Failure Analysis & Prevention
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Lecture – 28
General Procedure of Failure Analysis
Microscopy of Fracture Surfaces

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention and you know in this subject, now we are talking about the general procedure of the failure analysis we have talked about various aspects related with this procedure and in this presentation.

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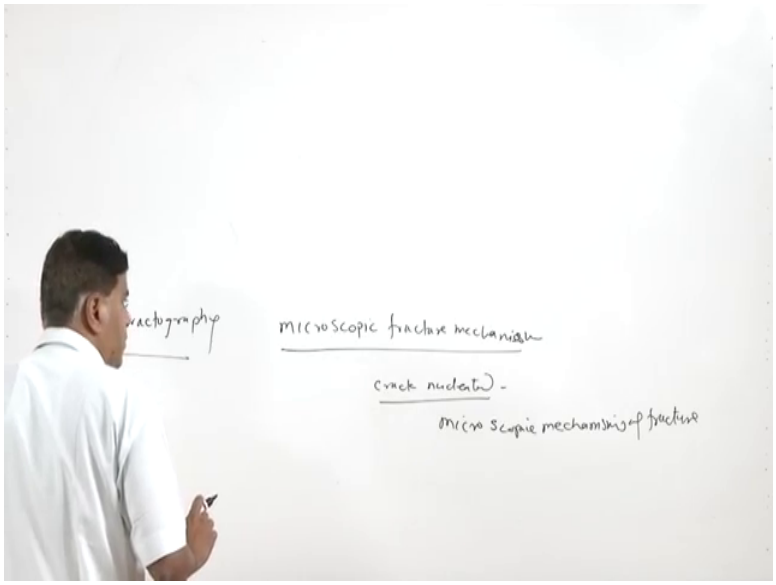

We will be talking about the microscopy of the fracture surfaces and this is also called a micro fractography, in the previous presentation we have talked about the macroscopic microscopy of the fracture surfaces in which just by observation of the failed component through naked eye or low magnification, a lenses stereo microscope and stereoscopic microscope and the scanning electron microscope.

The low magnification observations help in identifying in a number of aspects related with the fracture like, the location where from failure has taken place the direction of the crack propagation and the kind of the loading which was there whether the component was subject subjected to the plastic deformation prior to the fracture or not. So, the

whether there was a fatigue or cyclic loading or not, so number of aspects related with the loading the location of the fracture the direction of the fracture growth all that can be obtained through the micro a microscopy of the fracture surfaces, in a microscopy or a of the fracture surfaces or we can say micro fractography.

We try to understand the microscopic fracture mechanisms, where if the crack which has nucleated how this crack will be growing to facilitate the a fracture at a micro level. So, basically this is called microscopic these are also called microscopic mechanisms of fracture, because the way by which crack grows during the fracture that is what tried to we try to understand through the microscopy a of the fracture mechanisms.

They are certain a purposes of the a micro fractography which are achieved through this step, wherein the first one is to identify or to determine the microscopic fracture mechanism which may involve like the formation of the dimples or cleavage facets or the inter granular fracture surface or the fatigue striation.

So, these are the features which will indicate the way by which the crack has propagated and the kind of the micro fracture mechanisms which were responsible for the fracture. So, the one thing is that which is achieved through the micro photography is the that is the understanding on the microscopic fracture mechanisms and the second one it also helps us to understand and classify the fracture in better way; which means there are like we have the ductile fracture where significant plastic deformation prior to the fracture takes place, such kind of the fracture frequently occurred with the formation of the dimples on to the fracture surface.

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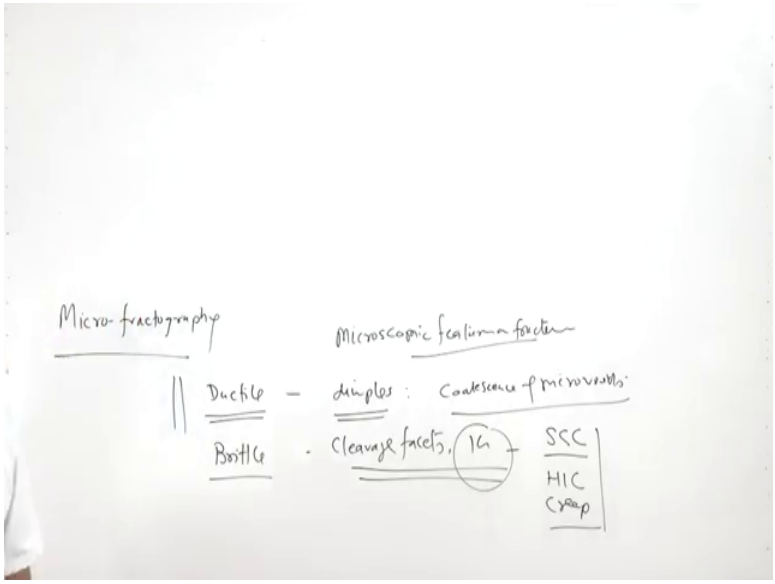

So, one the feature which is generally obtained in case of the ductile fractures, which involve lot of plastic deformation prior to the fracture is the formation of the dimples which is nothing just it is it is about the coalescence of the micro voids which are nucleating. So, whenever this mechanism is involved then it leads to the development of the dimples on the fracture mechanism and this leads to the ductile fracture or means the. This is a very general one but there can be is in some of the specialized cases, where the fracture is a brittle means there is no plastic deformation major plastic deformation, but still we see the a dimples.

But in general the ductile fractures are accompanied with the a brittle fracture, similarly it also helps like in brittle fractures the fracture may occur through the different the fracture surface features like the cleavage facets , cleavage facets or it there can be intergranular fracture or there can be the presence of. So, these are the 2 features which will be involving the brittle fracture and so these can be observed only at a higher magnification and that is why we call it as a microscopic features of the a features on fracture surfaces.

So, these are these are the two a broad grouping to understand, similarly if the there are many other the ways by which the inter granular fracture can take place like, if there can be involvement of the stress corrosion cracking there can be the hydrogen induced

cracking, there can be the creep fracture. So, true but these can be substantiated only through the now the microscopic fracture mechanisms.

So, means the microscopy of the fracture surface helps in identifying, these features a present on the fracture surface which will indicate the possibility of the ductile or the brittle fractures; however, there can be some of the however, there can be some of the exceptions where the just opposite situation may be there like, low carbon steel which shows lot of a plastic deformation play prior to the fracture.

But it may all indicate the cleavage presence of the cleavage facets in the steel. So, but neither we find a hundred percent dimple mostly we find the mixed mode of fracture where the presence of dimple and coupled with the cleavage facets are present. So, that will be indicating the existence of the mixed mode of fracture, then estimation of the service condition is the another thing mostly like.

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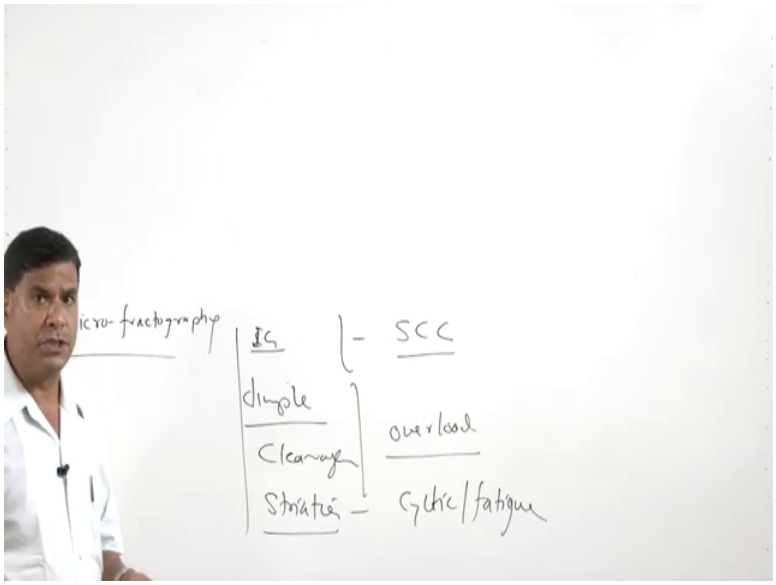

The dimple fracture in and a cleavage facets indicates the over load fracture, while the presence of the striations on the fracture surface indicates the cyclic loading or the fatigue fracture similarly the presence of the like say inter granular fracture inter granular fracture, where the grain boundaries have been eaten out by the corrosion indicating the stress corrosion cracking or a stress corrosion cracking in.

So, they the these are the basically the features which will indicate the load, the type of load under which failure has taken place or the conditions in which fracture has taken place

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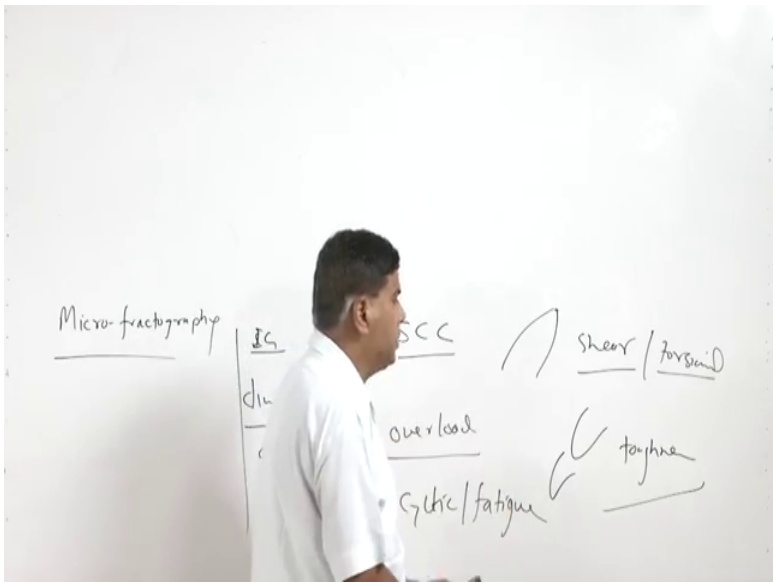

Likewise, if the dimples are elongated in a particular direction then that can indicate the possibility of the shear or the torsional loading, this kind of the features are also observed where the dimples are oriented in one particular direction on the fracture surface. So, that happens especially in case of the toughness test, where component surface is subjected to the shear loading. So, the kind of the load which has acted on to the under which the failure has taken place can also be identified through the micro fractography.

So, the type of load whether it is over load cyclic loading or the failure has or it is the shear load or the torsional load, that can be identified not through this these microscopic features present on to the fracture surface. Then sometimes a inappropriate the heat treatment also causes the a fracture of the particular kind like a Simple carbon steel, normally shows the presence of the dimples on the fracture surface indicating the ducktail fracture.

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But if the same steel is subjected to the heat treatment in temper embrittlement range, then temper embrittlement causes the precipitation of the certain unfavorable constituents at the grain boundaries and that in turn leads to the inter granular fracture.

So, intergranular fracture can also occur in the steel if it has been subjected to the improper heat treatment, similarly there are variety of the alloys and the metals which if are given in a appropriate environmental conditions at a elevated temperature or then they show embrittlement and that happens primarily due to the inappropriate manufacturing condition and this kind of the failures may occur in inform of the intergranular fracture.

So, the hydrogen induced cracking or the temper embrittlement or the precipitation of the undesirable things like in super alloys or in super alloys like in colonel presence of the oxygen at the grain boundaries can lead to the embrittlement of these.

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So, a hydrogen in case of the steels oxygen in case of the nickel alloys in like a wise presence of certain specific elements at the grain boundary, due to the unfavorable manufacturing conditions can lead to the inter granular fracture.

So, the purpose of the micro fractography is to understand the microscopic fracture mechanism to classify the fracture in better way and to estimate the possible service conditions in terms of the load and the kind of a unique environment like corrosion or oxidation and then if the component has been subjected to the inappropriate manufacturing conditions, wherein the precipitation of the certain components at the grain boundary has led to the inter granular fracture. So, those things can be estimated through the micro fractography.

Now, how to conduct the micro fractography this is the another aspect. So, for a micro fractography basically there are micro fractography, there are two ways which are commonly used one is the optical microscopy and another is a electron microscopy.

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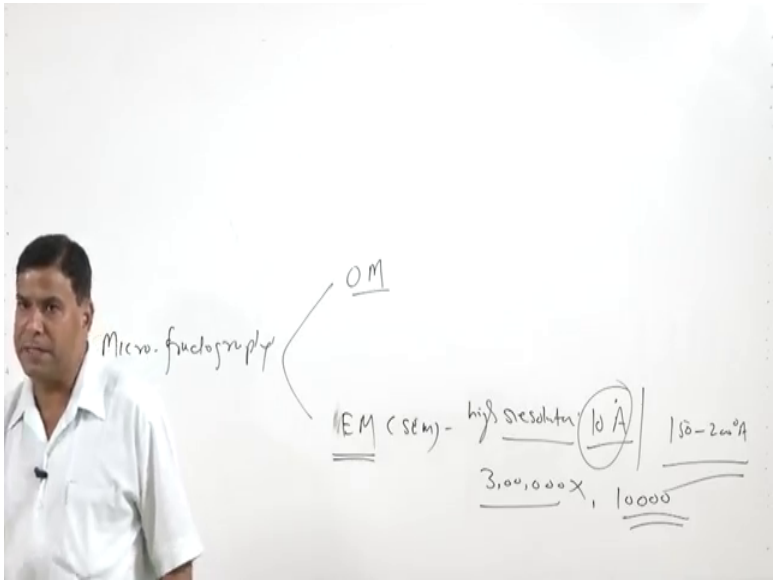

Wherein transmission electron microscopy or the scan electron microscopy both these can be used , it is common or it is preferred to use the scanning electron microscopy also known as SEM for the fractography of the surface and this is because of the certain regions like it allows very high resolution high resolution , which is the ability to identify the two close constituents clearly on the in case of the tam or sam, it the resolution can be as low as a 10 angstrom, but it is common to have the resolution in these systems of 150 to the 250 angstrom.

So, this is the minimum side which is which can be resolved and the magnification also very high magnifications are possible which can go as a high as a 3 lakhs of the times of the component the constituents. So, 3 lakh magnification is possible, but for a failure analysis it is common like up to 10000 magnifications are commonly used because above which we are not able to find any useful information with regard to the fractography.

Whether, it is a precipitation of from some fine precipitates at the grain boundary leading to the embrittlement and cause the intergranular fracture or the identification of the microscopic fracture mechanisms like the striations or the inter granular fracture or the cleavage facets the, dimples which are present on the fracture surface and one more thing that these do not require any surface preparation.

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So, it is very good that they offer very high depth of field, means the constituents which are present fracture surfaces are obviously rough. So, if the depth of field is very high then it all the microscopic features whatever they are present on the fracture surface all these can be seen very clearly with the with the clarity and the presence of the require the features which are there can be easily recorded.

So, high depth of field allow otherwise if the depth of field is limited then the this may be a good in focus, that is but other regions may not be good. So, uniformity in focus will not be good somewhere you will find that we will find that the one region is in focus and another region is out of focus.

So, it is good to have the high depth of field so that the entire fracture surface can be clearly seen, so these are the 3 aspects related with us some or electron microscopy than optical microscopy here this is normally limited although we have microscopes of higher range also.

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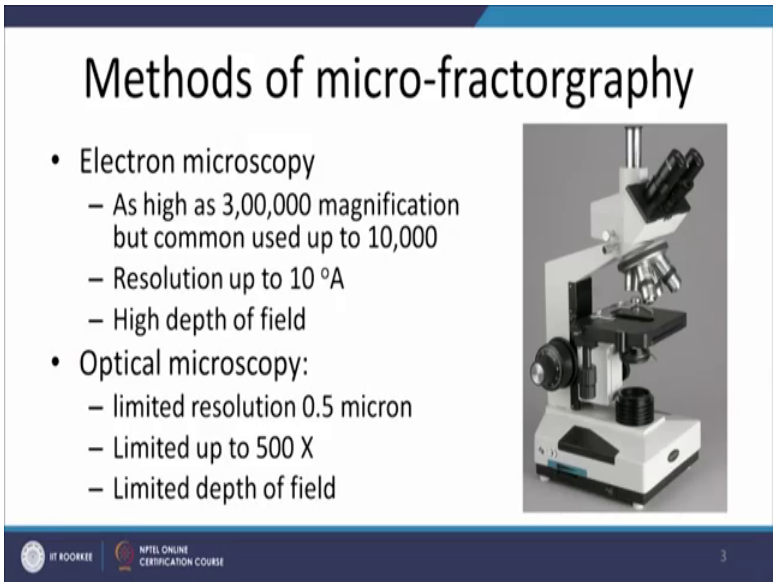

So, although we have the microscopes of the higher range also we are like 100 400 to the 1600 magnification.

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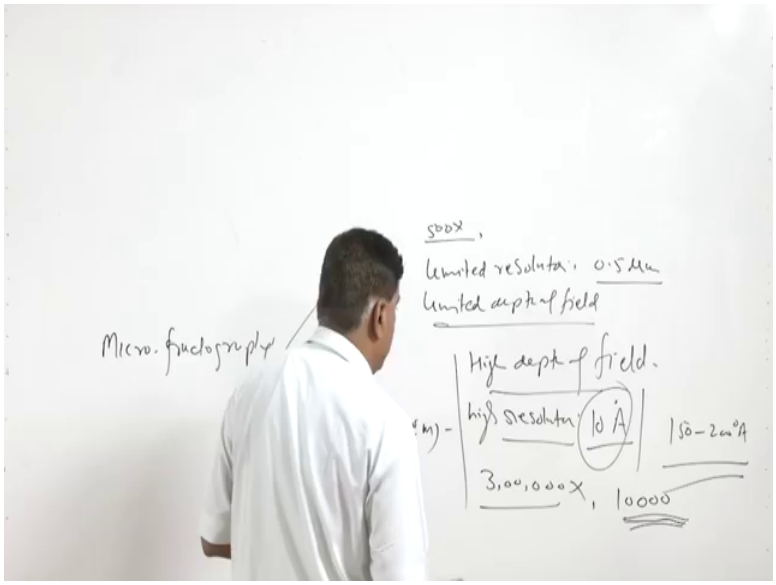

But it is common that 500 x is the maximum a magnification which is used and the resolution is also very limited. So, we can say the limited resolution of a 0.5 micrometer is a available with the optical microscopy. But another problem is the limited depth of field a depth of field and because, of this we come may come across the problem wherein 1 region is in focus another region is out of focus.

So, lack of clarity may be there in terms of the a clarity on the microscopic features which are present on the fracture surface and especially when these are seen at a high magnification. So, these are the two tools which are commonly used for a microscopy of the fracture surface and thereafter we have the preparation of the fracture surface, how we can undertake the microphotography of any component.

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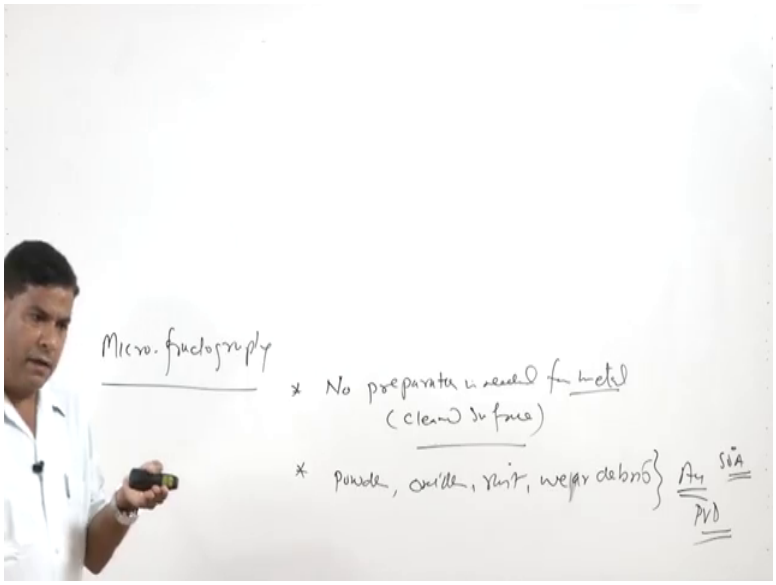

So, mostly in case of the metals no preparation is needed for metals because, they are good electrical conducting and for a microscopy it is required that the surface of the work piece is charged and the electron can be directed on to the surface of the fracture for capturing the images. So, but of course, a little bit clean a cleaned the surface which is to be observed is needed. So, now with the fracture surface if no oil dust dirt grit grease etcetera is present on the fracture surface, then it can be easily observed no special preparation is required.

But of course, if these are present then we need to clean the fracture surface in order to see the things see the microscopic fracture mechanisms. So, cleaning may be required if it is it is dirty, but in case of the powders or in case of a oxides like rust or the wear debris now wear debris wear, it is required to provide the gold coating of the gold which is of like say 50 angstrom thickness and this is applied through the a physical vapor deposition technique.

So, in order to make the electrical conducting as well as providing the good reflective surfaces it is required that the non conducting surfaces, if they are to be observed under the electron microscope, then these need to be coated with the gold of very using a coating thickness may be very thin just to make it electrically conducting and a good reflection for the electrons, then coming to the other microscopic fracture features.

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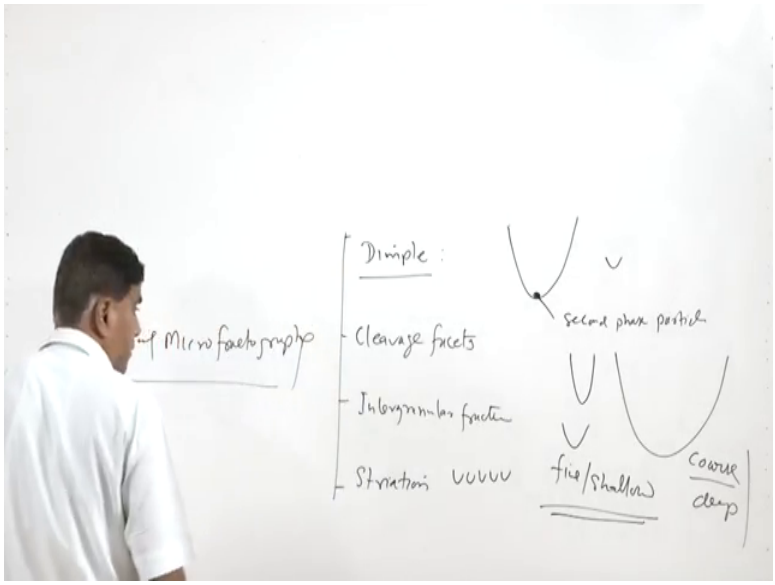

So, they are basically the features of the micro fractography. So, therefore, very standard microscopic a features of the fracture surfaces and these are like dimples and the cleavage facets inter granular fractures features and striations. We will try to talk about what these indicate and when these kinds of the features are observed. So, the dimples are basically these, these dimples are conical shaped features wherein mostly the inclusion or impurity which is nucleating the void is found at the bottom of the dimple.

So, this is basically the second phase particle which is comparatively harder than the metal matrix. So, this nucleates the voids and thereafter the metal matrix is subjected to the continuous deformation and it leads to the formation of the dimple kind of the features. So, the dimples may be shallow like this or these dimples may be very wide, so depending upon the thus the diameter of the dimples like this is a conical shape. So, the dimples may be of a smaller diameter or the large diameter a dimple may be shallow or fine.

So, basically fine and shallow dimple or it is a course or very deep dimple. So, if the course and deep dimples is there then the it will indicate very extensive plastic deformation as compared to the case when the dimples are fine and they are shallow, a large number of the fine dimples indicates the possibility of the good yield strength of the material.

But the limited deformation on the other hand extensive deformation and the large or course dimples indicates somewhat lower yield strength and the greater ductility or the percentage deformation prior to the fracture. So, the percentage elongation and the fracture would be more in case when the dimples are the large and the depth is more as compared to the case when they are fine.

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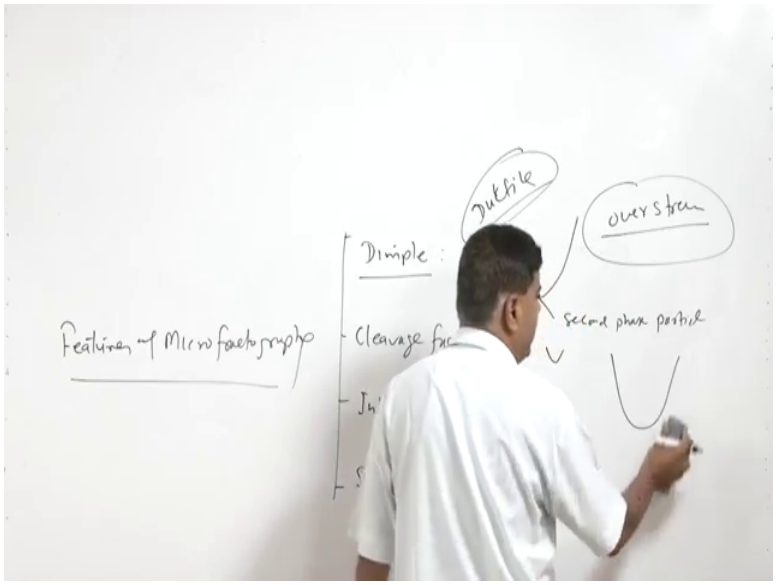

So, the dimples these are basically formed when the material which is filling is a ductile and this kind of the fracture is observed under the over stress conditions. So, this means the component has been subjected to the overloading.

So, the ductile metal subjected to the overloading will indicate the dimples, this is very common understanding when the dimples are shallow and the fine the loading capacity is high, but the ability to deform is limited of while when the dimples are large course and deep then yield strength will be low and ductility will be high. So, these are the kind of inferences about their ability to carry in the load and that the energy required to cause the fracture.

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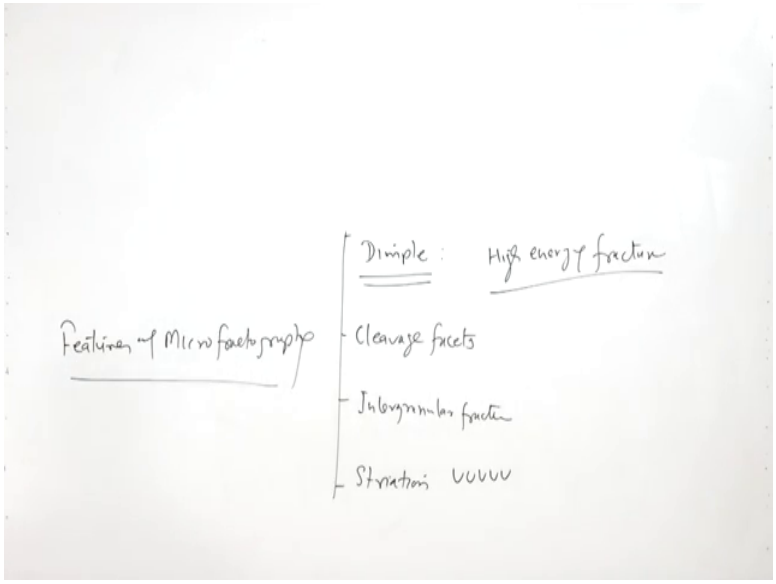

There is one thing which is common that whenever the dimples are observed dimples are considered to be high energy fracture, whenever dimples are present on to the fracture surface it is considered that it would have a it would have needed very high energy for a causing the fracture.

There while the presence of other features will indicate the possibility of the low energy fracture we will be talking about that. Now, so the cleavage facets yeah now the cleavage facets are the another a general microscopic features which are normally observed, when the material is the brittle in nature.

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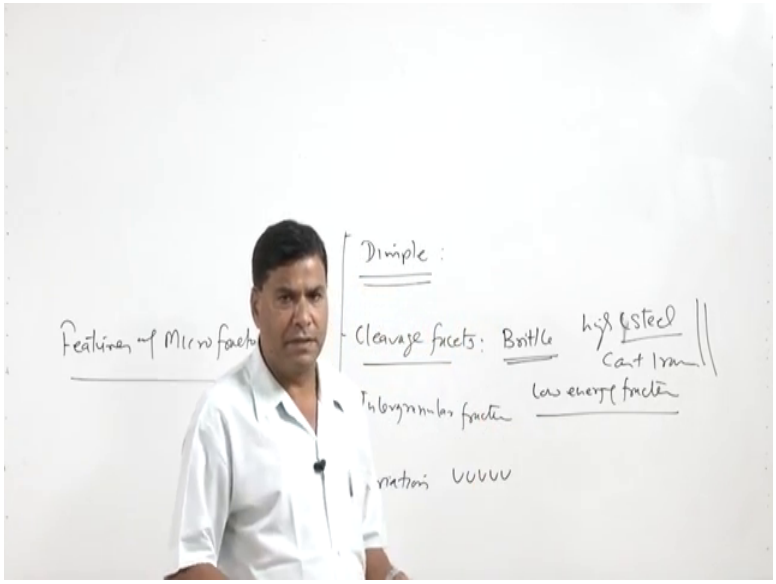

So, in metals like high carbon steels, high carbon steels which show limited ductility cast iron and other high strength metals which show very limited ductility they tend to fail in a brittle manner.

So, the cleavage facets is a one of the indicator of the a low energy fracture and whenever it is present material is said to be of the low fracture toughness, it will require less energy to cause the fracture as compared to the case when the where the dimples are present on to the fracture surface.

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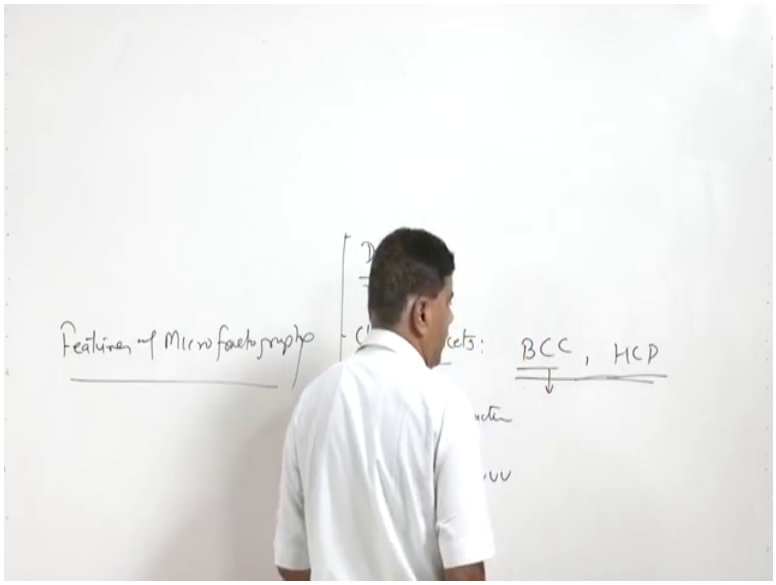

And this kind of the feature is observed normally in case of the BCC metals and the HCP metals, but not necessarily because the iron if it is a pure it will show a lot of elongation like 30 40 percent with a lot of ductility, but certain compositions of these metals indicate very limited ductility and the fracture in those cases is mostly through the cleavage facets mechanisms inter granular fracture.

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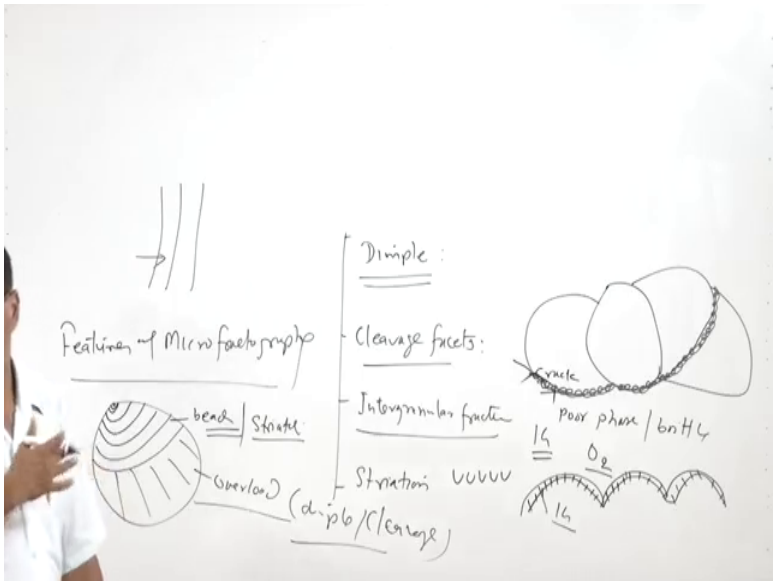

Inter granular fracture is the typical one where the crack if it is present that will be propagating through the grain boundaries.

So, like in a metal system these are the number of grains present on to the fracture surface; So, sometimes the presence of the poor phases at the grain boundary or undesirable precipitates in form of the pleats or in form of the flat in form of a like thin layer.

This kind of the poor phases which are brittle have limited load carrying capability or like precipitation of undesirable constituents like a oxygen in case of the nickel alloys. So, these provide very the low strength low ductility zones where which under the favorable conditions if the crack has a nucleated then, it will easily propagate through these a grain boundaries.

So, the propagation of the crack around along the grain boundary will be leading to the will be leading to the inter granular fracture and whenever it happens what will find that

fracture has a separated fracture, the suppression of the grain grains have taken place through the grain boundaries and in that case the grain boundaries will be exposed to the surface in this form. So, we will be able to see that different ball shape constituents are present onto the fracture surface, indicating that fracture has taken place in inter granular manner.

So, this is what we can see here that the brittle intergranular fracture whenever it occurs the fracture, the different grains will be clearly visible on to the fracture surfaces and which is indicating that the crack has propagated along the grain boundary and the suppression of the grains have taken place through the grain boundary.

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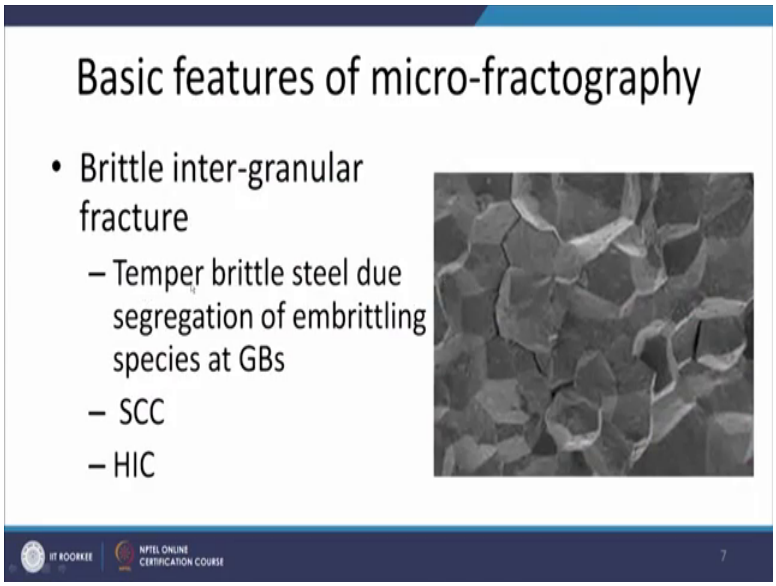

And this kind of the fracture is observed like say in case of the temper brittle steels, due to the segregation of the embrittling species at the grain boundaries this kind of fracture is also observed in case of the stress corrosion cracking and hydrogen induced cracking.

So, this feature is indicative of the brittle fracture due to the growth of the crack through the grain boundaries leading to the exposure of the grains at the fracture surface and so this is a basically brittle intergranular fracture and the fourth feature is it is the striations. As I have explained earlier whenever during the fatigue fracture a first of all the nucleation of the crack takes place and thereafter the crack will be growing in a particular direction in case of the unidirectional loading.

So, this will be leading to the presence of the beach marks which are the concentric circles having the a center at the a location of the crack initiation and thereafter it experiences the sudden fracture which is basically overload fracture.

Overload fracture may occur through the dimple or through the cleavage facets crack growth mechanisms and these beach marks at a high magnification appears in form of striations, which indicate the magnitude by which the crack is growing under the each load cycle this is the theoretical one, but actually it requires lot of a load cycles for growth of the crack. So, whenever the new striations are represent on the fracture surface it indicates that the load has been the cyclic in nature and the fracture has occurred in fatigue manner.

Now, I will summarize this presentation in this presentation I have talked about the purpose of the micro fractography and what are the general microscopic fracture mechanisms or the features which can be used to interpret the kind of the way by which fracture has taken place and the kind of loading conditions which were experienced by the component during the fracture.

Thank you for your attention.