Failure Analysis & Prevention
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Lecture – 29
General Procedure of Failure Analysis:
Metallographic of Failed Components

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention and we are talking about the general procedure of the failure analysis and under this heading.

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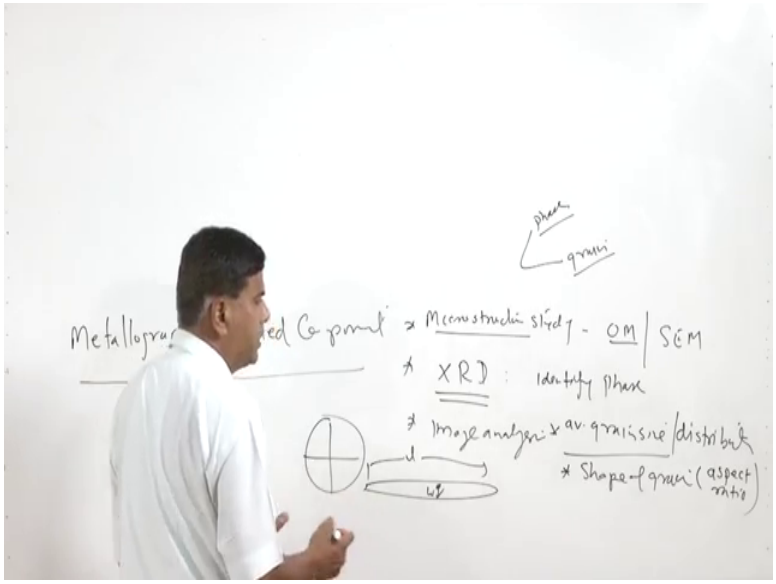

Now, we will be taking up the metallography of the failed component metallography of failed component, metallography is a very wide word which involves the various aspects like micro structure study. This we basically try to carry out with the help of the optical microscopy or a scanning electron microscopy, they are after identification of the phases because micro structure is study will be involving the phase and the grain structure study.

So, type of the phase is relative amount of the phases and their distribution, similarly in the grain structure study the size shape size of the grains have a shape of the grains and their distribution. For phase analysis we need to carry out the XRD analysis. So, this is another aspect will be taking up it separately which has to identify the phases present in the metal, then image analysis is carried out image analysis is carried out basically for 2

3 purposes, like the average grain size this is one aspect and the distribution of the grains also can be obtained.

Similarly, the shape of the grains can also be identified through the image analysis, where in factors like aspect ratio or the shape factor ah; which is like length to width ratio is use to quantify the shape of the grains. Like for the circular grains the shape factor will be one and in needle shape grains the shape factor will be very high like say 5 to 10 it can be like, so this is the length and this is the width.

So, length to width ratio gives us the idea about the shape of the grains then it also helps in determining the percentage fraction of the different phases which are there and in addition to that the distribution of the phases is also identified, so there these are the various aspects are related with the metallography.

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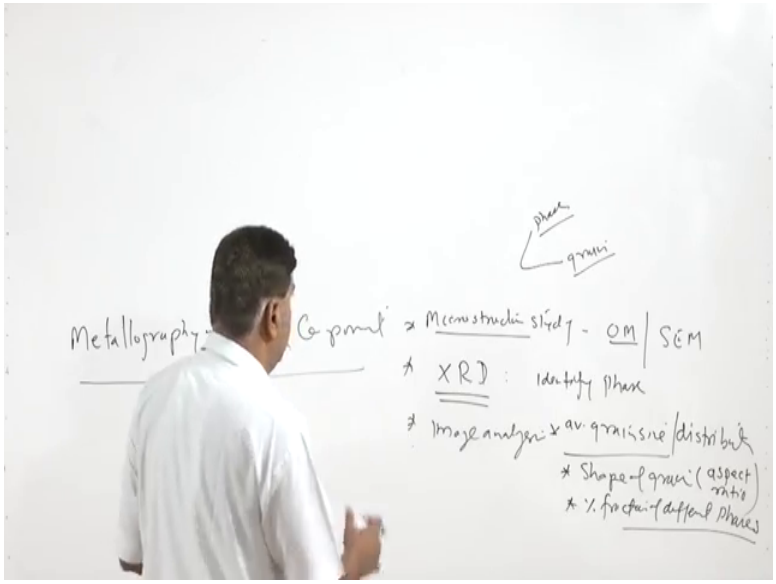

So, when we will be carrying it out it helps us to identify or determine the number of important aspects related with the material which has failed. So, as far as the purpose of the metallography is concerned, it will help in determining the first the class of the metal which has failed, like the class is identified if the it is having the desired features or what kind of undesirable features are there.

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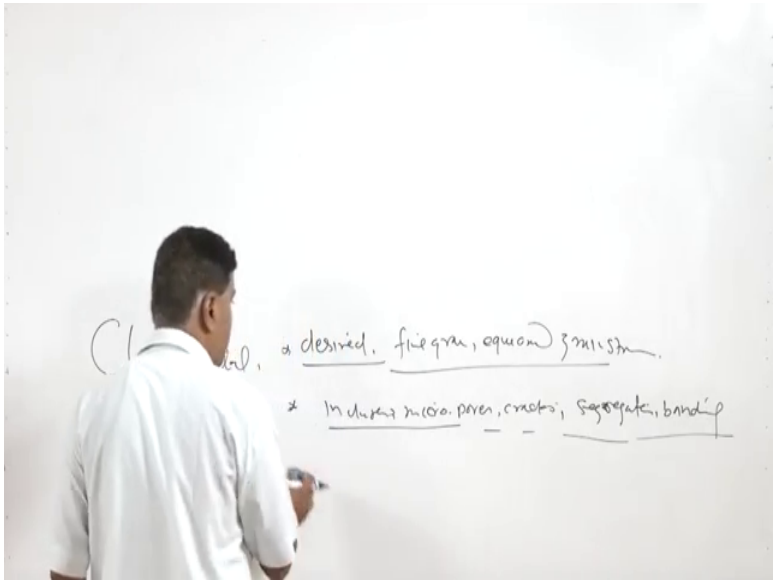

So, in terms of the desired features like the fine grain size equates grain structure equates grain structure, this is what we want what things actually may not be of the same type, there can be undesirable features in form of the inclusions micro force or the cracks there can be a segregation or there can be bending. So, these are the metallurgical defects which can be identified through the microscopy or metallography only.

So, the whether the desired features are there or whether they are undesirable features are also present. So, that will help to identify the class of the metal, whether it is of the premium quality free from the impurities defects undesirable gases and the kind of the grain structure and the grain shape.

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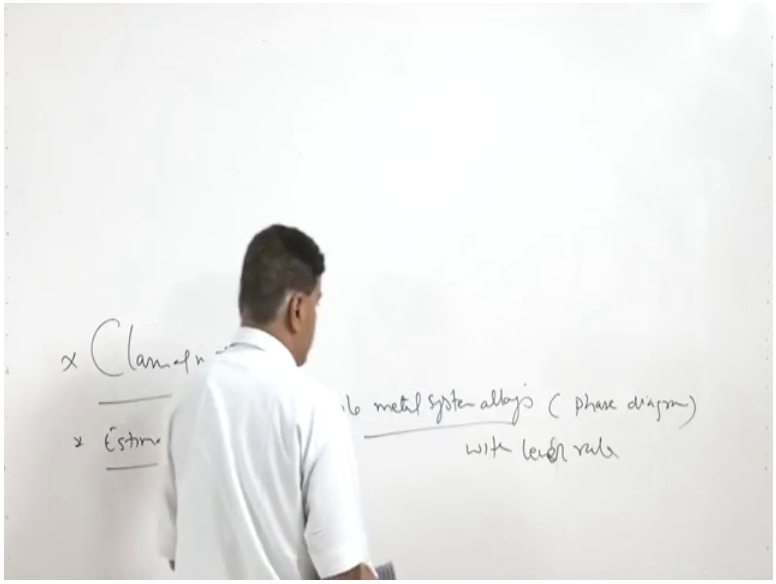

It has then estimation another one is the estimation of the composition estimation of the chemical composition. So, for the simple metallic components like for the simple metal systems and alloys the composition can be estimated using the using the respective phase diagrams, with the help of lever rule with the help of lever rule.

So, if we understand if we determine the approximate a fraction or the percentage of the different phases which are present different phases which are present in the given metal.

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Then using these percentage of the phases we can determine the we can estimate the composition of the metal system, this is particularly used in case of the a steel.

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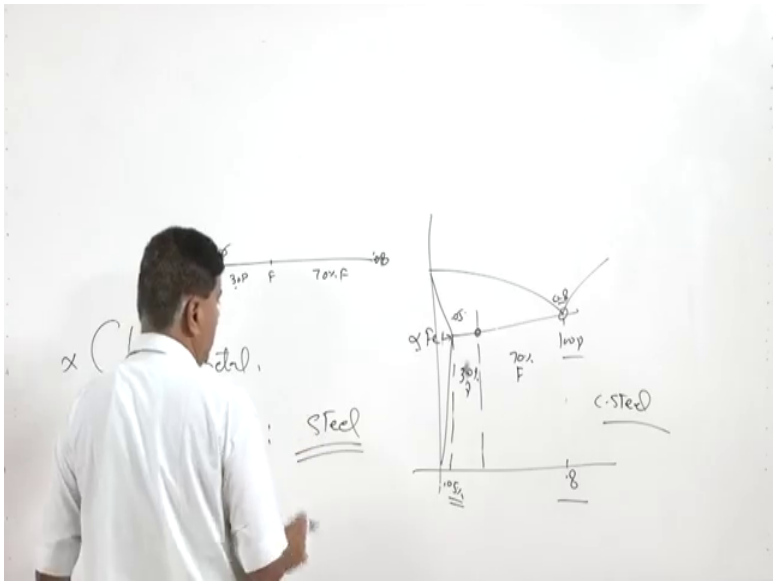

So, will take up a one typical example to understand this like in case of the steels we have the phase diagram of this kind, where this is corresponding to say eutectoid point where we have the 100 percent pearlite and this is corresponding to the 0.05 percent of the carbon, where we assume that the ferrite this side we have alpha iron or the ferrite and between these two.

If we have the steel of particular composition where the fraction of the ferrite is say seventy percent ferrite and 80 and 30 percent is pearlite. So, using these fractions we can determine the chemical composition of the simple carbon steel, for this what we use the 1 side this is the fulcrum of the lever and this is the location of the 0.8percent and this is location of the 0.05 percent.

So, in the lever what we have fulcrum f 0.0 sorry 0.8 percent 0.8 percent and 0.05 percent and this corresponds to the 70 percent of the ferrite in this particular example and 30 percent of the pearlite. So, we can take up any phase to determine this one. So, that carbon content in the steel can be obtained, next is to determine the effect of the service conditions when the component is exposed to the service conditions. It experiences the load it experiences the environment and it also experiences the like the deformation.

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So, in some of the conditions if the surface layer deformation is taking place then there will be work hardening, environment may be there like enrichment or the enrichment or the loss of alloying elements can alloying elements can take place, sometimes due to the high temperature the precipitation of the undesirable constituents in form of say like the chromium carbide; chromium carbide or there can be formation of the iron nitride.

So, these will be embrittling the metal system. So, iron nitride will be embrittling the steel increasing the hardness while the chromium carbide formation will be leading to the loss of corrosion resistance, especially the intergranular corrosion takes place if the chromium carbide precipitation is occurring.

So, metallography has to identify whether there has been a loss of alloying elements or enrichment of the alloying elements and these losses or enrichment will be leading to the change in structure which will indicate the possibility of the change in chemical composition. Similarly, the deformed grain structure near the surface layer will indicate the possibility of the work hardening or the formation of the undesirable precipitates at the high temperature in form of the chromium carbide are a nitride will also indicate the possibility of the change in mechanical properties, then method of manufacturing can also be identified through the metallography.

For example, that if the dendrite structure is observed in the failed component that will suggest that component has been found by the casting or if the grains are elongated in a

particular direction, then it will indicate that it has been produced by the bulk deformation processes then in the heat treatment of the component. If it has taken place then heat treatment was designed as or heat treatment was imparted at the stage of manufacturing or it has been accidentally exposed to the higher temperature conditions which was modified it is structure.

So, based on the background history of the failed component and the service conditions of the failed component we can identify through the structural modification through the microstructure study, if it has been really subjected during the manufacturing stage or it has been if it has been exposed to the temperature during the service.

So, this possibility of the structural modification due to the high temperature exposure can be identified, through the collection of the background information or the service conditions it will indicate whether the heat treatment was designed or heat treatment has occurred accidentally and which because of which the metallographic changes in the component have taken place.

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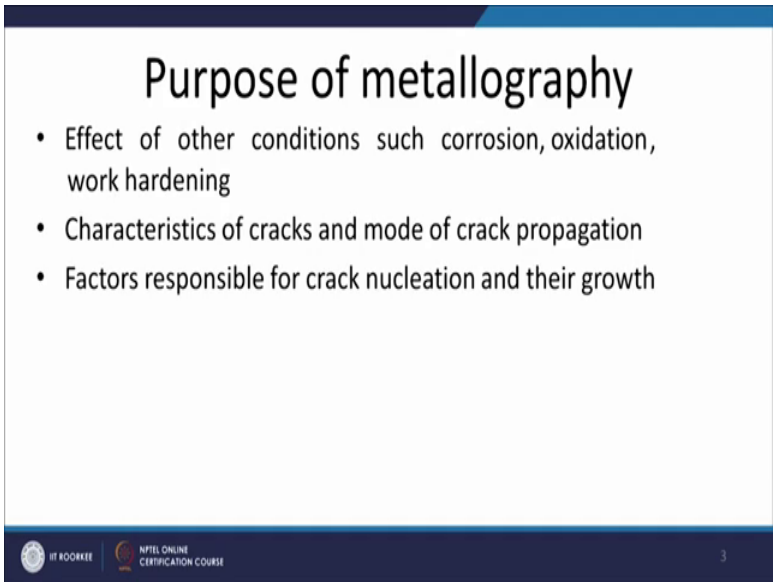

Then other conditions if are experienced by the component like oxidation corrosion and the work hardening, these also can be identified through the metallography in terms of the kind of the micro structural damage or the oxidation presence of the oxides or the deformation of the grains, near the surface layers will help to identify and that if the work hardening has taken place on to the component.

Then metallography is also helpful in identifying the characteristics of the cracks and the way by which it has been propagating whether the whether the crack is a trans granular means it is moving, irrespective of the grains and the grain boundaries in a particular direction or it is following a particular path whether it is whether it is a that path is the following particular grain boundary or particular kind of the micro constituents.

So, the characteristics of the cracks can also be identified or a studied through the metallography and that also help can help us in identifying the way by which crack is propagating during the crack has propagated during the fracture. Then the what were the factors responsible for nucleation and the growth especially this point is especially important for the failure fracture initiation point.

So, metallography of the initiation point is also done with the very great care to identify what are the factors which have contributed towards the nucleation and their growth and for that we try to look for if some kind of the diffracts in form of inclusions or poles are present or some particular kind of the macro structural defect is present in form of the bending, which has led to the softening and weakening of the metal and the because of which the crack has nucleated at the at that particular location.

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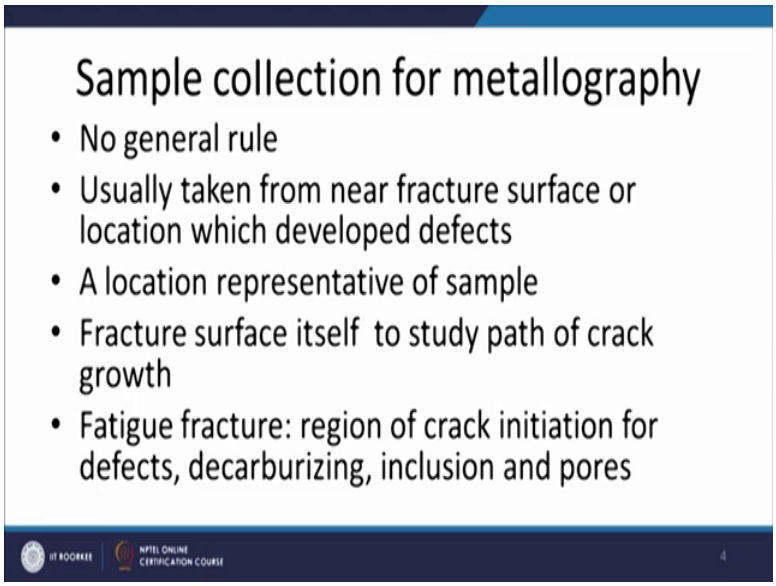

So, for the metallography we need 1 sample and sample need to be collected from the failed component, as far as the collection of the sample is concerned there is no fixed

rule. But it is a normally sample is normally collected from the location from the fracture surface location.

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In there because of the fracture surface is also large. So, especially we try to focus near the fracture through the macrofactography, if you are able to identify the fracture initiation point then near the fracture initiation point. The sample is collected normally from this location this will help us to under identify why the crack has nucleated working the weakness in the component was present because, of which fracture has been triggered from that particular location.

So, the sample is normally collected from the location where from where from the fracture has initiated, another general thing which is kept in mind in collection of the sample is like if the sample is very big the sample is collected in such a way that it represents the entire mass of the component which has failed; So, representative a location representative of the failed component.

So, this is an another thing which is kept in mind when selecting the sample and if the component is failed from a particular point to identify that, if in that zone only there was some problem or other areas were good. So, basically we also try to collect the sample from another location which has not failed this is one thing or we can take another new component for the comparison purpose or another unfilled component which has experienced similar kind of the service conditions. Sometimes if it is of our interest to

see it will study the path of fracture then definitely the sample is collected from the fracture surface, especially where cracks are present especially where secondary cracks are present.

So, like this is the fracture surface in some of the cracks are present, here like this on the fracture surface then we need to collect the samples in such a way that the crack tip and crack tip can be studied to see how it was propagating and such kind of these studies definitely or of the specific and are of more importance especially in the fatigue fracture, especially in the region where crack has nucleated to identify if there was some kind of defect or some kind of decarburization has taken place or some kind of inclusions or the pores were present and which has which have led to the nucleation of the crack to cause the fracture of the component.

So, the fracture initiation points point definitely becomes of the importance in the failure analysis for the fractro for the metallography. So, whenever we collect the sample and metallography is carried out will what is the target of the metallography and what we try to observe. So, basically the first thing as I have said that we try to study the microstructure of the component fail component, where in phase structure and grain structure will be studied will also try to see if there is any structural variation sometimes, we find that structure at the center is different from the surface.

So, that will indicate the possibility of the segregation of certain alloying elements or if some loss of the carbon from the steel component has taken place and which has led to the decarburization of the component. Similarly opposite is also possible if the a steel component is working in carbon rich environment at a high temperature then it can pick up the carbon and which can also change the microstructure and mechanical properties.

So, the carbon pickup decarburization segregation microstructure of variation if it has taken place due to the service conditions and that can be studied. It can also indicate the possibility of the heat treatment like if the component was subjected to the annealing, but annealing of a steel has been carried out; but actually it is showing the very refining grain structure indicating the normalizing or if it is indicating the martensitic transformation due to the quenching.

So, that will be indicate the possibility of the incorrect heat treatment which has been applied microstructure study can also help us to identify, if there has been damage in the

component due to the inter granular corrosion attack or the martensitic transformation. So, these are the some of the things which can be done as for the need and now will be seeing some of the micro structural aspects, like this diagram shows that one structure is different from other one structure is finer than other.

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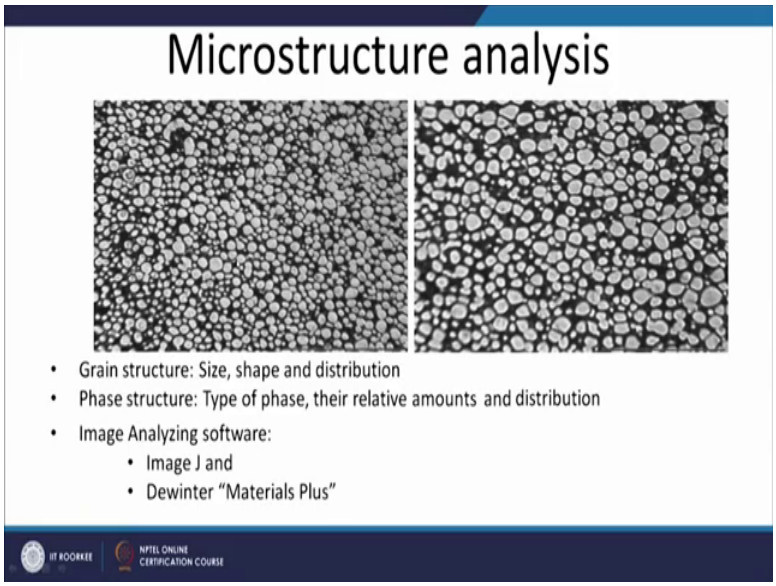

And we can through the image analysis we can easily identify what is the average size of the white constitutes, this is basically cellular structure within eutectic matrix which is dark and cellular grains are light etched and we can determine the fraction and the size of the cellular grains while the matrix is the dark.

So, the image analysis it can be a very useful tool to identify the average size of the grain shape of the grain and the and the relative amount of the different phases which are present and that is why once the microstructure is captured of the component image analysis provides much better information about the micro structural aspects; The as I said that the compositional estimation through the micro a metallography is also possible, wherein we try to determine the fraction of the ferrite and the pearlite.

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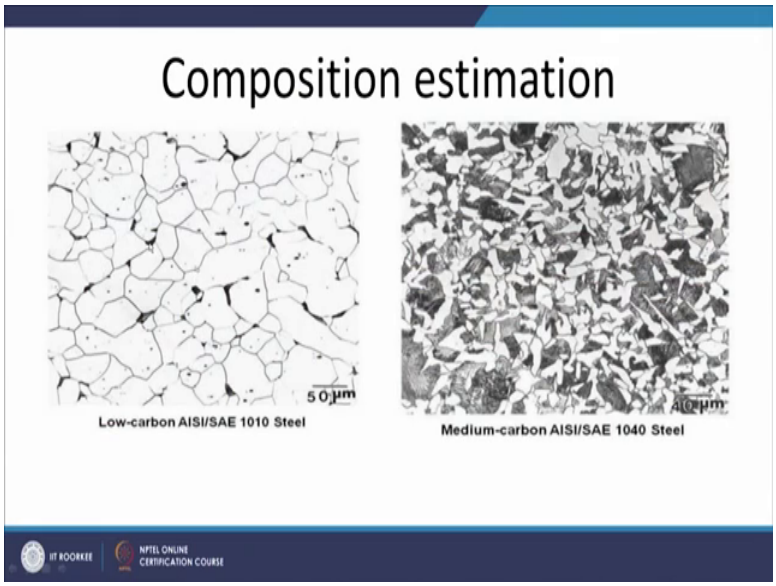

So, this dark phases at the boundary of the light etched ferrite is indicating the pearlite and the fraction of pearlite is very less and this is corresponding to the 1010 is steel, which is indicating that it is having very low carbon that is 0.1 percent carbon say it is a plane carbon steel and another one is 101 1040 is steel which is indicating where there is a 0.4 percent carbon.

So obviously, in 0.1 percent carbon pearlite fraction is very limited. So, this is what can we determine we can easily through the image analysis we can identify what is the fraction of pearlite and then using lever rule we can easily determine the we can estimate the composition of the carbon or content of the carbon in the steel and this is 1040 steel having much higher fraction of the pearlite indicating the higher carbon content in the steel.

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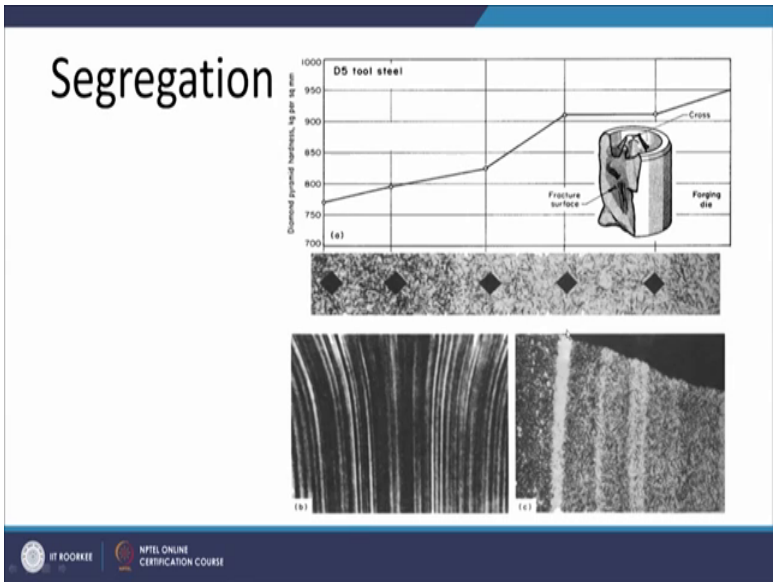

As we can see the segregation, segregation here in this particular case like say this is the case of the piston, where we can see the made of the truly steel what it shows that the failed component at the center has the and the different morphology than at the surface and if we measure the hardness from the center to the surface. Then what it will indicate that at the center hardness is very less, as compared to that at the surface which is a being is shown through the help with the help of this increasing size of the indent.

So, presence of certain localized the presence of certain element or absence of certain element in particular region, leads to the variation in mechanical properties of the component similarly this shows the binary structure where which is indicating that the ferrite grains and the peralite grains are present.

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So, such kind of the variations lead to the lot of heterogeneity and variation and mechanical properties in which under unfavorable conditions of the loading easily facilitate the nucleation and the growth of crack here is another example of the segregation way which is leading to the presence of the undesirable constituents at a particular location, which are facilitating the nucleation and then nucleation of the crack and then the fracture.

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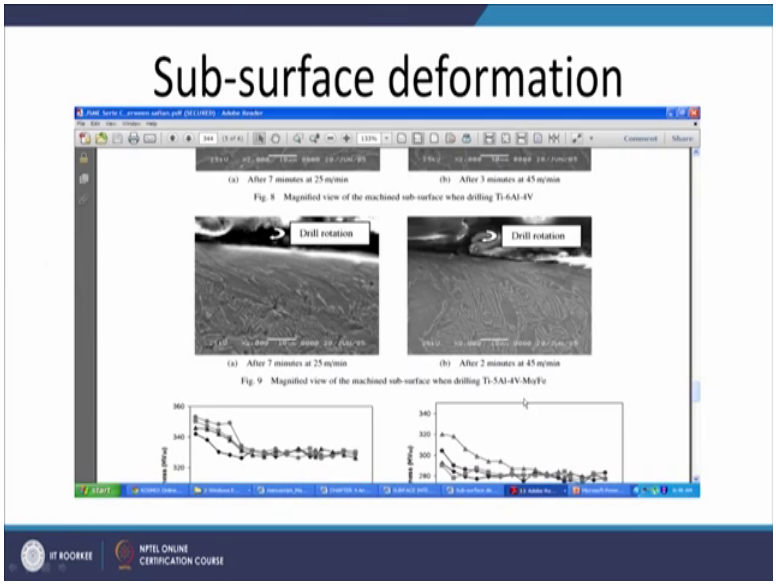

In case when the surface of the component is subjected to the external deform deformation due to the, when they surface of the component is subjected to the surface layer deformation due to the external loading or component surface is subject to the deformation during the manufacturing itself. So, in this particular case what we can see a drill hole is having very deformed grain structure near the surface and this is of about like say 20 to 30 micrometer.

So, very deformed grain structure can be seen at the surface of the hole and the hardness variation of the surface of the hole also indicates that the surface has been deformed. So, not just the hardness variation indicates the deformation means work hardening due to the deformation, but the microstructure is sturdy also indicates the surface has been badly deformed due to the abusive grinding or this is the typical nature of the machining process also where surface layers are deformed.

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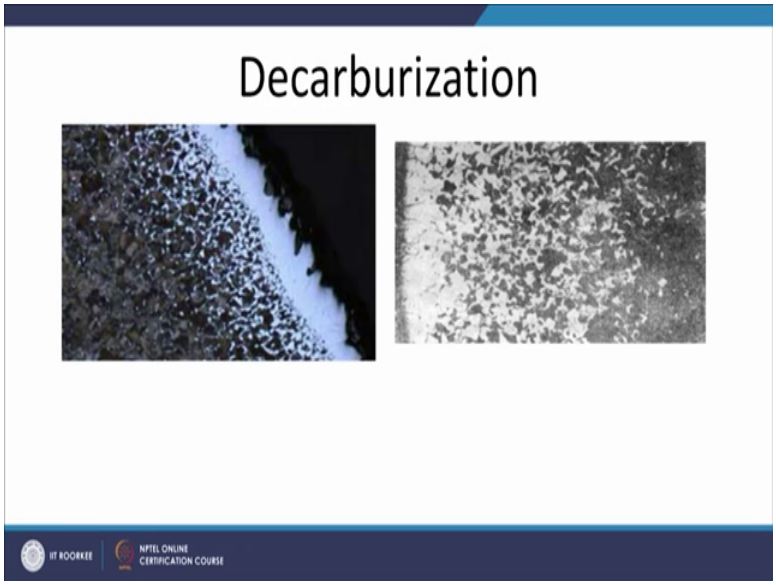

In case when the steel component is exposed to the higher temperature conditions then sometimes the loss of the carbon from the surface, leads to the presence of the axis ferrite at the surface which is soft and this is termed as the decarburization.

So, the loss of carbon from the surface is most decarburization and such kind of the losses reduces the hardness and the strength of the metal sometimes such kind of the variation reduces the yield strength of the material, and facilitate the failure of the component is. In opposite manner also if the steel component is exposed to the high

carbon rich environment, then that will indicate that carburization of the component has taken place and overheating will be indicated through the coarsening of the grains.

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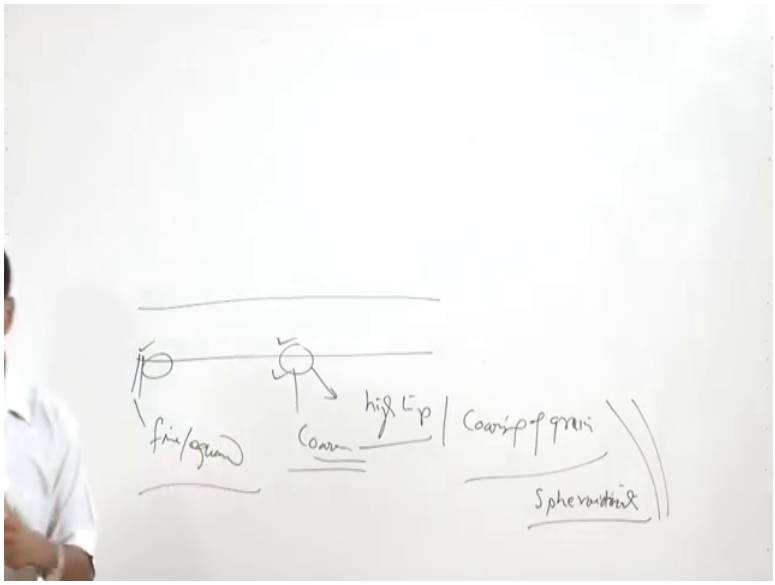

For example, at one particular location this is the tube and this location and this location here if the failure has taken place from this location, then sample collection from this location will indicate that at the high temperature this zone has been subjected to the coarsening of the grains or if excessive coarsening and prolonged high temperature exposure can also lead to the a spheroid digestion of the digestion of the a steel component; this is the kind of problem especially observed in case of the boilers.

So, if we compare if the failure has occurred from this place then will take the sample from the two locations, one where from failure has occurred another where failure has not occurred. So, this location may show us very fine and equates grain structure as compared to the coarse grain. So, the excessive means high temperature exposure can also be a possibility of accidentally high exposure accidental exposure to the high temperature, conditions are can be identified through the variation in the grain structure which will be indicated through the coarsening of the grain.

So, apart from the carburizing in carbon rich environment a structural modification in terms of the coarsening can occur at a high temperature, similarly the soundness of the components can also be identified through the through the presence of some whites or the pores if these are present in the steel.

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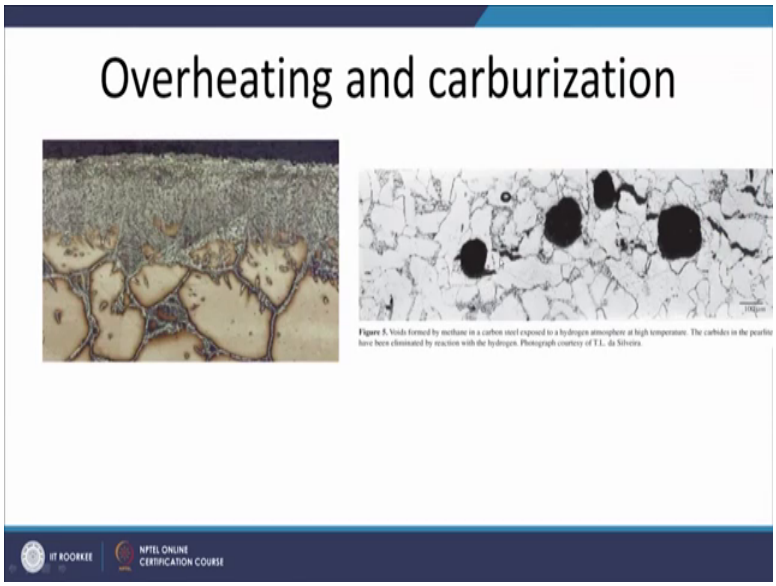

So, that will indicate if these have what quality of the metal was and if they have contributed in failure of the component

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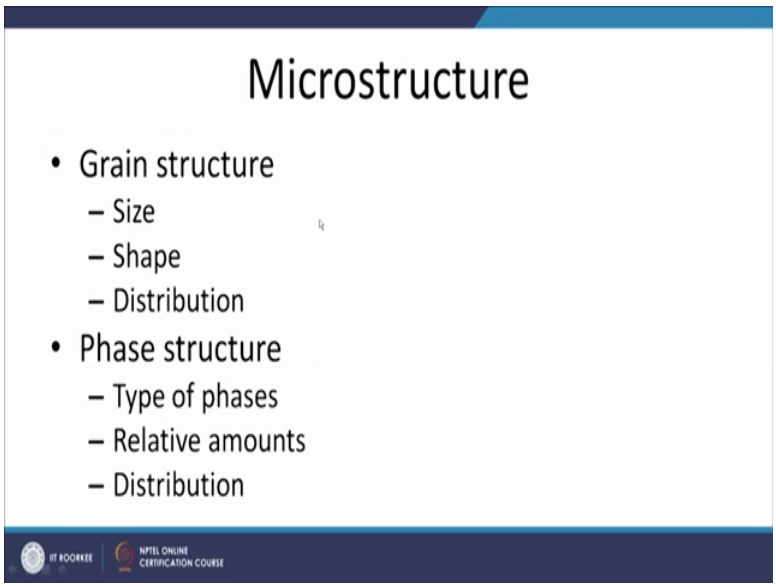

So, this are the ways things that we observe and during the microstructure is reduce to the phase structure and grain structure and systematically image analysis help us in identifying the things with better clarity about the various aspects relate to the microstructure.

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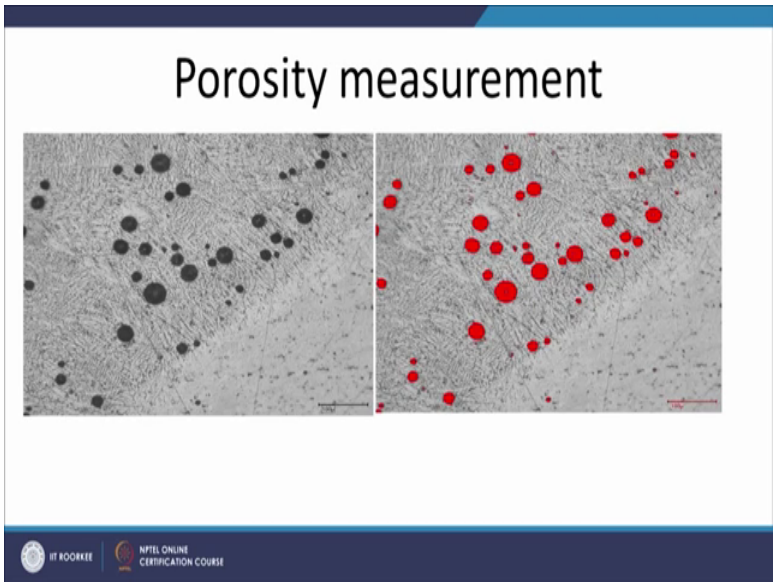

Image analysis of one particular weld joint here what it shows a darkest parts are indicating the porosity and image analysis and when image analysis carried out all these darkest parts are selected and their fraction can be identified.

So, not just the soundness not just the microstructure study um, the area fraction average grain size can be identified to the image analysis, but it also can help in identify the crack length or the fraction of the porosity.

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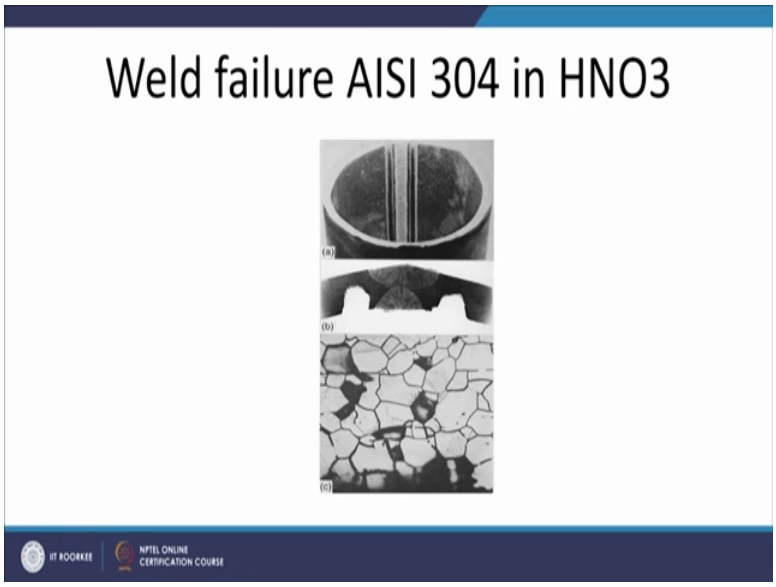

If it is present in the component like this component which has fail due to the stress corrosion cracking, what it shows that grain boundaries have been completely eaten out. So, the failure of the weld is taking place in the corrosive environment especially of the corrosive sensitive environment a means, the corrosion sensitive metal exposed to that particular kind of environment then the grain boundaries are eaten out and that will be causing the intergranular fracture especially in case of the AISI 3 naught 4 steel which is exposed to the nitric acid environment.

So, the eating of the grain boundaries can be simply seen that there is a gap between the grains which have been created. Now the microstructure sometimes facilitated the crack nucleation and growth is easily especially when the grain structure is of the needler shape tip of the needles provide easy site for the crack nucleation and their growth. So, needler structures are more sensitive for crack nucleation and growth than the spheroidal or a spherical shape grain structures likewise. So, this is another aluminum silicon hyper eutectoid aluminum silicon structure, we are coarse polyhedral shape particles are present along with the needler structures.

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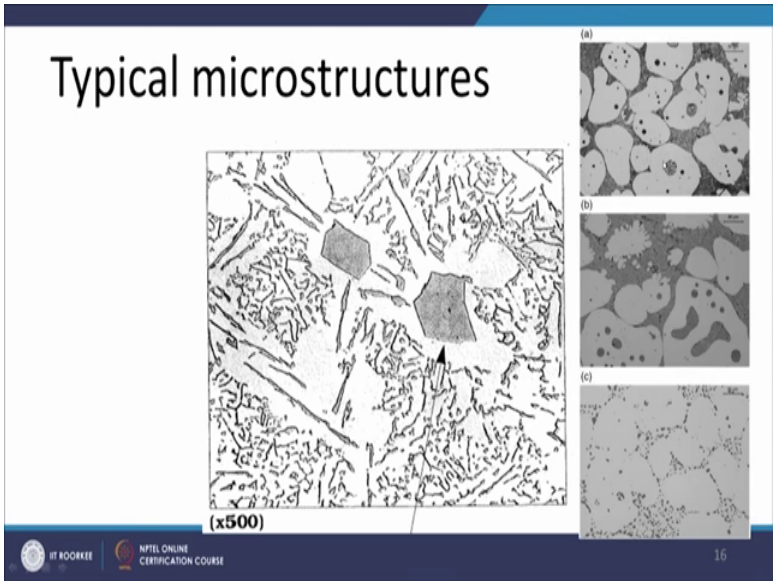

So, such kind of the blocky particles as well as the needle shape constituents facilitates the easy nucleation and the growth of crack. So, if these are present these may provide the easy sight for the nucleation and growth of crack in like semi solid processed aluminum alloys show here. So, the non dendritic structure and when such kind of these

structures are subject to the heat treatment we find that at the grain boundary, it is having a refine precipitates is more difficult to nucleate the crack whether it is grain boundary or within the grain if the precipitates are fine and they are a spherical.

So, it is more difficult to have the crack nucleation and their growth in such fine the precipitates as compared to the such kind of the needler constitutes. So, it is always favorable to have the finest spherical constituents as compared to the needler shape.

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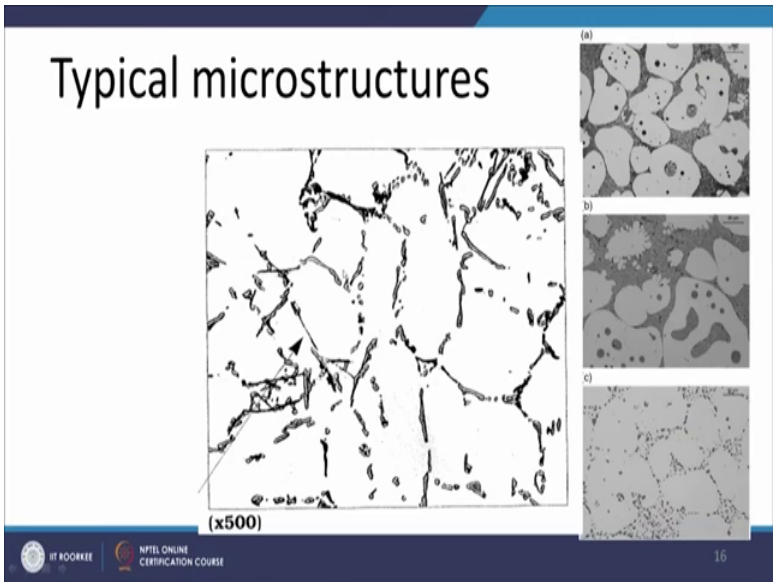

So, this is the another one where the needler shape constitutes are presented the grain boundary and it will be easy for crack to grow along the grain boundaries in such a kind of the cases.

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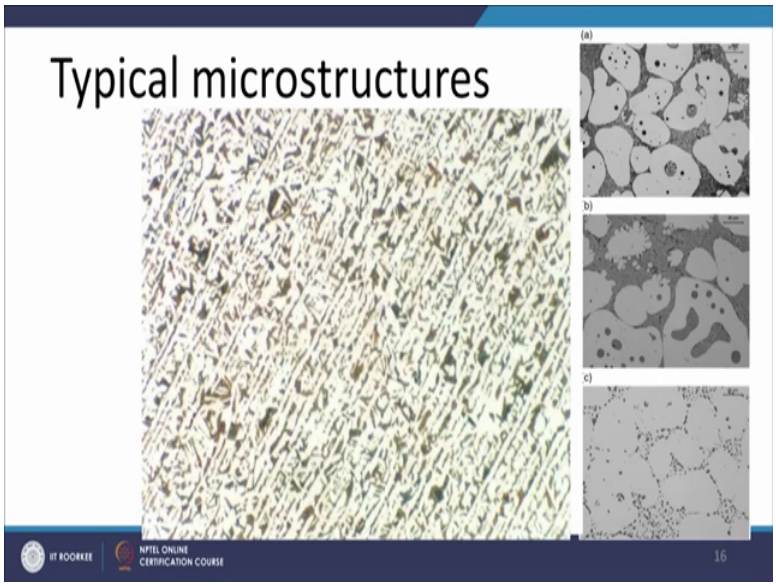

This is the another structure which is showing that the particular kind of the grain is in a one layer then another grain is another layer; So, such kind of the grains where the bends of particular phases are present, which is termed as the banded structure. So, here the ferrite layers are present continuously. So, this is not considered to be a good structure where the one type of phases present all along the length, it will easy provide it will easily provide the that the location or path for the growth of the crack in a particular direction, if such kind of the banded structure is present.

It is always there it is always good to have this structure equates a structure where the proper distribution of the ferrytic and the paralytic structure is phases are present in a in the steel rather than having the bended structure. So, now I will conclude this presentation in this presentation basically I have talked about the importance of the metallography and how can we do the metallography and what is the importance of the metallography in the failure analysis.

Thank you for your attention.