Failure Analysis and Prevention
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Lecture - 24
General Procedure of Failure Analysis: Macroscopy of Fracture Surfaces- I

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention. You know we have talked about the fundamental sources of the failure and in this presentation we will be talking about a specific aspect related with the general procedure of the failure analysis.

Now, in this presentation we will be talking about the like say the Fractography.

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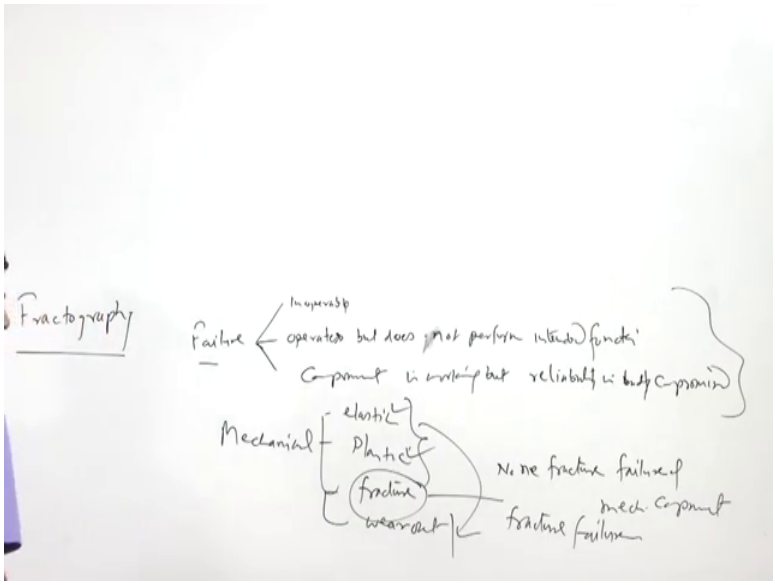

Ah we know that the failure of the component can occur in number of ways ; like if you have to define a failure means the component in operable this is the one way, where it operates another way where like component operates ah, but does not does not perform intended function, intended function. So, again in this condition we say that component has failed. And third one where the component is working, but reliability, reliability is badly compromised badly compromised.

So, for this situation for these are the 3 ways by which or 3 categories under which we say that the component has failed; for any kind of the component, but if it is about the

mechanical component then we say that when the elastic deformation beyond this limit or when you say the plastic deformation beyond the limit or when the fracture has taken place.

So, in case of the mechanical component these are the 3 ways or like say, there is one more wear out of the sample beyond the acceptable limits. So, in this 2 cases like elastic deformation beyond the limit or plastic deformation beyond the limit and the wearing out of the component these are, these 3 we can say as non fracture failures of mechanical component, where elastic deformation or plastic deformation or wearing out of the component is beyond the acceptable limits.

This is the one wear fracture or the suppression will be taking place. So, this will be the like the fracture failures and others are non-fracture failures, like a elastic plastic deformation and the wearing of the component. So, to a study the fracture related failures our approach has to be different then the non-fracture related failures of the mechanical component.

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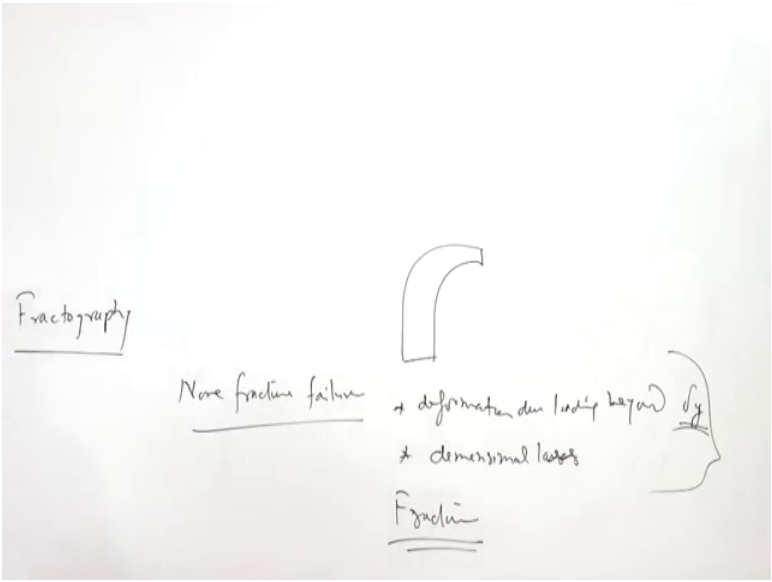

So, non-fracture failures can occur in the number of ways like, a the component has been subjected due to the external extra excessive loading and it has got bend. So, like it has been subjected to deformation due to the loading beyond yield strength of material. So, beyond the yield strength of the material.

So, this is one typical case or where like the dimensional loss due to the variety of the dimensional losses has been excessive and because of which the component has started to not to perform as intended. So, the, these dimensional losses also will be leading the failure. And if we see sometimes the non-fracture fingers eventually cause the fracture.

So, there may be possibility that initially the failure has started with the non-fracture failure, but if it continues for longer period then we will say that due to the excessive dimensional analysis under the given set of the loading conditions even the fracture may take place. So, those ah, but primary cause for in those failures will be the different then those which will be occurring due to the fracture like the component will be defined even when it has restarted not to function as per the requirement much before then when fracture has occurred.

So, I mean to say like the non-fracture failures eventually can lead to the fracture of the component. So, like if we see, like if any failure we have to group then there can be those failures where the fracture occurs or there can be the failures where no fracture occurs or the failure with fracture or without fracture.

So, without fracture failures like a galling which takes place in the engine or the fretting so the galling and fretting are the kind of the mechanisms which will be reading to the minor surface roughness or a regularity generation or the galling will be leading to the scissor kind of conditions and eventually; this can lead to the failure or the deformation of the component. If the fracture failures are to be investigated then we have one special branch of the engineering or science, where in investigations are carried out primarily to see; that under what loading conditions and under what environmental conditions failure has taken place.

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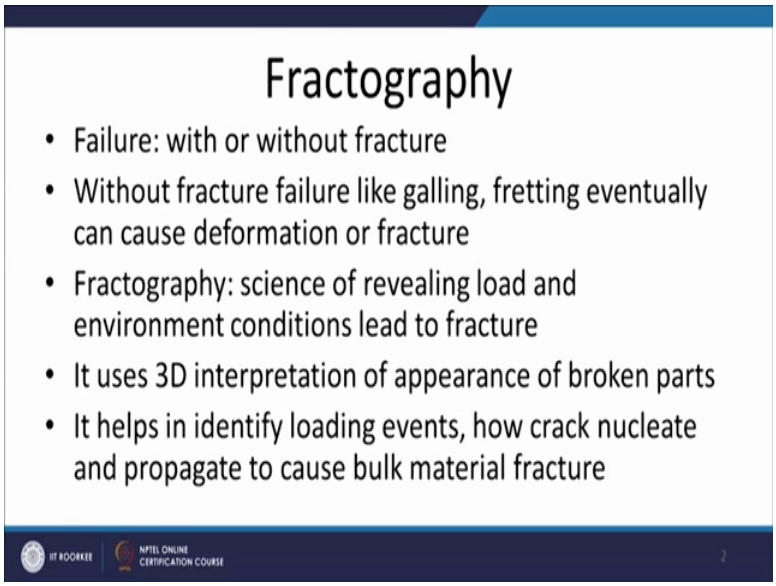

So, basically the Fractography is the science of revealing the load and environmental conditions which have led to the failure of the fracture of the component. And what it uses? It uses the understanding of the different areas related with the mechanical failures and that is and; that is why we say that it uses 3 dimensional interpretation of the appearance of the broken part, wherein like we will be trying to in observe the fractured component or broken part visually using the naked eye then we will be using the macroscopy macroscopy of the failed part, wherein the low magnification cameras low magnification lenses a stereoscopic cameras and even the scanning electron microscopy is used at the low magnification. So, these are the macroscopic observation of the failed part and then further we have we carry out the microscopic observation of the fracture part.

So, the combination of the various approaches helped us to understand and to reveal the loading an environmental conditions under which failure or the fracture of the component has taken place. So, that is why what we say that it uses 3-dimensional interpretation of the appearance of the broken parts. So, when the Fractography is carried out it helps in identifying the loading events, how the crack has nucleated and it has propagated during the fracture of the bulk materials.

So, when the Fractography tool is systematically applied it will help us to know the kind of loading conditions, the where crack has nucleated and how it has propagated during

the fracture of the bulk materials. So, what we need to do for the Fractography of the broken parts? There are basically as I have said there is a macroscopic observation and the microscopic observation.

So, for microscopic observation first of all we start with the observation of the failed component using the naked eye, where which we can say as the observation is starts with the visual examination of the failed component is starting from very low magnification like using naked eye then low magnification lenses, then stereoscopic microscope and then scanning electronic electron microscope.

So, these are normally written at a very low magnification which may be in the range of 1 to 100 x.

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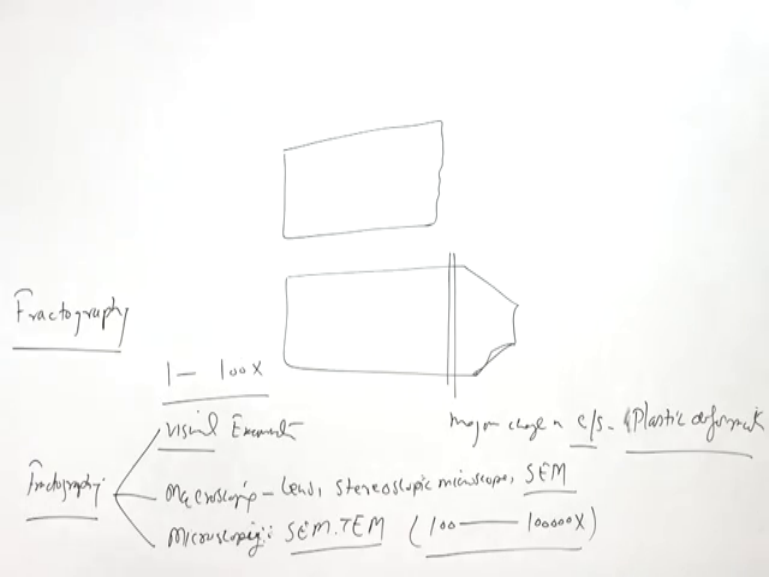

And when these observations are carried on it reveals lot of information; like if the failed component is really very big and if it has a failed like this and end is showing, in this manner what it will be showing that cross section actually of the component has reduced significantly.

Magnif means no microscope or a scanning electron microscope can show such kind of the variation in the failed component, where variation in cross section where or the deformation in the component or the wearing of the component cannot be observed. It can simply be observed through the visual examination.

So, the major change major change in cross section of the component can simply be observed through the visual examination. And this will indicate that will be component has been subjected to lot of plastic deformation prior to the fracture. And which indicates that really this is the, this is where the material has been subjected to the deformation material is ductile and it has been it has given enough indication prior to the fracture.

There can be another possibility when the same section component may fail abruptly without it giving any kind of indication. So, in this case there would not be any change in cross section of the component. So, such major changes can only be observed through the visual examination of the broken component. And this will indicate lot of information; these will reveal lot of information about the stresses come under which component has work the kind of the load which has been experienced by the component.

So, for doing the Fractography they are systematic approaches primarily, it is like say we can put it in 3 categories visual examination is one the microscopy which uses the lenses or stereo scopic microscope or a scanning electron microscope. So, all these are used at low magnification like 1 to 100. Then the third aspect related with the Fractography, Fractography is a the microscopic observation microscopy, which we can say microscopy other fracture surface. So, it is carried out normally using the a scanning electron microscope or transmission electron microscope. And this can be done over very wide range of magnification from like say 100 to even like 1 lakh magnification range.

So, this is very wide range it allows us a to look very closely in various microscopic features which are generated in course of the fracture of the bulk materials and they will be indicating they will be giving idea about the kind of the loading conditions, the type of load the whether low load was monotonic or it was cyclic or the kind of environmental conditions under which failure has taken place.

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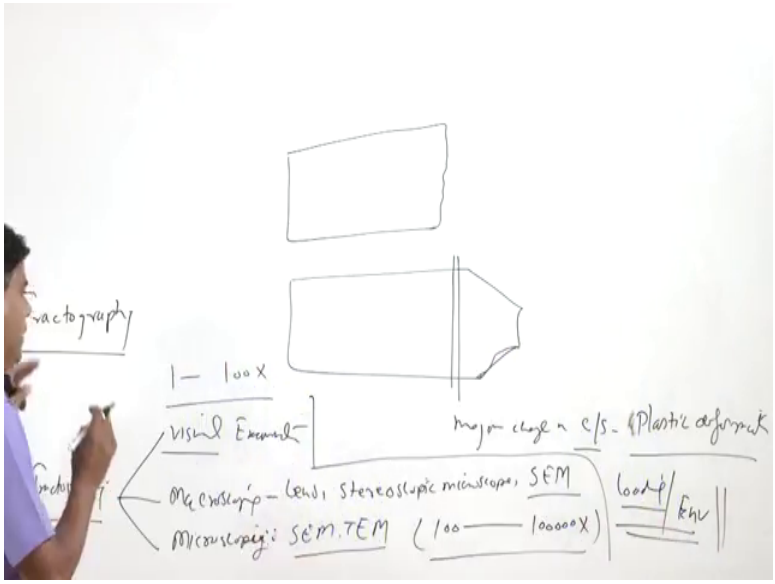

So, loading and the environment under which the failure has taken place. These things can be investigated through the Fractography using these 3 approaches. All these 3 techniques should be coherent with regard to the mode of failure fracture or the mechanisms which will be leading to the failure of the, or fracture of the component.

Now, what for it is carried out? Actually, likes Fractography as I have said it helps to identify the loading conditions and the environmental conditions which have led to the failure of the component. And in line of that the basic purpose of the Fractography is that it helps to determine the root cause of the failure among the so root cause of the failure will be among the fundamental sources of the failure, like if the if some of the fundamental sources of the failure like improper deficient improper or deficient design, improper material selection or improper manufacturing improper, service conditions improper maintenance improper assembly and improper maintenance plan.

So, all these things if they have been improper then they will be leading to the conditions with regard to the load and environment; such that the fracture will be occurring. So, those things are established among the fundamental sources of the failure which one was a basically responsible for fracture of the component. So, that is what is identified through the Fractography.

So, determination of the root cause of the failure among the fundamental sources of the failure. So, part from that how the Fractography helps in determining the root cause of the fracture.

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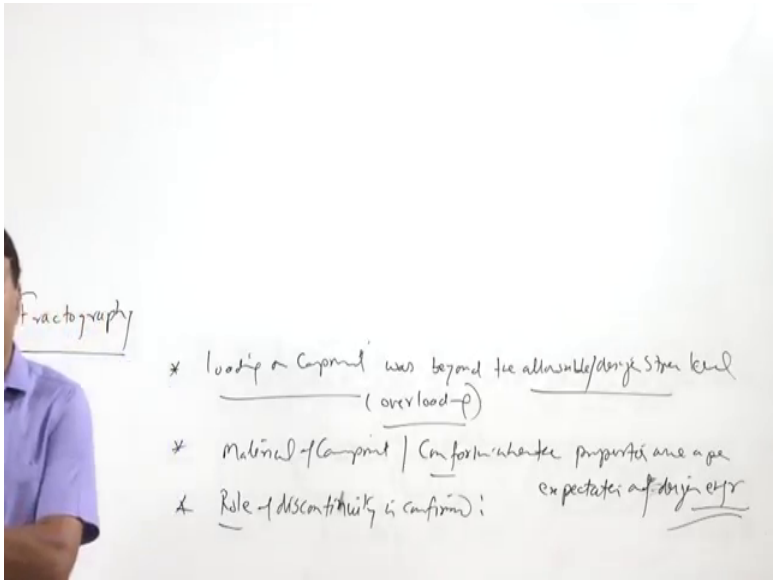

So, whenever there is a Fractogarphy is carried out it helps in determining whether the loading on the component, loading on the component which has fractured was beyond the allowable design stress level.

So, this is one thing that; so it means whether the component was over loaded or not and because of it is fracture has occurred. So, the if the failure is due to the overloading, that is what is identified basically. So, during the service if the component was overloaded it will show the different kind of feature as compared to the case when it the failure fracture has occurred. below the within the allowable or the design stress level. So, if the applied stresses are more than the allowable design allowable or the design stress levels, then it the surface features will be different than the case when the component is fracture of the component is occurring under the stress levels which are well with in the design stress level.

So, this is one thing it helps to rule out the possibility of the overloading or it will confirm the possibility of the overloading for as a cause of the fracture. the second one is that whether the failed component like component material or the material of the component had the required properties or not as excepted by the design engineer.

So, it will conform basically, it will conform whether the properties over as per expectation, as expectation of the design engineer or not. like the design engineers will assume that the material will have these set up the properties if due to some kind of the fault with material if the material does not have those set up the properties. So, it will be leading to the failure of the components.

So, that kind of conformation if the material is having the required set up properties or not as expected by the engineer that is what can be conformed through the Fractography. And the third one is that if there are discontinuities in the materials. So, if they have contributed towards the fracture. So, the role of the discontinuity role of the discounti nuity is conformed with regard to the fracture.

So, whether really the discontinuity is have played a crucial role towards the fracture or not; that is what can also be identified through the Fractography. So, whenever Fractography is carried out it helps in ruling out the possibilities these 3 possibilities, one if the material has been subjected to the overloading if the material had the desired set up the properties as expected by the design engineer or if the discontinuity is present in the failed component had played a crucial role or not towards the failure. So, that is what also can be identified.

Now, like if we if the fracture has the taken place so how to group or categorize these fracture? So, based on the appearance means on the microscopic observation the fractures are grouped in 4 or 5 types there ah, like say the 5 types of the fractures based on the appearance of the failed component.

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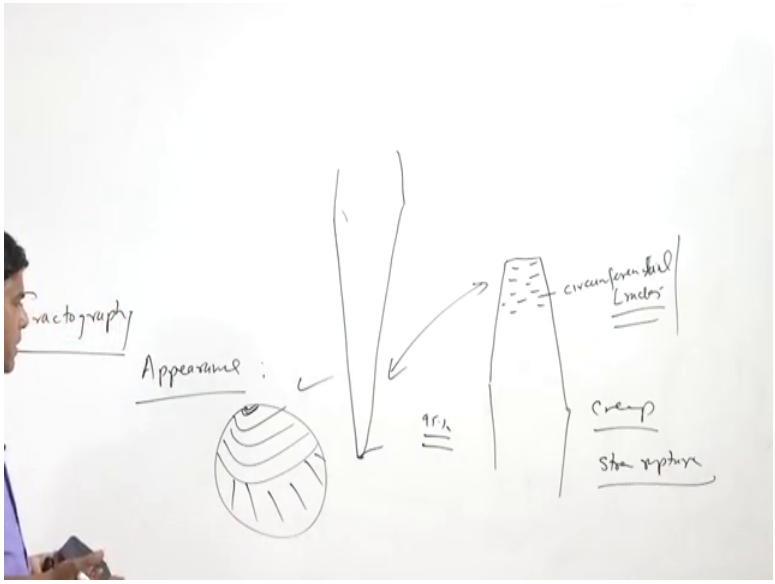

And this include like the ductile fracture, where significant plastic deformation of the failed component will be taking place. The brittle fracture where no indication of the deformation will be there prior to the fracture the fatigue fracture where the fracture surface will show the typical appearance of the beach marks, indicating that the component has been subjected to the fatigue loading. So, the fatigue fracture will be unique and the different with regard to the ductile and brittle fractures; in terms of the fracture appearance because it shows the typical beach marks on the fracture surface.

The creep fractures show again the different kind of behavior, where because the creep will be occurring at a high temperature where the material may show lot of the ductility. So, this is one where the reduction in cross section has been up to such an extent that it component has been subjected to do component cross section has been reduce to such an extent; that it is like the percentage reduction is like say more than 95 percent.

So, this is one possibility another one where what will say that although reduction in cross section is not much, but near the fracture surface there are lot of circumferential cracks. So, circumferential cracks is one of the typical circumferential cracks on the component subjected to the elevated temperature and that has led to the creep. So, the in both the cases basically it is termed as the stress rupture because the fracture occurring at high temperature is defined as a stress rupture, which can of the 2 types wear reduction in cross section takes place to such an extent that it is not able to take the external load

that will be this case, and in this case particularly where grain boundary sliding is so huge that lot of circumferential cracks are developed near the fraction surface and which eventually causes the fracture.

So, these are the 2 types of the appearances of the fracture surfaces of the component which are subjected to the creep. similarly as I said under the fatigue conditions somewhere crack will nucleate and then we it will grow like this beach marks, which are whose these are basically the concentric circles having the radius having a center at the nuclei crack nucleation point and thereafter the certain fracture zone.

So, such kind of the general features are observed in case of the fatigue fractures; and thereafter we have one more type of the fracture which we can say as a environmentally assisted fractures, wherein if the component is subjected to the external loading in the corrosive environment then it will be leading to the corrosion assisted fractures so which may be inform of a like say a stress corrosion cracking or stress corrosion fatigue.

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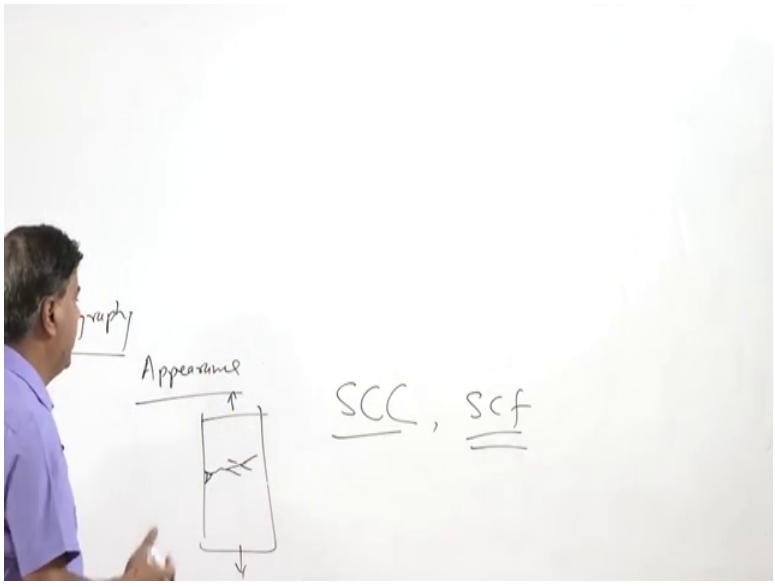

So, these are the 2 types of the fractures where in one case unlike the component subjected to the external tensile stresses and in corrosive environment some cracks nucleate and they grow in very localized manner like in branched manner. And then some the crack will be growing gradually and eventually fracture will be taking place.

So, in this case the load is monotonic.

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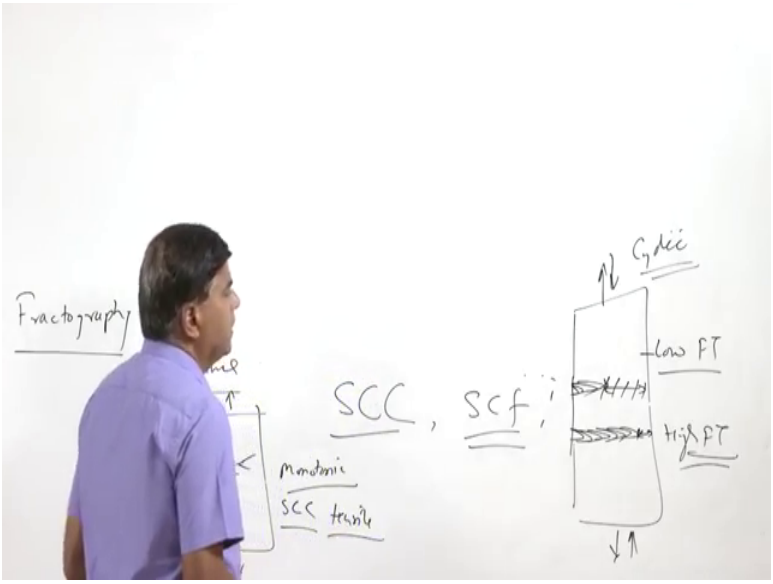

In case of the stress corrosion cracking of curse it has to be tensile. And on the other hand when the component is subjected to the corro exposed to the corrosive environment so, corrosion will be causing the pits and the cravi crevices here and there as per the corrosion sensitive zones and if it is also subjected to the fluctuating loads.

So, in that case so you can say component subjected to the cyclic loading, at the same time it is also exposed to the environmental corrosive environment. Then out of these number of the pits and the cavities which are which have developed at the surface due to the corrosion some of them will grow. and then under the fatigue conditions cyclic loading conditions and there growth eventually will cause the fatigue fracture.

So, here such kind of fractures are very fast and; in this case the nucleation facilitated by the pits and the crevices which are being generated at the surface. And the cyclic loading will be facilitating the growth of crack and eventually the certain fracture will be taking place as soon as the cross section is reduced to such an extent; that the external loading is beyond the capacity of the load resisting cross sectional area left out and the certain fracture will be occurring.

So, that will depend upon the fracture toughness of the material like if the low fracture toughness material the crack will be growing up to such an extent and thereafter certain fracture will be taking place, but in high fracture toughness material the crack can grow gradually, and thereafter the fati certain fracture will be occurring when the left load

resisting cross sectional area is reduced to a great extent. So, in this case low resisting cross sectional area is large; in case of the low fracture tough materials and this is the case of the high fracture tough material.

So, depending upon the fracture toughness of the material the third stage of the catastrophic fracture will vary and that will decide the extent up to which; the crack and grow during the cyclic loading prior to the catastrophic fracture . So, these were the categorization or the types of basic types of the fractions based on the appearance. So, based on the appearance we have ductile fracture, brittle fracture, fatigue fracture, creep and environmentally assisted fractures like stress corrosion cracking and the hydrogen embrittlement .

So, now if you have make the useful observations and inferences after observing the failed component, say visual examination or the macroscopic observations then or the microscopic observations. Then what observations we can make in with regard to the loading conditions.

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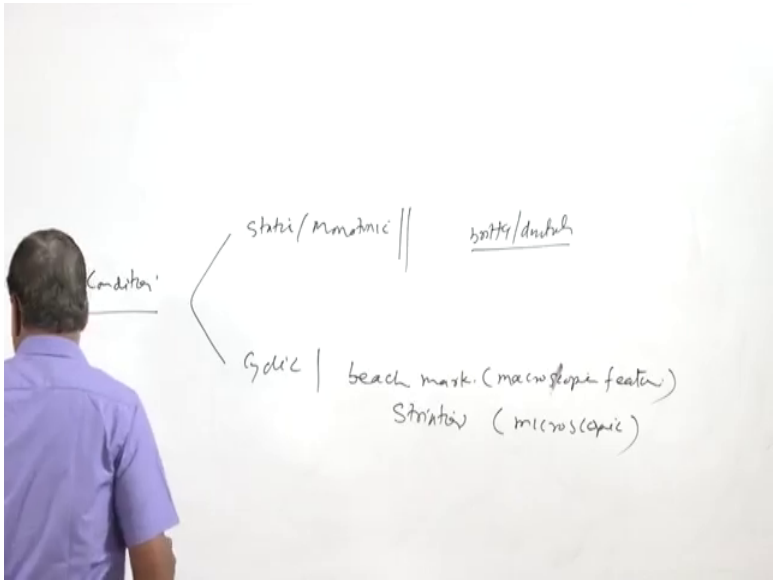

So, with regard to the loading conditions, loading can be like say like static or we can say the monotonic or cyclic where load is wearing or changing or fluctuating.

So, cyclic loading in case of the monotonic loading and in case of the cyclic loading so, in case of cyclic loading we can see the beach marks which is a macroscopic feature

macroscopic feature or we get the striation on the fracture surface striations, which is microscopic features we do not get the striation using the naked eye low magnification lenses. So, the, we need the scanning electron microscope to observe these striations ah.

On the other hand the no such kind of the beach marks or a striations will be there on the fracture surface. So, they will be the static or the, they will be the monotonic fractures. So, for this case we have like the brittle or the ductile fractures which like say this is the case of the, in case of the monotonic loading. So, there is no special feature like beach marks or striations in case of the static and the monotonic loading.

There are other microscopic features which are used to the, define if the fracture has occurred either like dimple or the cleavage facets.

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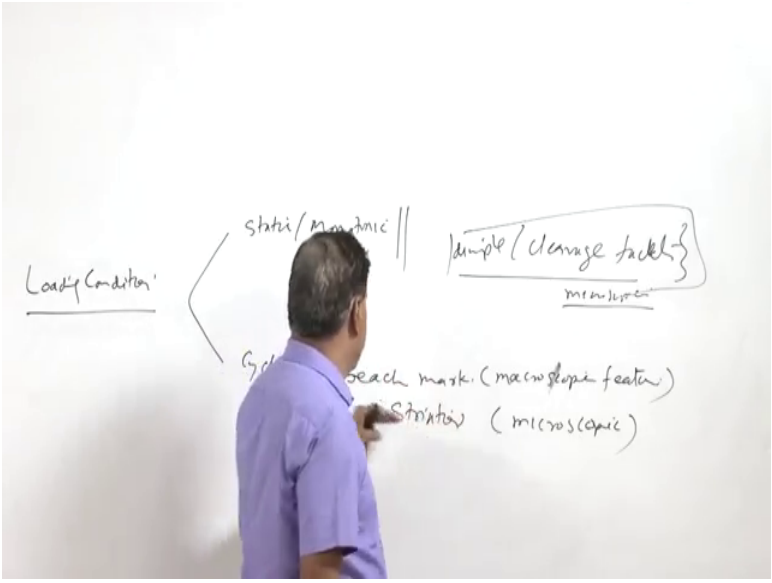

Ah their presence will so the these are the microscopic features which will indicate that the loading has been the monotonic and which we will be leading to the either ductile or the brittle fracture.

But these features are different then what we get in on the fracture surface in from of the beach marks or a striations for the cyclic load and there is no a special feature as such which can be observed using the naked eye or macroscopic observations, macroscopic observations to say that this is the is monotonic loading. So, be indication of the beach

marks will suggest the cyclic lading and absence of any such kind of the feature will indicate the possibility of the static or the monotonic loading.

Then the macro scale based on the macro scale observations the fracture is ductile or it is brittle.

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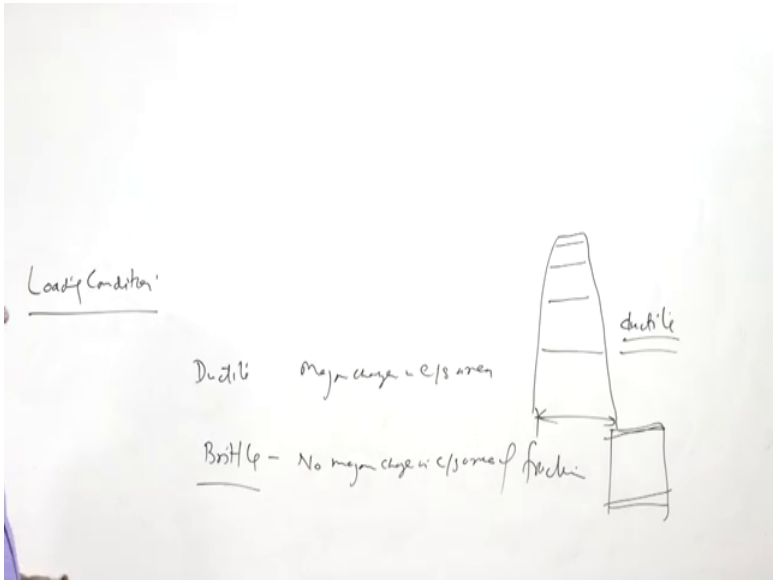

So, in this case in case of brittle there is no major change in cross section area of the fractured component like this. So, the component whatever cross section is here same is near the fracture surface, while major change in cross section area is observed in case of the ductile fracture so this may be in this form where there has been lot of change in that this is the initial diameter and there has been reduction in the diameter near the fracture surface. The significant reduction in the diameter has taking place; indicating that the this is the ductile fractures.

And at the same time like in case of the ductile fracture it is feature in the case of the ductile fractures it may be a like the.

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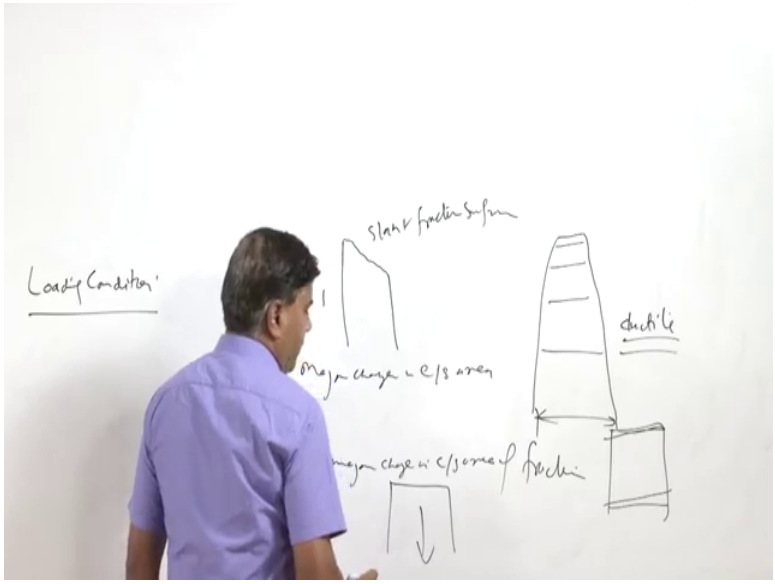

The shear lip fraction the surface fracture surface may have the shear lips or the slant fracture surface slant fracture surface. And it may be the fracture surface is normal to the external loading.

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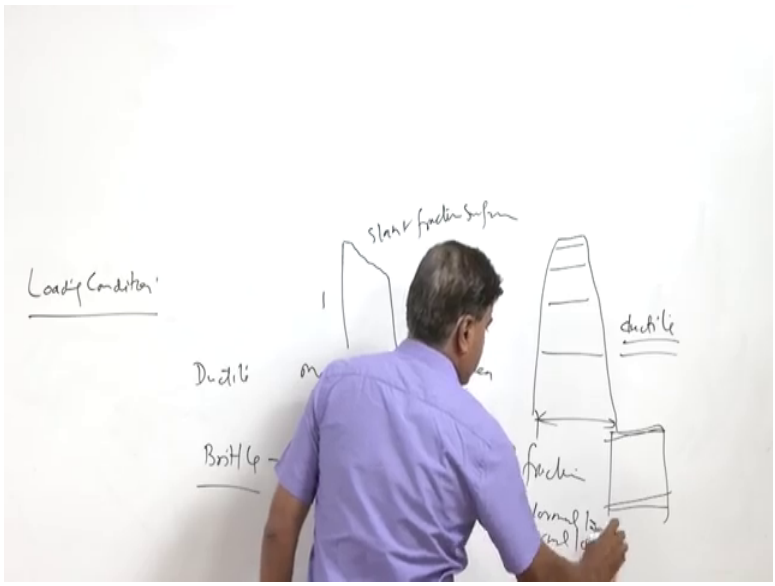

So, the square or you can say the fracture surface is normal to the external loading. then third one is like the macroscopic observation with regard to the mode of the fractures say for based on the micro scale or microscopic observation the ductile fractures.

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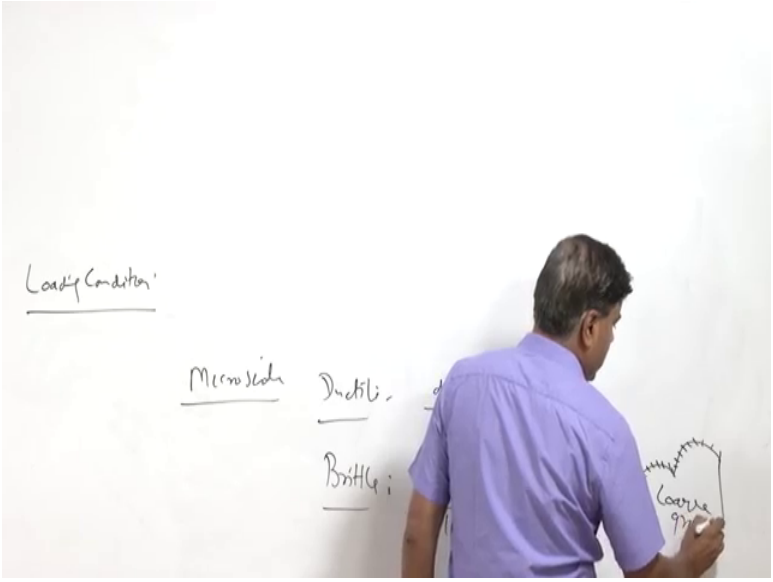

Ah is indicated by the presence of dimples.

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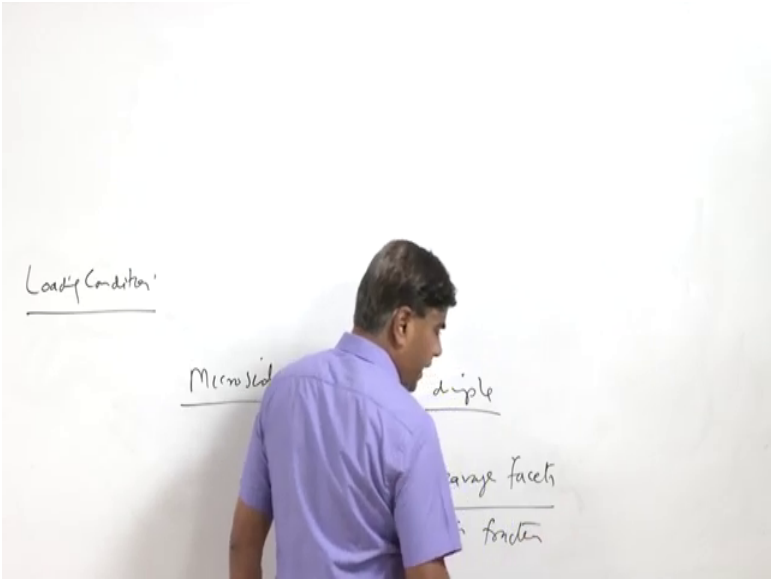

Ah while the brittle fractures or indicated by the cleavage facets or it can be the inter granular fracture.

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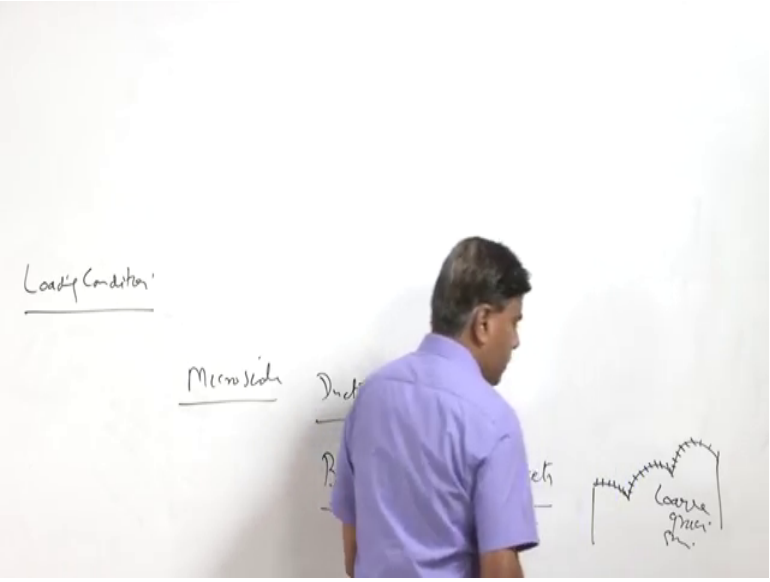

Inter granular fracture is shows the like say the ball shape surface features, especially when the large grain sizes there.

So, the failure in this case occurs along the crack with the growth of crack along the grains and that is why each grain appears like a ball especially when the coarse grain size is there of the component. So, the presence of the weak faces some times lead to the inter granular fracture. And the cleavage facets or observed in case of the brittle fracture when the trans granular fracture takes place.

So, the brittle fractures can be trans granular in form of cleavage facets, cleavage facets and it can be inter granular when the grain size is large and there is a presence of the weak material along the grain boundary. Now I will summarize this presentation, in this presentation I have talked about the Fractography and how it is useful in the failure analysis and what information can be gathered from some of the macroscopic features present on the broken component.

Thank you for your attention.