is applicable to steam and here you do get very high hardness we talked about treats a little detail. There is another so normally in order to have a low I mean top core it is often necessary that you have low carbon on the core. So, low carbon in the core gives you very good toughness, and it can also gives some special hardening treatment, special heat treatment by which you can indeed the toughness of the coal by making the cementite, which is actually the present carbon is mostly present as cementite.

And if it is present in politic it may not have that kind of a toughness, that if you can give a special heat treatment by which you can (( )) the plate cementite plats in politing into small globules. Then what you will have a dispersion of globules find globules are cementite in a ferrite matrix and that type of structure has very high good toughness and also they are they can be machined. They have good mach inability, many large components surface giving this kind of heat treatments (( ))annealing they are machined and then finally, the surface hardening heat treatment is given and let us see and in that case.

If you have low carbon content, you know even if you heat this surface and quench you may not get desire hardness. So, therefore you need to modify the composition of this surface. So, you need and this is then by some amount of by diffusing that element which can increase the hardness of surface and then subsequent heat treatment. And apart from this there are lots of other coating processes where you can give hard coatings, and usually coatings are they are the multi layer coatings. You may have to give to maintain the compatibility with the base material; you may have to give several layers of coating. Bond coat then you have an ultimately you will have hard that resistant coating, wear resistance coating or since some material you want thermal gradient coating. So, different types of coatings are possible for different types of application but we are going to the details we will concentrate on because these two are related to heat treatment of steels and bulk of the components that we used they are may tough steel.

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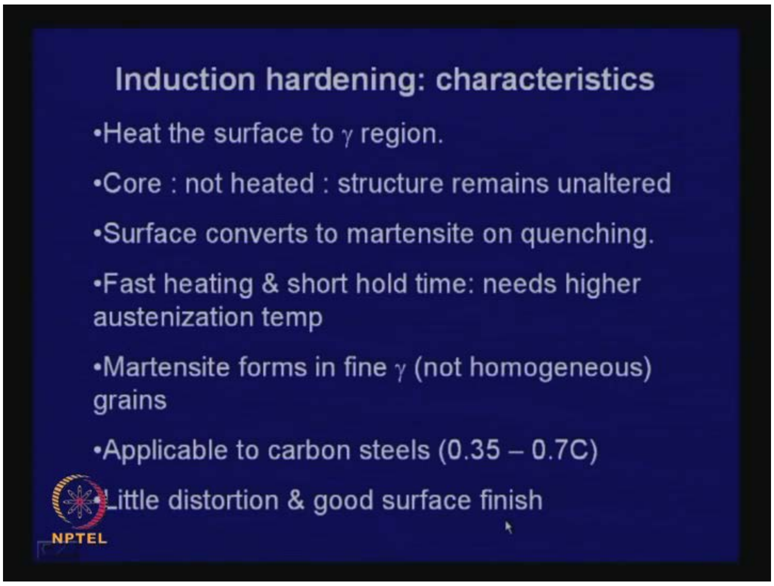

Induction hardening: characteristics

- Heat the surface to γ region.
- Core : not heated : structure remains unaltered
- Surface converts to martensite on quenching.
- Fast heating & short hold time: needs higher austenization temp
- Martensite forms in fine γ (not homogeneous) grains
- Applicable to carbon steels (0.35 – 0.7C)
- Little distortion & good surface finish

Now one such heat treatment process is induction hardening. And induction hardening what you do is you heat the surface that is local heating? We will see apart from this there may be some few other methods of local heating, but let us concentrate on induction, hardening and here you heat this surface by induction heating, put the job in an within an induction coil and it gets heated, because of the eddy current of that high frequency is either current that flows through the coil and it gets heated to the austenitic region. Here core does not get heated because of that alternating current because of the stream effect the core does not get heated and structuring in some alters surface (( )).

And then surface after since it has converted into austenite. If you quenched this surface many times you know the quenching facility is are also melting with the coil. After it has hardened you can quench by spraying water or any other quenched and therefore, you can get marten site on the surface. So, one of the main characteristic of this is very fast heating, and the time is very short that whole time is very short. So, therefore what we may need you may need littler higher austeniting temperature than the normal hardening process and then marten site that forms will be form in very fine austenitic grain.

And this austenite grain to make it homogenous also we have seen that this a diffusion control process. If whole time is very short that is quite likely that this austenite may not have homogenous. That austenite grains may not have homogenous compositions it may have different carbon contain, and different region there may be some amount of un dissolved carbides also. So, therefore that martensite that forms will be forming in a non homogenous austenite there will be some amount of un dissolved carbides. But which will gain and because of all this combinations it may often have higher than expected hardness that higher than hardness that you normally that you normally would have got and the steam having the same carbon content.

And this statement can be given to carbon steels also plain carbon steels. You use may not have any alloying element, any anime I mean intentional alloying element to improve hard inabilities may not be require. You mean simple plain carbon steels that will an it must have a little high carbon, because if you want high hardness at the surface this hardness is determined primarily by carbon content in the steel. So, it should have relatively high carbon content and since only the surface is being heated and heating time is also very short. So, normally when you give a heat treatment, if there is a long soaking period then the surface gets oxidized, surface finish is disturbed but here the heating time is very short. So, therefore it remains good surface finish there is little distortion because the total heat content is also less.

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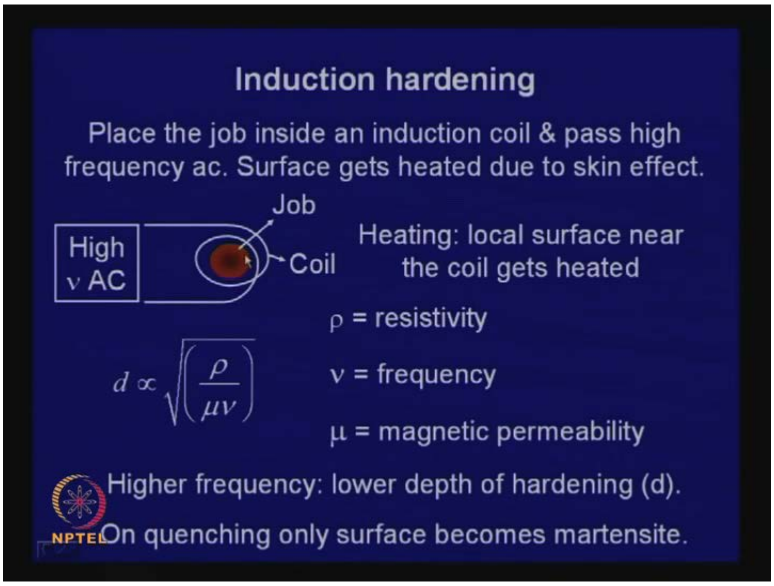

Induction hardening

Place the job inside an induction coil & pass high frequency ac. Surface gets heated due to skin effect.

High ν AC

Job

Coil

Heating: local surface near the coil gets heated

$$d \propto \sqrt{\left(\frac{\rho}{\mu\nu}\right)}$$

ρ = resistivity

ν = frequency

μ = magnetic permeability

Higher frequency: lower depth of hardening (d).

On quenching only surface becomes martensite.

And this in this particular slide; now we have a particular you know scribes this is the high frequency alternating currents shows and this is the coil and usually this coils are water cooled. And here is the job and which gets heated, and it is we are tried to show that dramatically. Even it heated this is assumption value the core central region does not get heated it is the surface that give heated. And after you get heated you know that the depth of hardness will be determined. This is a particular explosion which describes the relationship between the depth of hardening and parameters which you can control. And what you can control is the frequency of the current? And if you use a very high frequency because of the steam effect the thickness, the depth of hardening is low.

So, depth of hardening can also be increased by increasing the whole time also, because if this gets heated and this heat will get transmitted as they get conducted to through a little more through this is a core also, if you have a longer heating time may be the thickness depth of hardening also you can control. So, by controlling the frequency; controlling the whole time you can control the depth of hardening and this is the primarily depend depends on that principle of heating is because of the eddy current. So, therefore resistivity is an important factor and it will also determine by the flux linkage so that is which will be determine by the magnetic permeability. So, obviously with high temperature now austenitic region it will be little low so but, in the image surely it is quite high.

So if you give low and that case you can see it is inversely proportional to this. So, high permeability will slow depth of hardening but, in the austenitic it will be relatively low. So, main factor which you can using to control because these two are material property you may not have many option to play with, that what you can play it is the frequency? Frequency and whole time and on quenching after it has reach the particular it can be automated also. You can temperature listening devices and immediately after this it reaches the temperature, you can stop water spill it is cooled. And since an during cooling you know the heat will be flowing outside as well as it is inside as well. Now let us look at the structure within where they I mean in a induction harden steel.

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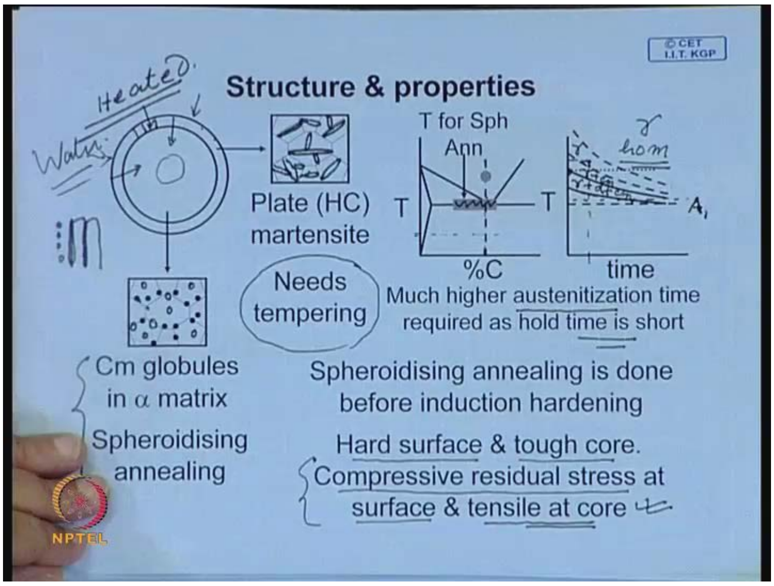

Structure & properties

Plate (HC) martensite

Needs tempering

Much higher austenitization time required as hold time is short

Cm globules in α matrix

Spheroidising annealing

Spheroidising annealing is done before induction hardening

Hard surface & tough core.

Compressive residual stress at surface & tensile at core

So here, if you look at this part where I said in order to get good the tough core it is previously given as Spheroidising annealing. And this diagram which shows the usual Spheroidising annealing temperature, and usually if you keep around this (( ))if the temperature is slightly fluctuating it gets were Spheroidised very quickly. That cem1entite plate less that means cementite plates and palette. So, this is the cementite plates in a palette and if you keep it for little longer this breaks down into globules and by this it is possible to have a totally globular structure within this. And in microstructure of course, of in this particles are very small they may look like a dot and if it is (( )) they will look this type of globules and if the boundary will be and there will be such globules.

Although an amount of this cementitite will dependent on the carbon content. By this spheroidising element you will get a very top core that also has some machine ability and after the full machining you give induction hardening. And here let us say only this is that area which gets heated this is the area which gets heated so the during it this induction hardening the transformation will be localized. So, only this area has been heated so expect transformation and look at what will the temperature. Now you have to convert into austenite. So, therefore if this an you have to keep it in the austenatinic region. That let us see this is the critical temperature and say let us see in the surface if the carbon content is around this.

So this is the critical temperature, this is A1andA3 will be little over this but we will try to heat it with sufficiently high temperature. Because your time of hold time will be very short, because of long hold time the purpose of surface hardening will be lost. Because (( )) to strike will flow inwards and make this very that heated section will be much thicker then you may land up a problem. So, what happens here we have to treat with to a little hard temperature and then we have to add just your time? So, here may be the austenite first appears a already you have austenite plus ferrite type of structure and that you means also have some amount of cementite also present, here you may have some austenite plus some carbide cementite, and here possibly you have in homogenous austenite, and here this line beyond this you will get homogenous austenite but often this time may be very long.

So one way of heating it may be you heat it where relatively higher temperature short time you may have to quench from this region. So, that is why since say you have to use much higher austenite excitation temperature as in time is very short, and when you quench it has reach that particular temperature kept it for certain length of time. You quench that mean by spraying water, water spray you quench and this usually the quenching rate will be very fast and in this high carbon steel say if is the high medium carbon steel you will get plate type of. So, these are like this kind of an (( )) shape plates type which develop which partitions that austenite boundary.

So initial plate will be longer and subsequence and we can this will be totally thermal and entire structure will be converted into plate martensite and it will have a very high hardness. And since this is a plate and this is a non stable temp microstructure so it gives a little bit of tempering and in fact it can be automated after you quench and you can same coil heating coil can also be used to heat the surface. But this time you heat it to lower and here lower range and you can give the tempering. So, this is a very highly automated and easy I mean and can be easily implemented in mass production. And when you do this we will see later also not only you develop hard surface and tough core.

But you also develop compressive residual stress at this surface and always whenever you have residual stresses develop in a component. Because of local plastic deformation and whenever in a region you will have compressive stress then will be in certain region. You must have tensile and in fact in the core there will be tensile stress and the components were particularly in shaft that core. A core the stresses will be very low. So, therefore, you can effort to have little tensile strength at this surface, but at the core but not at the surface because surface is the most highly stressed part of the component.

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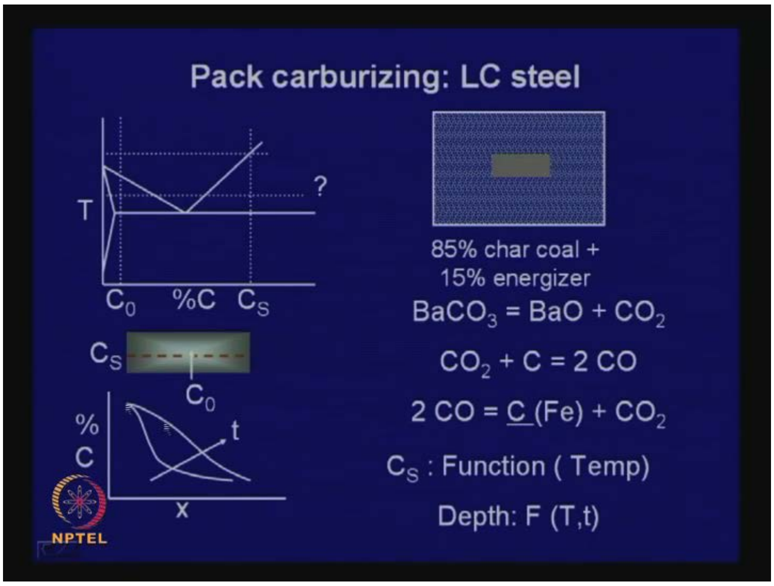

Pack carburizing: LC steel

85% char coal +
15% energizer

$BaCO_3 = BaO + CO_2$

$CO_2 + C = 2\,CO$

$2\,CO = \underline{C}\,(Fe) + CO_2$

C_S : Function (Temp)

Depth: F (T,t)

Now the problem comes up when you try to harden a steel where the carbon content is low. Many times for many application particularly gear, say you want that gear threat it to be quite cheap. So, if you fed is made up of mostly plane carbon; it will be quite cheap so if you have a low plane carbon steel say having more than 0.15carbons.And then if you can somehow enrich the carbon content on the surface and then you give heat treatment and infect this is the most common heat treatment which is given to gears. And heavy duty gears and here what is done one of the there are several types of methods by which you can increase the carbon content of this surface, and one way popular method is pack carburizing and this treatment is able to low carbon steel.

So, here you have a material say suppose this is the job which is kept in a mixture of carburizing mixture, which is made up of activated char coal say around 85 percent char coal and you also need some energizer 15 percent energizer to promote carburization process. And how does it promote carburization process? When you heat it to higher temperature many 900ferohms and 950 degree centigrade, what happens this bariums carbonate and this is and this is the pack get and in fact, this is you do not have enough oxygen in this oxygen is only limited to the extent, which is that air which is trapped with in these spaces between a charcoal particles and the energizer.

So, what happens here this primarily you get oxidizing it. I mean how do you get this carburization this barium carbonate decomposes and you have you do not have enough oxygen here; this CO 2 then plenty of carbon so CO 2 will react with carbon to form carbon monoxide. So, surrounding this particular job say if you look at here surrounding this particular job, you will have an environment a gases environment which will consists of primarily as CO and CO 2 and infect this CO in presence of steel at the surface it decomposes in to this is and this carbon this is a nascent carbon which has very high activity.

And this can get this can this is an interstitial element and 950 degree centigrade iron can dissolve large amount of significant amount of carbon. So, it diffuses very fast and moves into austenite and this is the reaction name carburization reaction. So, two things you have you have acquired disposal to control the exploit of carburization; one is the temperature, higher the temperature higher will be carbon content at this surface and faster will be the reaction. And also you have to allow the carbon tine to allow you have you need time for carbon atom to diffuse moving to iron lattice. So, therefore you have to allow certain amount of time. So this is dependant so that the carburization will be a strong function about temperature and time.

Now the question comes to what temperature will leave heat it to? Now suppose you if you heat it to a lower temperature over here; now the problem is at this low temperature. First is solubility of carbon in ferrite in this region is very low. So, ferrite can only very limited amount which is possibly less than the carbon content which is already there so this ferrite is saturated so it cannot absorb much carbon. So, you cannot now the question is can you do carburization over here? But the problem is here; if you heat it will be a two phase structure at this temperature, the structure will be made up of here, if you look up here it is made up of ferrite plus austenite. Yes of course, austenite can dissolve high amount of carbon but not ferrite so if you have on the surface you have ferrite grain you also have austenite grain.

So, you will find the carbon will diffuse more here and very little over here; because ferrite solubility is very little so here again the problem will be the carbon distribution is not likely to be uniform less structure. So, this is the problem so obvious choice will be you have to heat it within this austenitic region and better is you keep it at little higher temperature. So where mobility of carbon atom diffusion coefficient is high and say this is the temperature so may be around 950. If you heat then the austenite can dissolve after this much amount of this carbon. So, this carbon contain at this surface will primarily determined by this temperature at which you are performing pack carburizing operation.

So this determines surface carbon content and the depth of carburization will dependent on the diffuse ability of carbon at higher temperature; it has higher diffuse ability. So, therefore high temperature will have actually high temperature will get higher the temperature, will higher will be the depth of carburization and higher carbon content at this surface. And the process of mechanism is illustrated here; if you heat this in a carburizing atmosphere what you have you maintain a high carbon concentration at this surface, and here you have high carbon concentration.

Whereas, at the coat. This is the sectional view and so carbon heat and so there is concentration variant and carbon will diffuse from high concentration to low concentration. So, you will have a concentration gradient which is shown over here; you have maximum carbon content at this surface as you go inside deeper a carbon content will be low. So, it will you will have this kind of a plot and if you hold it for longer time same temperature carbon content of the surface will remains same. But the depth of hardening the depth to reach the carbon concentration increases that will increase. So, like here this is the depth whereas here this is the depth. Let us see and it is possible we learned about the diffusivity the process and how to calculate this depth of carburization.

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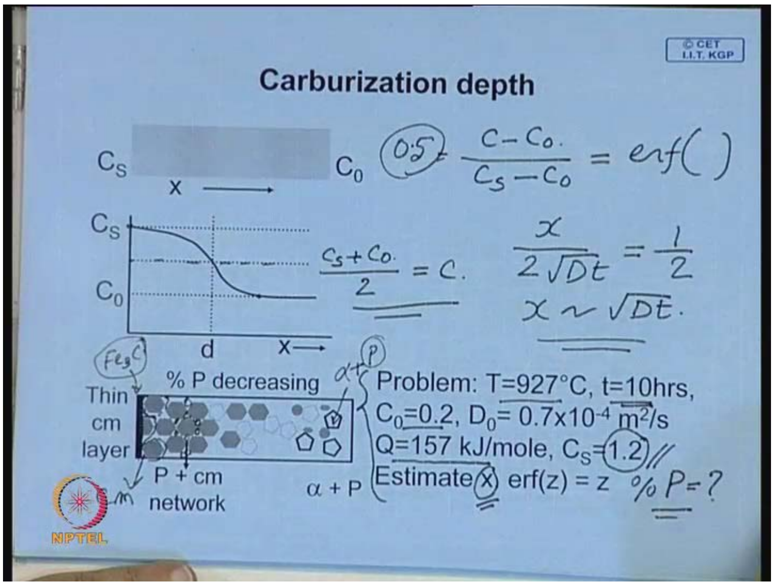

Carburization depth

$$\boxed{0.5} = \frac{C - C_0}{C_S - C_0} = erf(\ )$$

$$\frac{C_s + C_0}{2} = C$$

$$\frac{x}{2\sqrt{Dt}} = \frac{1}{2}$$

$$x \sim \sqrt{Dt}$$

Problem: T=927°C, t=10hrs, C_0=0.2, D_0= 0.7x10^{-4} m^2/s Q=157 kJ/mole, C_S=1.2 Estimate x erf(z) = z % P = ?

And next slide we lasted that say suppose we assume this as a one (( )) problem. You maintaining high carbon content at this surface and this is and this is the core where you have low carbon content. So, this is the position at time t 0, but with time the carbon will start diffusing and we have seen hat this carbon concentration at any instant at any position, when we this is the carbon content C, where as this is the initial carbon content of the steel, this is the carbon content which at the surface. So, this is given by this error function; where x is the distance from this end. Where you have high carbon concentration and D is the diffusivity t is the time. And in fact the diffusivity is given by this type of expression so this is the diffusivity of carbon in gamma (( )).

So, this is the diffusivity of carbon in gamma (( )) and many of these as I mean experimentally determine. So, it is actually possible to calculate also. And it is also not difficult and we can even makes some approximate calculations; say if we assume that if you look at this sheet here, if this is the surface content somewhere in the (( )) we will have average carbon content and if we define that this is the depth of carburization then it is quite easy to find out this depth of carburization using this equation here and we know that the air function around if this value this z is around 0.5 then error function is equal to 0.5. So, that is why you can say if this is equal to 0.5 because if you put C as C as I have explained if you put C this C equate it to C and substitute in that equation for that C minus C naught here in this equation error function here then you will find that this comes out to be 0.5.

So obviously then x over 2 root over Dt this is equal to 1 over 2therefore, depth of carburization is approximately equal to root over D t. And here is a problem we can try so the temperature is given the time is over here this initial C naught is given the activation energy for carbon in austenite the defuse ability carbon diffusion in austenite is given and the surface concentration is this and try and estimate the depth of carburization. And then if you estimate the depth of carburization, you can say that here what will be the amount of percentage parlite. You can this find out how much will be the percentage of parlite over here.

If you look at the microstructure after this carburization heat treatment; if you look at the micro structure you will finds there will be a thin layer a some carbide also, Some cases it is reported you may have a thin layer of which will be brittle and during quenching and all that cracks and gets removed. So there may be acementite and after that here you will have here, you will have a network of this bright network which will be made up of cementite network. And as you go inward the cementite network will become thinner and that will be a region where you will it will be mostly parlite100 percent mostly parlite, and some parameters possible to guess you know from the cemenite network.

What is the austenite grain size (( ))grain size of this material, and as you go downward here that structure will be mostly ferrite plus little amount of parlite depending on the carbon content. So, you have you in have a structure gradient when structure will vary from surface to over.

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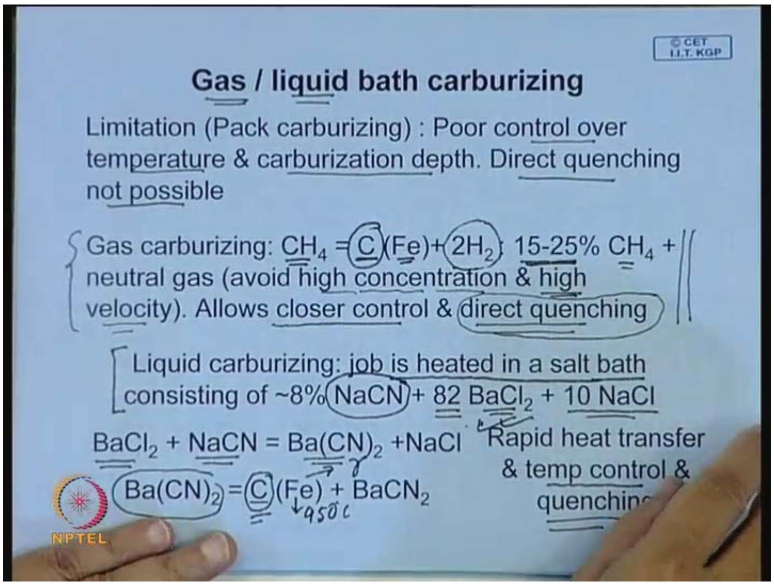

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Gas / liquid bath carburizing

Limitation (Pack carburizing) : Poor control over temperature & carburization depth. Direct quenching not possible

Gas carburizing: $CH_4 = C(Fe) + 2H_2$; 15-25% CH_4 + neutral gas (avoid high concentration & high velocity). Allows closer control & direct quenching

Liquid carburizing: job is heated in a salt bath consisting of ~8% NaCN + 82 $BaCl_2$ + 10 NaCl

$BaCl_2 + NaCN = Ba(CN)_2 + NaCl$

$Ba(CN)_2 = C(Fe) + BaCN_2$

950 c

Rapid heat transfer & temp control & quenchin

NPTEL

And now let us see there are certain limitations in pack carburizing; In pack carburizing of course, it is very easy you packet in a box consisting of that carburizing mixture. But here after you have done the carburizing you cannot lighten that is in hardening after it has harden and you can spray water, you can cool, you can quench. But here it is not possible so this is a major limitation second is the temperature control is also a major limitation by pack carburizing. You have some poor control over temperature and carburization depth; and also you cannot directly quench. Direct quenching is not possible so to import the productivity depending whether job sizes are small.

So many cases it will prefer gas and liquid bath carburizing. What are these? So, essence is you have to heat the job in environment where with high carbon potential. So, one way of doing it you can heat in a carburizing atmosphere there very common gas make sure is around 15 to 20 percent methane with some nuclear gas carrier. It could be nitrogen or argon or which is does not react with steel .so, it could be nitrogen is quite cheap and quite popular so you can use that an under this condition this methane in presence of iron, you know it cracks this is that carbon which deposits and you also get hydrogen.

So it maintains reducing it does not oxidized so you have a good control on the surface quality that you need to await high concentration of this carburizing gas. You should not allow shoot formation and also say avoid you have to avoid also high velocity, because you have to allow some resistance you have to give, if you allow so avoid high concentration, high velocity. But this kind of control many of these temperature devices can be adopted, you can also have flow control devices and you so you have a very close control over the process so it allows close control and as so on this depth of carburization on temperature and also it allows direct quenching facility.

So, in certain cases it cuts down to post carburization heat treatment cost. Similarly, the liquid carburization is another alternative process where you have the job it is heated in a salt bath. And this salt bath are usually chloride bath which are say one common composition is around 82 percent barium chloride and 10 percent sodium chloride and you have an sodium cyanide. So, this is the source of carbon. And in fact the reaction which is given here is barium chloride reacts with this forms barium cyanide and sodium chloride; and this decomposes near the steel surface and giving this nascent carbon and which dissolves in iron. And at this temperature is around 900 or 950 degree centigrade where this will be austenite this will be in austenitic static state.

So, obviously you are dipping the job in a liquid bath which is already heated. So, there is a rapid heat transfer the process is quite fast, you have a better control and temperature. And you can after this that certain time, you whole time, you can take out the job and quench in an appropriate quenching medium. So, therefore this method is become very popular.

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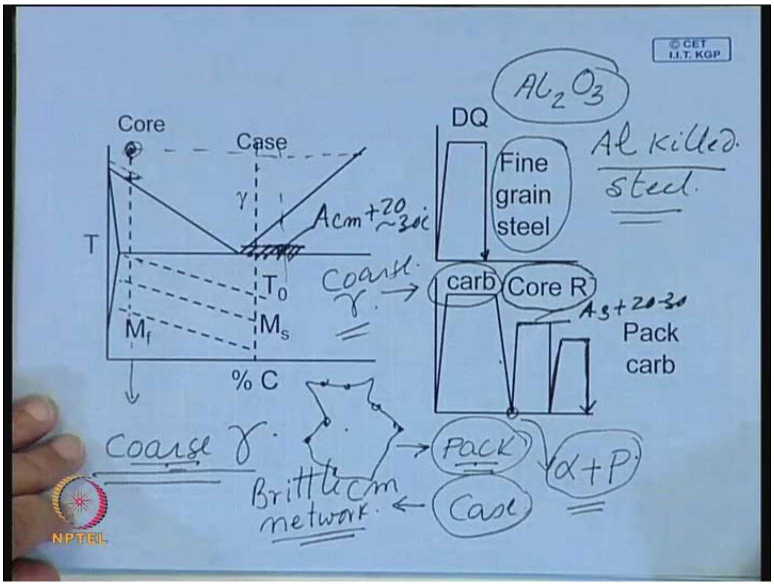

And but the now the problem comes up when you do carburizing; you are heating it toward relatively higher temperature, and when you heat a steel at relatively higher temperature. So, suppose pack carburizing you are heating it somewhere here which is much about a normal heat treatment temperature around here. So, you are heating it here; so that you have that carbon carburizing process is fast carbon content at the surface is higher. And after that what happens if you quench here you have a very coarse grain structure coarse austenite grain.

Now we know the coarse austenite grain, the austenite grains are coarse you know the sight for palette or diffusion product to form that reduces. So, therefore its harden ability increase so it is quite lightly after this you know if you directly quench from this particular temperature. You may have problem sometime you know the core can also get harden. So, usually this is avoiding but certain cases if you make sure that if this a steel is such that and you have a good control over whole time certainly not in case of a pack carburizing, this courses is ruled out in not in pack carburizing, if it is pack carburizing in anyway direct quenching is not possible.

So pack carburizing you have the heat it very complicated heat treatment sequence, but in case of a liquid carburizing or gas carburizing there is a possibility, if the steel is fine grain then such coarse grain will not develop. As it develops in pack carburizing and there you can quench directly and say you know lots of subsequent, you do not have to go through subsequent heat treatment and after that you just temper and use. So this is possible in fine grain steel as grains only such steels are aluminum killed steel this killed steel you know here aluminium is added then this aluminium reacts with oxygen present in molten steel and form alumina and these alumina they block the grain boundary movement migration of grain boundary so this is a important.

So depending on the type of steel that you have you can choose and if you are selecting gas carburizing or liquid carburizing; you can directly quench after carburization. But in case of a pack carburizing it is not possible; you have a very coarse austenite grain at the core. You have a case carburize proportion here; you have a high carbon content and because of this they also have different emission and Emmett temperature now you have to give to this type of step treatment, after this is the carburization medium where here it develops coarse austenite and in pack carburizing there is no way you can quench you will be cooling slowly.

So, that is the time where the core also core; you will have coarse austenite grain where that it will be made up of core will be made up of ferrite plus parlite. But pair austenite grain size will be coarse whereas case has a high carbon here somewhere in this region, and if you are cooling there is a lightly hold that cementite network will be form. So, core may be because of the slow cooling you may have a case may brittle cementite network; which is undesirable. So, therefore, you got to refine first core refine core by heating it above this temperature.

So this is normal A3 plus 20 to 30 degree centigrade whole time gives sufficient whole time then you quench and that was the time. you know you can refine since you are suppressing this one cementite network does not form over here this also gets converted into possibly, you will have globules of cementite or broken cementite network in case and finally, you give case hardening treatment and here if you retreat to this temperature. Because this case is hypereutectoid so you heat it to this temperature A cm plus 20 to 30 degree centigrade and after that you quench so you will have now the final heat treated structure.

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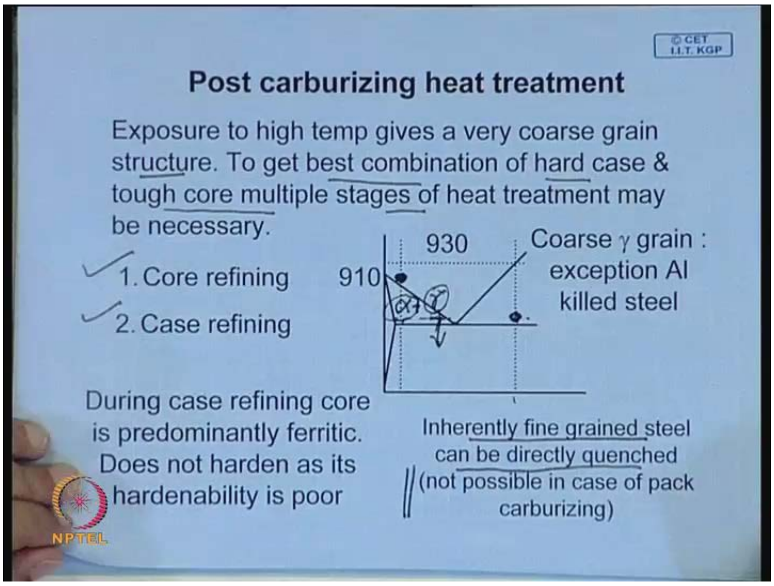

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Post carburizing heat treatment

Exposure to high temp gives a very coarse grain structure. To get best combination of hard case & tough core multiple stages of heat treatment may be necessary.

1. Core refining
2. Case refining

Coarse γ grain : exception Al killed steel

During case refining core is predominantly ferritic. Does not harden as its hardenability is poor

Inherently fine grained steel can be directly quenched (not possible in case of pack carburizing)

So, this is shown here you know exposer to high temperature; this temp gives a very coarse grain structure and the core and to get this combination of hard case and top core multiple stages of heat treatment may be necessary. So, this is why we talked about core refining talked about case refining and hardening and both cases here the core refining.

You have to retreat this region and in case of case hardening, you come here and from this temperature and then give the final heat treatment. And invariantly fine grained steel this steel can be directly quench. But that it is not possible in pack carburizing, and this I think and during the final hardening of course, this has a final hardening you know even if the core you are here.

So, what you will have it is predominantly ferried plus some amount of austenite? This austenite even if it is gets transformed into there is a possibility it can be depending on section size. But it will still have you know heaviness of matrix you will have hard face which is martensitic and it will give a very tough core, it will still have a very tough core and after this you also need to give some tempering heat treatment and one of the important thing in this type of hard heat treatment is that development of favorable residual stress why do you get it.

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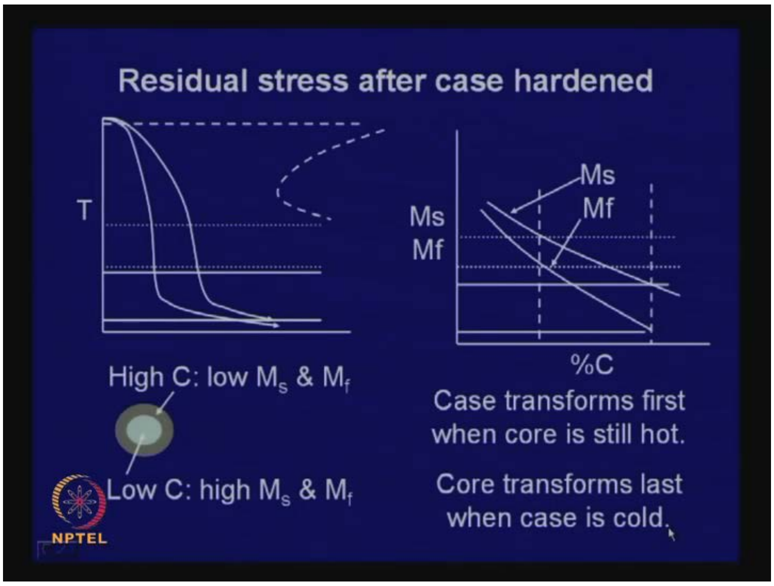

Residual stress after case hardened

High C: low M_s & M_f

Low C: high M_s & M_f

Case transforms first when core is still hot.

Core transforms last when case is cold.

And which is shown over here; you have a surface and the core and they have different carbon content which is shown over here schematically. I have shown this is a low carbon, this is core, this is case. So, these are I think this is we will look at this over here; there is you look at this over here at the core this is the Ms this is Mf. Similarly, case this is Mf Ms (( )) maternsitic temperature. This is Mf now you have different cooling rate when you are quenching this is the surface cools slower. So, this is initially temperature is same and final also temperature will going to be uniform so in have this times of cooling rate or cooling curve and this is the case.

So, these cools much faster where as the core cools much slower; now what happens where does the transformation takes place. First we look at it when the case reaches Ms temperature the core temperature is quite high, high temperature means it has low strength also, when this core is transforming the case is transforming core can accommodate the deformation associated it can plastically deform. Because it has it is still very hot it is plastic. So, the therefore what you have in this situation? The case transforms first and it become hard, and after it has become hard then this transformation at cores starts now the core will try to expand; if the core at this stage tries to expand say see here, if the core which is a low carbon content if this is trying to expand this will not allow it to expand. So, therefore this is trying to expand. So, therefore this will be subjected to say core this case transforms first when the core is still hot whereas, the core transform last when the case is cooled. So, therefore you have a residual compressive stress on the surface.

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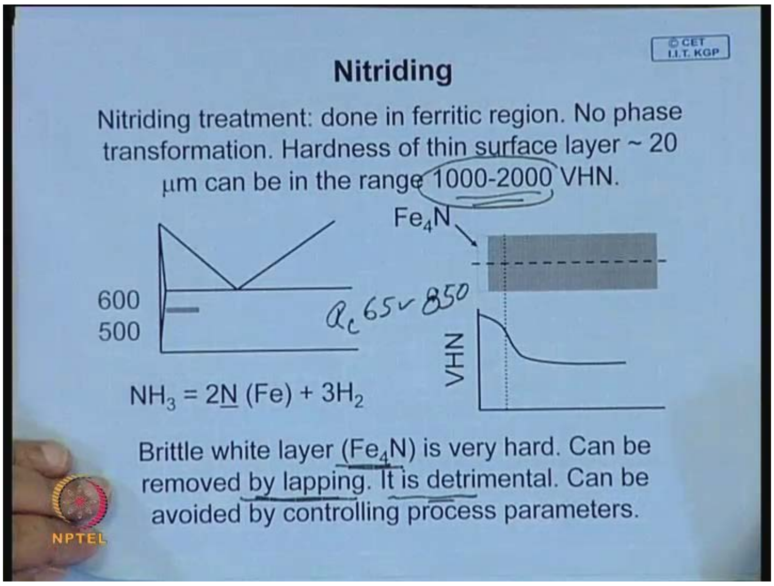

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Nitriding

Nitriding treatment: done in ferritic region. No phase transformation. Hardness of thin surface layer ~ 20 μm can be in the range 1000-2000 VHN.

$NH_3 = 2\underline{N}\,(Fe) + 3H_2$

Brittle white layer (Fe_4N) is very hard. Can be removed by lapping. It is detrimental. Can be avoided by controlling process parameters.

Now another important that heat treatment surface heat treatment is nitrogen also you can allow nitrogen to diffuse into the system. The process is exactly similar and this is done with the job is heated in a cracked ammonia environment and the temperature is much lower than the lower critical temperature, that means may be around 500 say in this temperature region if you heat and then the carbon diffuses and the nitrogen also can diffuse into steel and it can give this kind of hardness level. And therefore, and here you know and this hardness level that can be very high. Whereas, Rc around 65 is around say 850vpn we were weaker hardness number. So, imagine by this you can increase the surface hard gave very high level but, often you can form a brittle this nitrite layer and which is harmful. But this you can control by controlling the process also even it has formed later on by lapping by polishing, it can be removed it is detrimental, and but if you can control the partial pressure properly it is possible to avoid formation of this brittle layer at this type of treatment is very popular.

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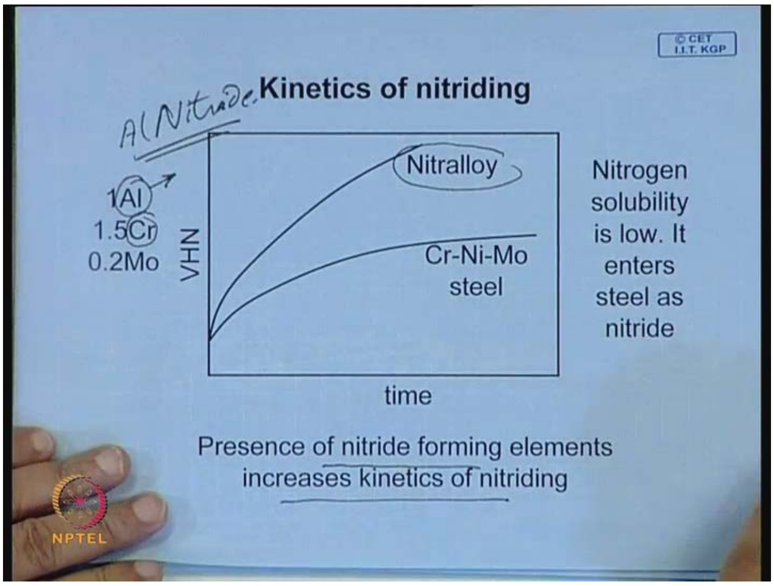

Kinetics of nitriding

Nitrogen solubility is low. It enters steel as nitride

Presence of nitride forming elements increases kinetics of nitriding

And given to different types of steel and there is a special type of steel nit alloy, where you do get very high hardness which is shown over here this is hardness against time. So, this and the depth of hardening also you have a similar type of profile and normal plane carbon steel you do not get that kind of effect. But if you have these alloy elements particularly the chromium particularly some aluminium is there; aluminium nitrite also aluminium nitride is also very hard and they add to the surface hardness and presence of this nitride forming elements is increases kinetics of nitriding.

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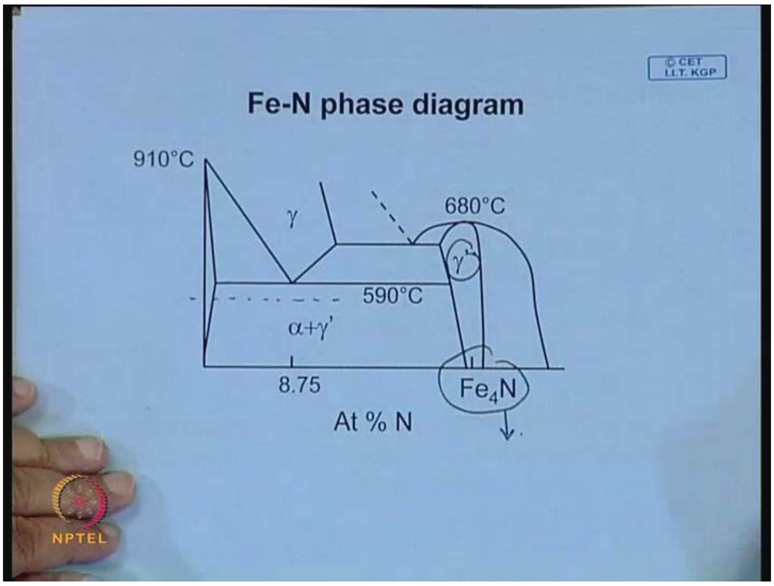

Fe-N phase diagram

And it will be interesting to look at iron nitrogen phase diagram, you are normal nitrogen a nitriding treatment in this region, and this is the gamma prime which is very brittle and you should try and avoid this.

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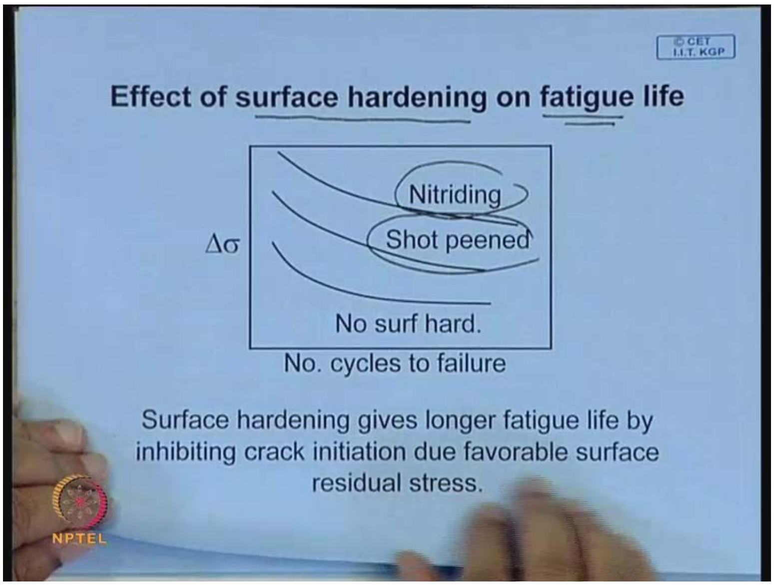

Effect of surface hardening on fatigue life

Surface hardening gives longer fatigue life by inhibiting crack initiation due favorable surface residual stress.

And main reason for this is you have a favorable surface hardening is on fatigue life. Many of these rotating components have given this treatment and which is shown over here, this is endurance limit it increases by giving this kind of this is the effect of shot preening this is nitriding many shafts are given this nitriding heat treatment particularly this hyper forming this turbine shafts are given this kind of heat treatment.

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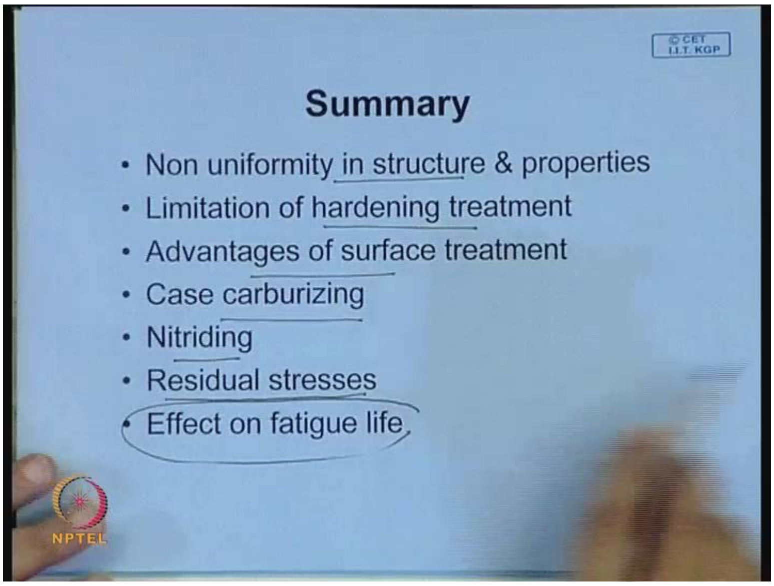

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Summary

- Non uniformity in structure & properties
- Limitation of hardening treatment
- Advantages of surface treatment
- Case carburizing
- Nitriding
- Residual stresses
- Effect on fatigue life

So, therefore to sum up what we have looked; at we looked at the non uniformity of structure, and uniformity structure properties, limitations of hardening treatment, advantages of surface hardening, we talked about case carburizing, nitriding, origin of residual stresses and its effect on extending fatigue life. Thank you very much.