Failure Analysis & Prevention

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Lecture - 09
Fundamental Sources of Failures: Improper Manufacturing III

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention, and we are talking about the fundamental sources of the failure, as a part of the failure analysis so, that we can get idea about the directions in which, we can look for the possible sources of failure. And in this connection, we have talked about the deficiency in design improper or imperfections in the material. And now, we are talking about the improper manufacturing conditions or deficient manufacturing or the processing conditions.

In this; under this heading also, we have talked a lot about the various aspects like, the manufacturing process or the improper selection of the manufacturing process parameters. Today we will be basically taking up, the failures which are caused by 2 steps related with the manufacturing; one is like indentation marks, during the manufacturing frequently the batch marks product number marked.

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So, if that is produced by the indenting indentation approach or by engraving using the electrochemical related processes, then these indentation frequently become the source of the failures. We will be talking about that little bit in detail and thereafter there is another aspect that, if for enhancing the properties, for improving the mechanical properties of the products made by the by the manufacturing processes like, casting, welding, forming and machining if subsequently, further improvement is needed and also to relive the residual stresses, if we have to perform the heat treatment.

So, if the heat treatment conditions are not selected properly, or the various aspects related with the heat treatment not chosen properly, for this treatment purpose then, that also can lead to the premature failure of the components. So, in this presentation basically about these 2 aspects will be talking about.

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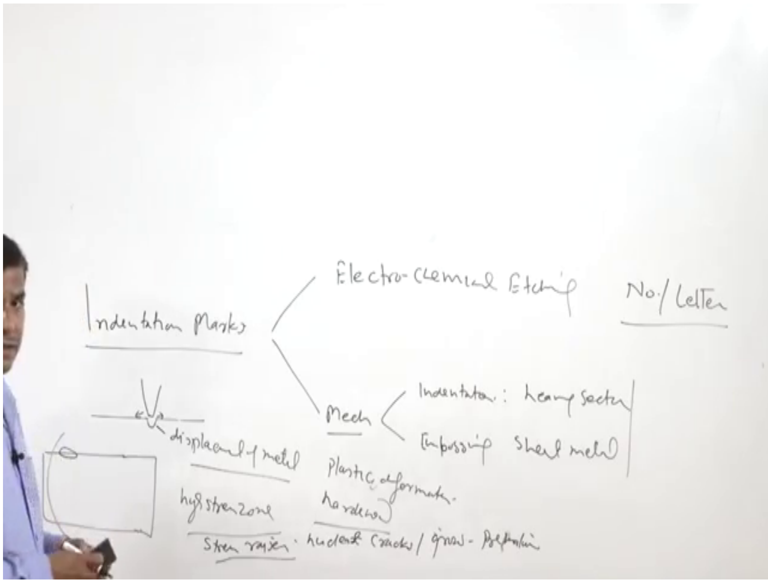

So, here if we take of the first indentation marks, indentation marks, there 2 basic approaches which normally applied like, one is you can say the mechanical based approach, where either we can use the indentation and we can use the embossing also for this purpose. embossing is primarily applied in case of the sheet metals, while in case of the heavy sections the indentation using the punches these marks applied.

Then there is a electrochemical based method which is normally termed as electro chemical etching which is about the control removal of the material, from the component on which the marking is to be done. So, that it can produce the required numbers or the letters. So, numbers like alphabets a b c d or number 1 2 3 4 or anything else also can be placed. So, these are the 2 approaches which are used for the indentation purpose.

The thing is like whenever the mechanical based approaches, like in heavy sections of the punches are applied for producing the indentation. So, application of the indentation, using suitable punch displaces the material sidewise for producing such kind of marks. So, such kind of the displacement basically, displacement of the metal for the indentation purpose by using the punch, causes the plastic deformation plastic deformation of the material and if the metal is work hardenable, then it tends to get hardened.

So, the formation of such kind of indents, especially in high stress areas like, this is the shaft and if the shaft is marked with some of the indentation mark, in at the surface. So, if such kind of marks are located in the high stress zones, which are critical for the performance of components, then this these marks will be acting as a huge stress razor stress razor and such kind of the stress razor can increase the actual stresses acting at those locations and can easily nucleate, nucleate the cracks and which under the subsequent loading conditions can and grow or propagate and to cause the premature fracture.

So, basically the indentation mechanical indentation using the punches, sometimes hardens and if at the same time it also acts as a stress razor, because some kind of the irregularity in cross section is created intentionally. So, these are that 2 aspects which are related with one is the stress concentration.

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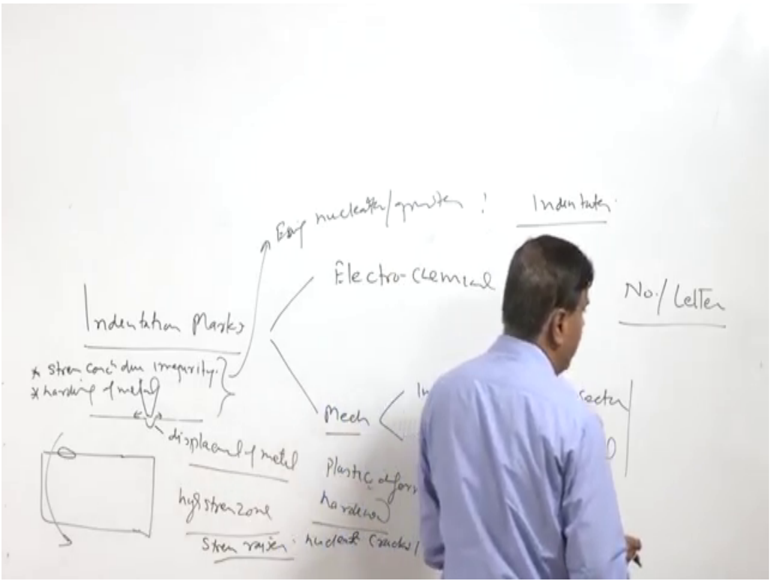

Stress concentration due to irregularity being created, irregularity being created and the second when is the hardening of the metal around the locations, where this kind of punching is done or a indentation are being applied for marking purpose. So, hardening of the metal will be will also be reducing their tolerance, for the growth of the crack nucleation and growth of the cracks.

So, a combination of both these factors, will be providing easy nucleation and the growth of crack, which can lead to the failure of the components. Since the especially in those components where, the stresses acting onto the surfaces are maximum. So, such kind of the components are like, shaft or springs where the surfaces will be having the higher magnitude of the shear stresses torsional stresses, as compared to that of the those which will be acting at the in the core.

So, indentation marks are basically more harmful for those components where, the surfaces stresses are higher than those, which are acting the core of the component and they get hardened rapidly, due to the indentation marks. So, and if the marks are deeper then irregularities being imposed, due to these indentation will be providing the easy stress razors, for the stress concentration which will facilitate the nucleation and the growth of crack and which in turn will be leading to the premature failure.

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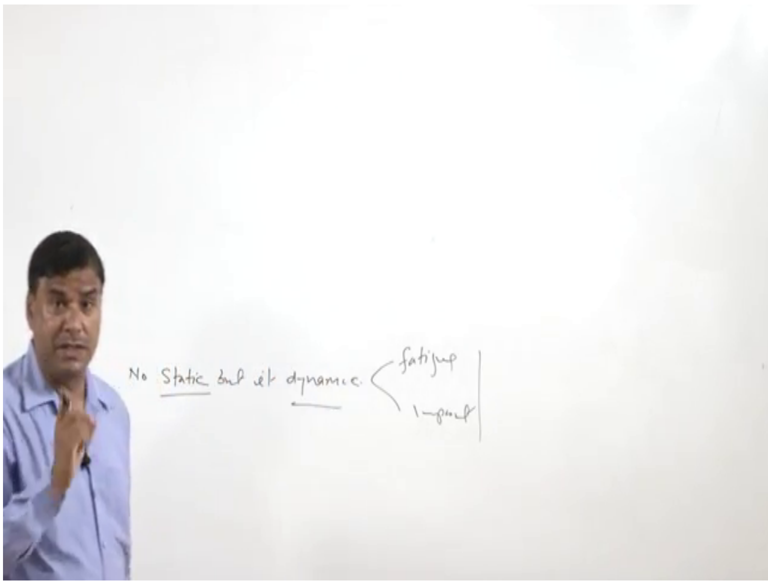

And we know that the nucleation and growth becomes easier and faster, especially if the load is not static load is not static, but it is it is dynamic like the load is fluctuating say, the fatigue loading or the impact load conditions such kind of the stress razors become more harmful because, the time available is not much for the stresses to get relaxed due to the localized yielding and therefore, if such kind of this stress razors are present in form of the indentation mark, then under the fatigue and impact conditions such kind of the marks will be facilitating the nucleation and growth of crack easily, and therefore, the presence of the indentation mark especially in higher stress areas, become more harmful.

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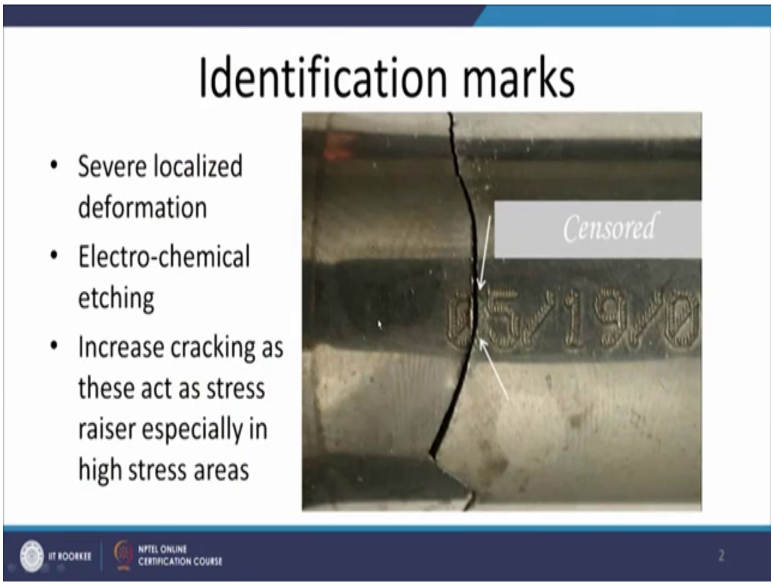

So, that is what has been shown in this diagram also here what we can see, this is the shaft on which indentation marks were present in form of the date, on which it was manufactured and at the periphery of this number, we can see which acted as site for the nucleation and growth of the crack and this is how it works in saviour localized deformation, electrochemical etching this increase the stress concentration especially where, these letters have been made and this will be increasing the actual stresses.

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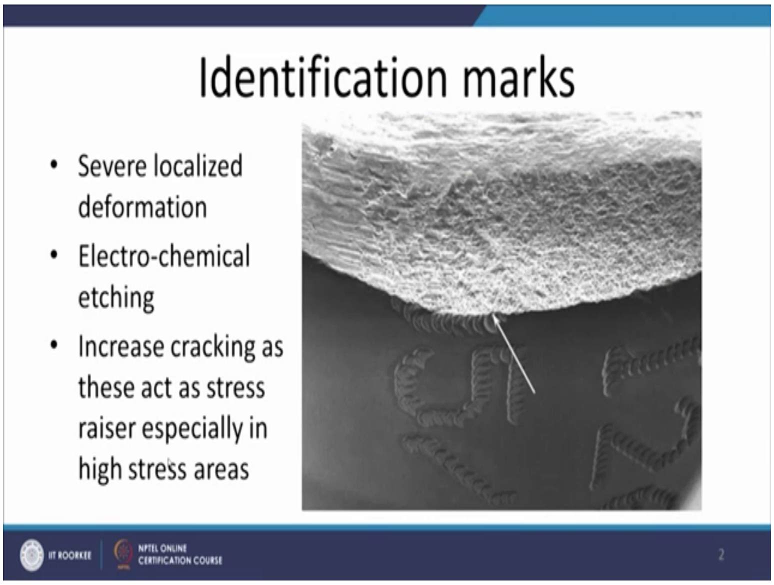

Ah this what we can see how the cracks, at these locations how the fracture surface is created, these will be providing the easy site for the nucleation and growth of cracks. So, this is the location where such kind of the crack has grown in the first and second first stage and there after second stage, followed by the third stage for catastrophic fracture for the indentation marks.

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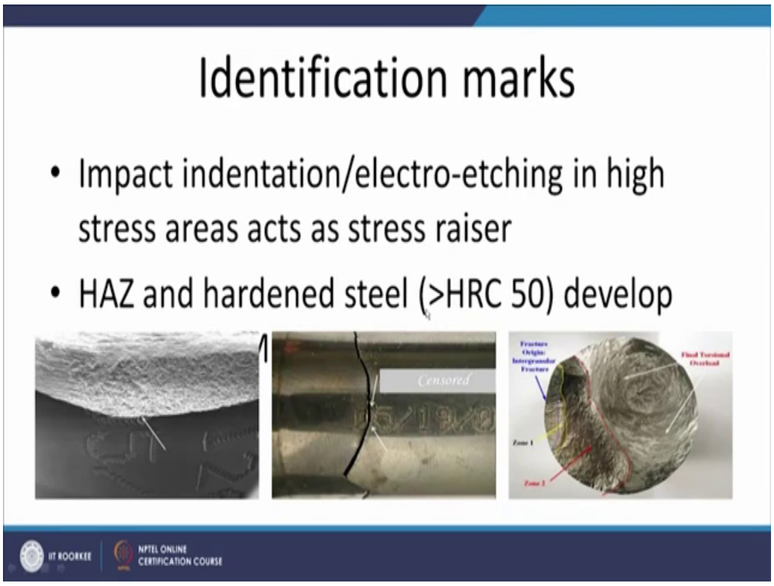

So, as I have said indentation marks, especially in high stress areas are harmful and especially in the metal systems, which are hard brittle and are of the low ductility, because such kind of the metals do not provide the localized yielding easily. So, absence of the localized yielding, maintains the stress concentration and which in turn increases the chances for cracking and such kind of things especially happen in the hardened heat affected zone, or a hardened steels having the hardness greater than 50 HRC. So, this kind of the indentation marks are more harmful for those situations.

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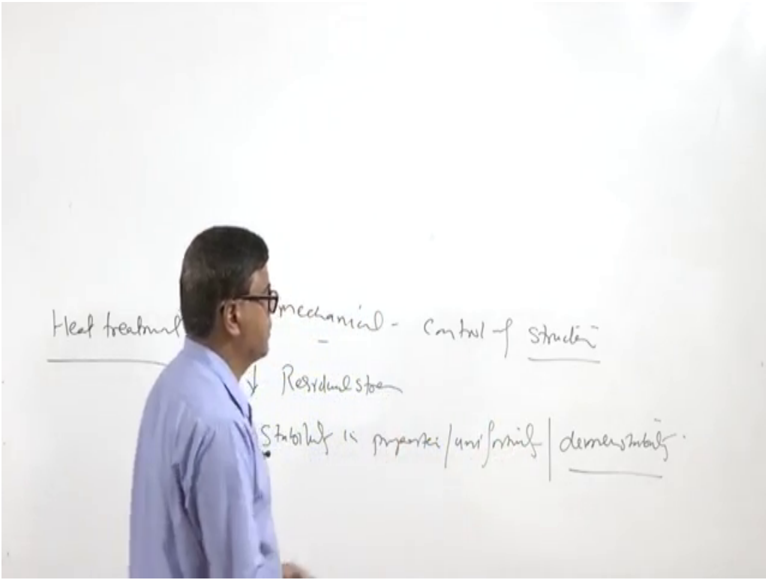

Another as I have said another important step in manufacturing process is, the heat treatment. We know that heat treatment is used for variety of purposes, one is primarily to improve the mechanical properties, through the control of through the control of the microstructure of the metal.

And the second purpose is also, to reduce or relive the residual stresses residual stresses, if they have been produced in course of the manufacturing. So, releasing the residual stress and when it is performed there, so many other secondary benefits which are obtained, like the more or increased stability in terms of the properties more uniformity in properties and also increased dimensional stability, is achieved if the component is especially is to be exposed under the high temperature conditions. So, the heat treatment helps otherwise in number of ways.

The simple steps which are used in the in heat treatment, if we have to generalize the procedure, which is used for the heat treatment purpose will depend upon although depend will depend upon the type of metal system, which is to be used and the purpose for which heat treatment is to be applied.

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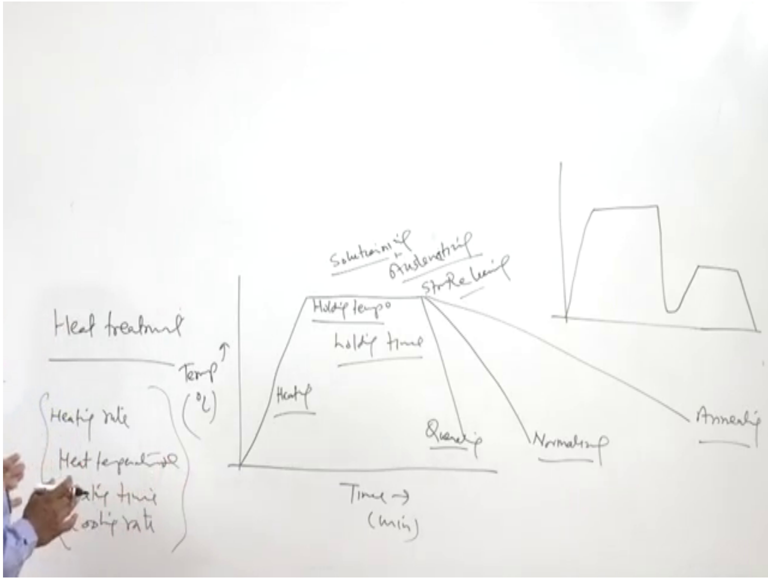

But in general in the heat treatment, if you see the thermal cycle which is applied in y axis if we have temperature and in x axis we have the time, which may be say we can write in minutes and here it may be in degree centigrade. So, initially the things the component to heat it is heated slowly not at very high rate. So, that the temperature of the entire cross section of the component is, increased gracefully and does not lead to the differential expansion during the heating.

Otherwise it may cause the buckling or the distortion in the a component, because the surface will be heated at much faster rate than the core and that may otherwise, lead to the differential temperature too high difference in temperature in the core under the surface.

So, due to the differential expansion, there may be rapping or the distortion in the shape of the component. So, the rate of heating is to be optimum not very high enough, because the high heating rate is harmful. Thereafter the component is held for a particular period of time. So, that the purpose of the heating to the high temperature is solved and depending upon the heat treatment purpose depending upon the type of the heat treatment will perform, it may be held at a different temperatures.

So, according to the heat treatment purpose also, heat treatment type of the heat treatment also sometimes like for precipitation hardening system, it is called solutionizing it is called solutionizing, and in case of the steel it is called austenitizing austenitizing and then it may also be done like for stress relieving, it is like say the stress relieving temperature stress relieving stress relieving temperature.

So, it is expected that there would not be any space transformation during the stress relieving. And thereafter as per the kind of purpose again the cooling rate different cooling rates are applied, it may be cooled very slowly or it may be cooled at faster rate or it may be cooled at very high rates.

So, depending upon the purpose, this kind of the cooling rate is used for the quenching or hardening of these steels, may be somewhat lower cooling rate is used for the normalising purpose and thereafter very low cooling rates are used for the annealing purpose, this is the case of the steel for precipitation hardening systems, the different kind of heat treatment cycle is used, wherein first we heat to the first solutionize the things. So, that homogeneous solution is obtained thereafter it is quenched and after quenching again the system is heated, to the for the artificial easing purpose and then, it is held at the temperature and then again it is cooled.

So, depending upon the kind of heat treatment, is which is being applied different kind of the heat treatment cycles can be used. So, the point here is, our heating rate has to be proper, the correct the solution the temperature at which it is held holding temperature or it is also called soaking temperature has to be correct, and holding time also has to be soaking time or holding time should also be the proper one. It has to be optimized as a part of the procedure and thereafter as per the purpose the different cooling rates need to be applied.

So, there are 3 things basically the heating rate and then the heating temperature or you can say holding temperature or soaking temperature, and then like soaking time and thereafter cooling rate. So, proper control over this proper determination, and control over these parameters is required so, that we can get the desired set of the properties.

So, in appropriate control over the heating rate, holding temperature or soaking temperature holding time and cooling rate, lead to the such kind of the structures and properties which will be deuterating the performance or mechanical performance of the component. Therefore, reduced performance which in turn can lead to the reduced performance or premature failure or inability to take up the service conditions, in terms of the mechanical load or the environmental conditions which will be experienced by the component during the service and therefore, heat treatment has to be heat treatment parameters has to be identified properly and they need to be controlled and if that does not happen, then various possibilities are there one is like overheating.

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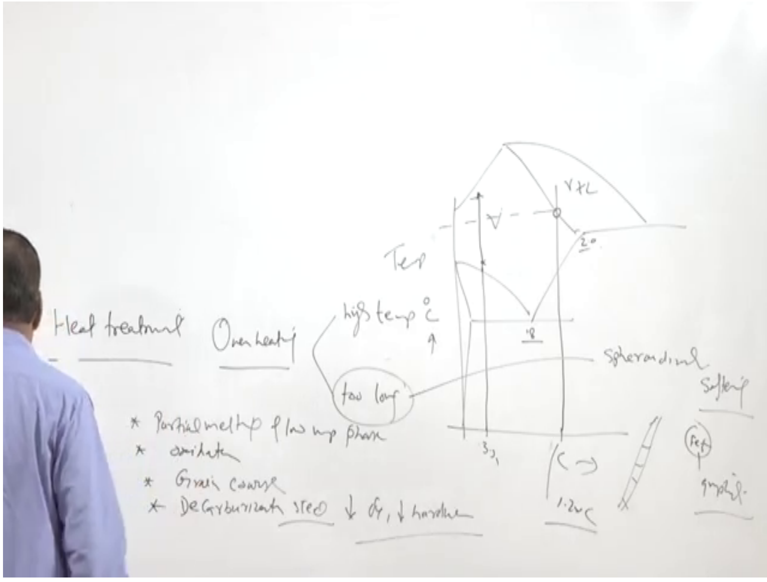

Overheating there are 2 possibilities, one is heating to the too high temperature and heating for the too long duration, both will be deuterating the things. especially like say, if we consider an example of the steel. So, here this is the gamma zone this is the gamma zone say, this is corresponding to the 0.8 percent carbon steel, this is corresponding to about 2 percent carbon steel. Here carbon and here the temperature in degree centigrade this is iron basically iron carbon diagram.

So, if the steel of say point 3 percent carbon is heated say, about the 30 degree 30 to 50 degree centigrade above the upper critical temperature. Like say this is the, but instead of heating just up to this temperature, if this steel is heated to the too high temperature then, there are various undesirable effects on the properties.

And similarly,. So, this kind of effects may be in form of due to the overheating, it can lead to the partial melting partial melting, this happens primarily in case of the alloys where we have the 2 phase zone at a high temperature say, if the steel is of like say iron carbon system having 1.2 percent carbon high per steel in that case. As soon as, heating is performed above this temperature will have the 2-phase zone, which is gamma plus liquid. So, heating the too high temperature, at this temperature it will not get to the molten state, but the steel if it is 1.2 percent carbon steel it will get to the 2-phase stage, even at the lower temperature.

So, depending upon the completion of the steel correct heating temperature has to be identified, otherwise it can lead to the partial melting of the ; obviously, low melting point phases and here, what it is what it will be basically, the eutectic system which is the lauderate? Which is formed? Which will lauderate will be melting above the liquidus sorry solidus temperature apart from this one.

If heating to the high temperature for long can lead to the oxidation of the metal surface, it can also lead to the excessive grain coarsening, in form of the coarse grain austenite, which can increase the hardenability and produce the martensity martensite in place of the fine pearlite. Otherwise which will be needed, excessive prolonged heating at high temperature can also lead to the decarburization. It is it happens mainly in case of the steel, where the loss of the carbon from the surface of a steel take place, and that loss leads to the reduction in yield strength reduction in the hardness which in turn decreases their capacity to carry the load.

So, this is what happens, if the heating if the overheating is done similarly, prolonged heating also causes the spheroidization especially, in case of the is steel. So, a spheroidization is basically the cementite plates basically, they get spheroidize they form nodules and a spherical shape particles of again f a 3 c or sometimes the grain fight also. So, leaving the iron in the matrix.

So, basically this leads to the softening of the steel reduction in mechanical properties, in terms of the tensile strength and the hardness. So, unnecessary prolonged heating is also not good and if that happens inadvertently unknowingly, then these undesirable effects can be there. As I have said the partial melting can reduce the ductility and the toughness no sense can increase no sensitivity and can reduce the resistance to the fatigue, and the tensile load carrying capacity.

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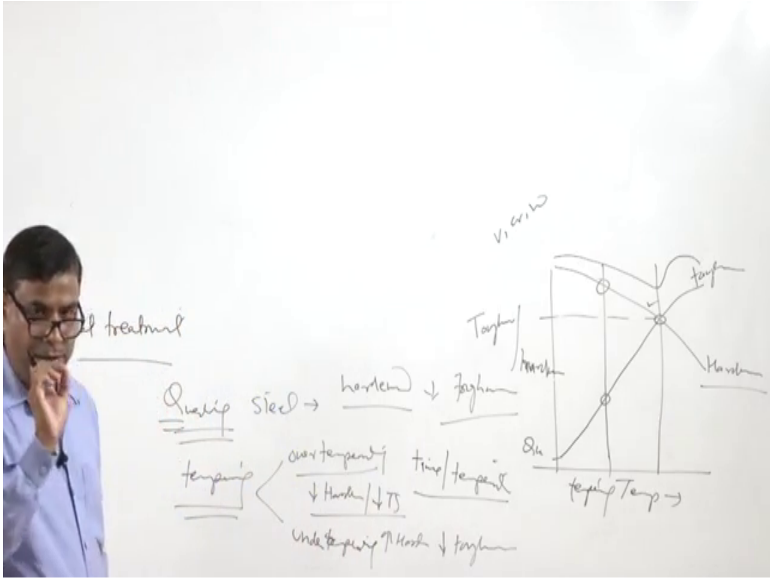

Ah there is another important aspect like, the heat treatment quenched steels normally subject quenching, after quenching of the steels steel normally gets hardened, too high hardness actually reduces the toughness. So, the steel with reduce a toughness finds the very limited use and there limited use in the mechanic in the application. So, therefore, it is required that all the quenched steels are tempered. So, tempering will lead the increased in toughness and the reduction in hardness.

So, if we see the typical plot, temperature versus the tempering temperature basically, this is tempering temperature versus the toughness and hardness and the hardness. So, basically the toughness, which is low after quenching in quenched state, toughness is low and this keeps on increasing with the increase of tempering temperature, on the other hand the hardness decreases like this.

So, we can see that if the tempering temperature, is not proper then we will be having something else, say for this tempering temperature steel will have one particular set of the hardness and the toughness. So, this much hardness may not be good enough for the application. So, as per the purpose and the required set of the properties with regard to the hardness and toughness, we have to select suitable tempering temperature. So, this temperature will be giving us this set of the hardness and the toughness. So, here these are the 2 curves, this is showing the toughness and this is showing the variation in hardness. What we can see here? Increase in tempering temperature reduces the hardness and increases the toughness.

A different kind of trend is observed especially in the, steels having the vanadium chromium tungsten. So, this steels above particular temperature, they start forming the secondary carbide. So, this is called secondary hardening especially, when primary hardening is one where quenching helps to achieve the desired hardness and during the tempering, when these carbides precipitates at higher temperature. So, the secondary hardening is facilitated.

So, this tempering has to be done for the correct time and at the correct temperature both are not good, because the under tempering will be leading to the there 2 words, which are used regarding the tempering process. So, over tempering and under tempering, over tempering means excessive tempering which will be leading to the reduction in hardness beyond the acceptable level and. So, reducing the tensile strength. So, both may not be acceptable and under tempering is the just opposite, where in the hardness is still high enough, then that is required and toughness is low enough.

So, for any given applications; so it is required that both over and under tempering under tempering is avoided. So, that we can have the optimum tempering, where in we have the required combination of the strength and hardness for achieving the required mechanical properties, in the steel after the hardening.

So, inappropriate selection of the tempering conditions, can lead to the under tempering or the over tempering and that becomes the result of like say, untempered martensite which increases although increases the hardness, but at the cost of toughness.

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Ah similarly, as I have said another way by which the failure of the component due to the improper heat treatment conditions can take place is the thermal shock, like for the heat treatment purpose normally from the 800 and above degree centigrade. We have to cool it very fast and this is in seconds, like in cct diagram if we see if the too high cooling rate is applied, then it will be leading to the austenite transformation into the martensite.

So, if the large components are quenched like this, then surface will be cooled at rapidly while the core will remain at high temperatures. So, such a high difference in the temperature or high temperature gradient at the surface and the core sometimes leads to the quench cracks. So, so that will promoting the surface crack and these cracks can lead to the premature failure of the component, this kind of high temperature gradient can also cause the distortion in the components, which are of the thin sections and the complex in shape.

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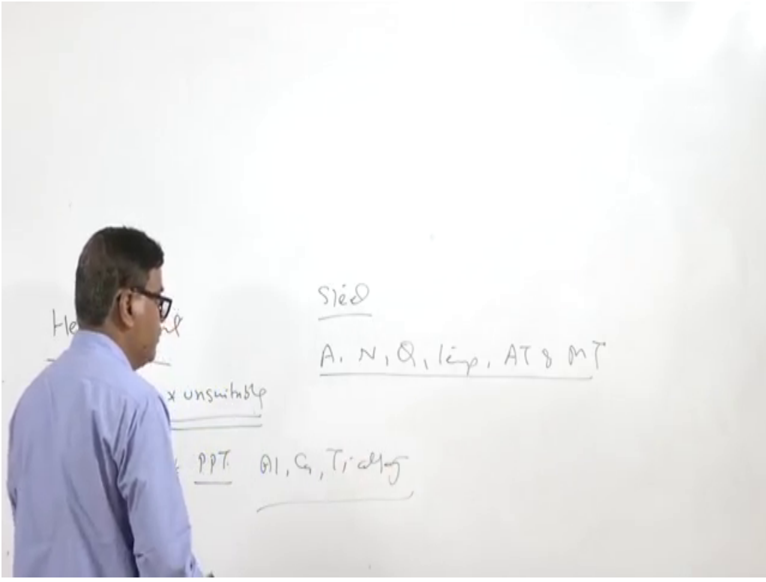

Ah then unsuitable recommendation of the unsuitable heat treatment, like there are different heat treatment processes, like for steels like annealing, normalizing, quenching tempering, then austempering and martempering. So, as for the kind all the steels may not be responding in the same way, to the different category of the heat treatment.

So, depending upon the composition of the steels, we need to recommend suitable heat treatment. So, that target properties can be achieved, but if that kind of selection is improper means, selection of the heat treatment type of heat treatment to be applied, is improper then we will not be able to realize such kind of the properties.

For example precipitation hardenable alloys like aluminium, copper, titanium alloys, magnesium alloys etc. They will required different type of the heat treatment like, solutionizing, quenching and then ageing which may be like at room temperature or at high temperature for artificial using purpose. So, selection of the suitable heat treatment is also important, for achieving the desired combination of the properties which will help us to have the required combination of the mechanical properties for the target performance.

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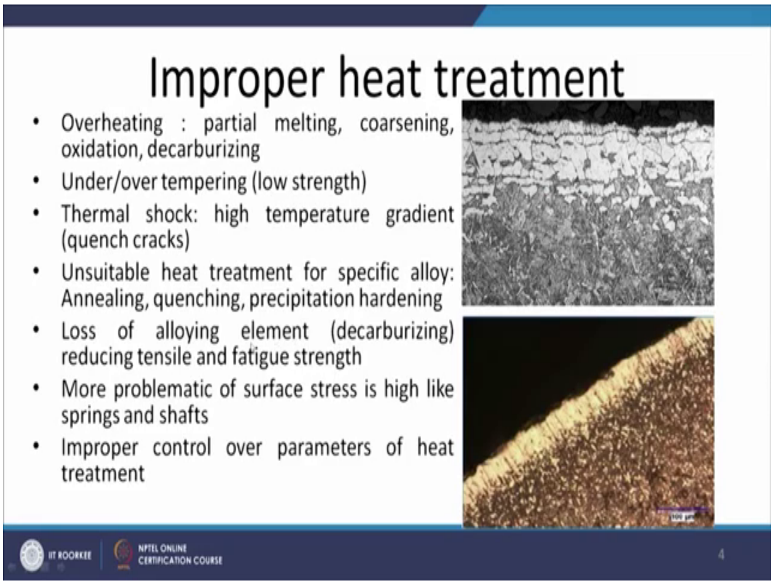

Now, we will see that the loss of alloying element as I have said loss alloying elements may be in form of the decarburizing or the loss of other alloying elements, due to the excessive exposure at high temperature in the oxidizing environment. So, such kind of losses of the alloying elements reduces, the tensile strength and the fatigue strength. Especially in those components, which are subjected to the high stress conditions and the components which are subjected to the high surface stresses, like springs and shafts.

Then another is, the improper control over the parameters like during the design of the heat treatment, we can identify that, this will be the heating rate, this will be the cooling rate and, this will be the soaking time, but if the system does not respond accordingly it is showing the data, but actually the conditions for which the component is being exposed or not according to the design of the heat treatment. So, that kind of thing also can lead to the improper combination of the structure and the properties, which may not be favourable for the applications desired.

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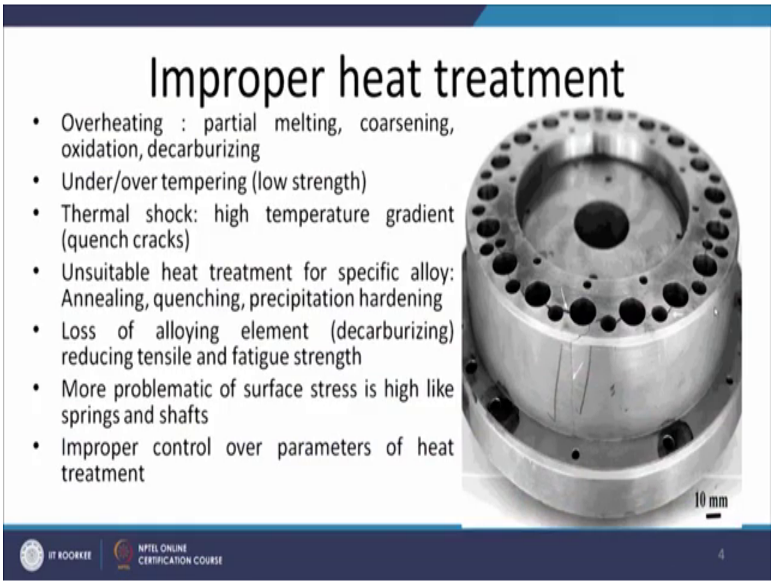

So, improper heat treatment can lead to the failure in number of like this one example, where the cracks develop along and due to in the quenching, due to the unfavourable the temperature gradient conditions, under the development of the tensile stresses at the surface. these are the 2 diagrams, which are showing that how the loss of the carbon from the surface, due to the decarburizing leads to the change in the phases.

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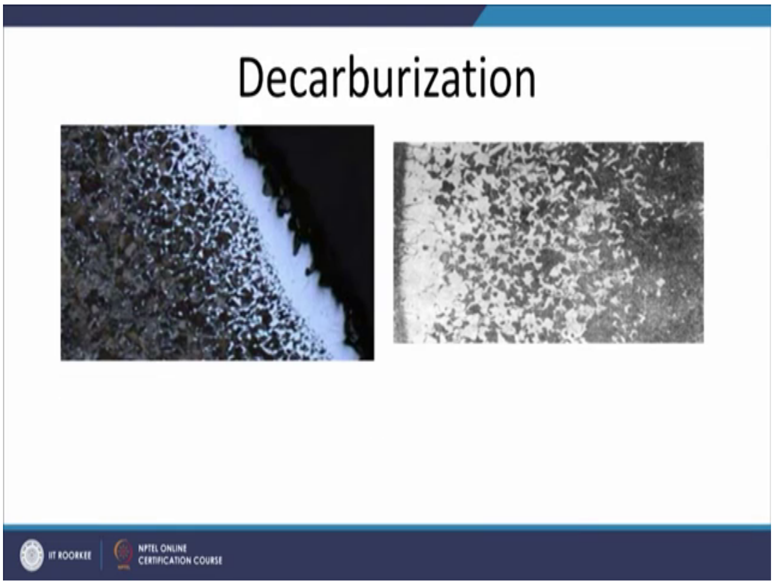

Here we can see the ferrite and the pearlitic structure, but the ferritic structure which is light etched, white is in colour this is increasing, as we approach towards the surface, and this can be seen in the both diagrams, increasing a percentage of the ferrite on approaching towards the surface, increase in indicating the loss of the carbon and we know that, ferrite is softer and of the high ductility and of lower yield strength, as compared to that of the pearlite and therefore, if the surface is full of the ferrite, then it will be leading to the reduced strength, reduced hardness and the increased ductility, especially at the surface.

So, such kind of the unfavourable structural change, due to the loss of alloying elements in form of carbon can lead to the premature failure, of the component.

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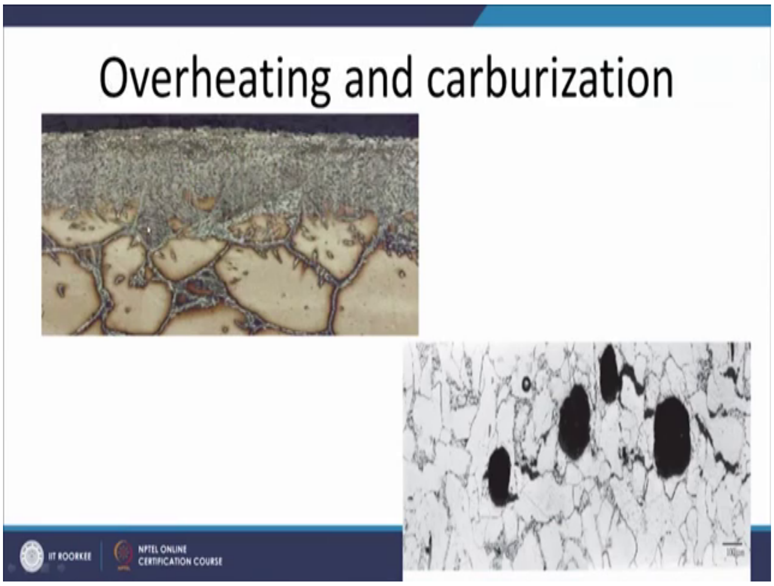

This is another example which is showing that how the decarburization how the overheating simply coarsens the grain structure? And the carburizing leads to the enrichment, sometimes undesirable induction or introduction or in when the carbon is introduced at the surface of the steel. So, too high enrichment of the carbon can lead to the excessive formation of the, either iron carbide or the martensite if the favourable conditions exist, which will be deuterating the mechanical properties especially in terms of the increased hardness, reduced toughness at the surface and this kind of thing can also lead to the development of the tensile residual stresses.

So, here now I will summarize this presentation. In this presentation basically, I have talked about the 2 steps related with the manufacturing, one was the indentation and another was unfavourable heat treatment conditions, and the ways by which the inappropriate the combination of the parameters can lead to the failure of the component.

Thank you for your attention.