Failure Analysis & Prevention

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Lecture - 31
General Procedure of Failure Analysis:
Determination of Type of Fracture II

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention and now we are talking about the determination of the type of fracture, this is the second presentation in continuation.

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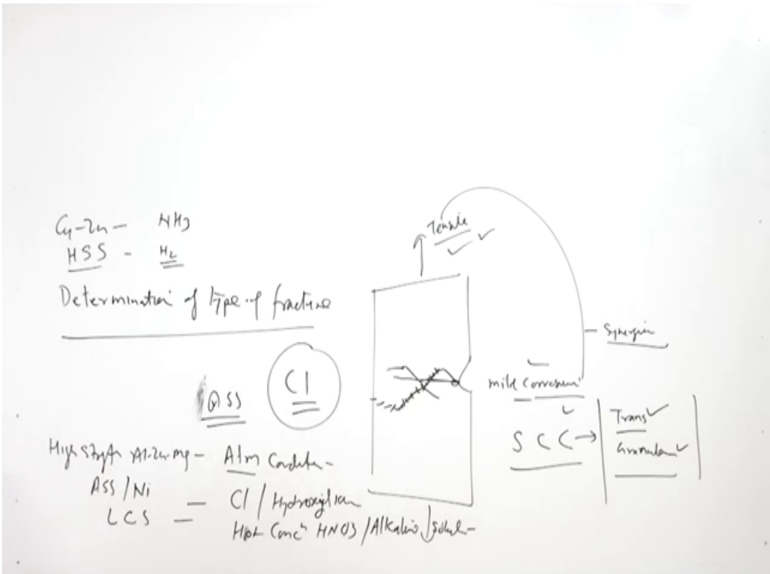

So, in the last presentation we have a talked about the dimple fracture and the related aspects; so, the determinations of type of fracture.

So, there are some typical names which are given to the way by which the fracture progresses and the direction in which it progresses. For example, in this particular case where in the crack propagates perpendicular to the direction of the external loading, through the coalescence of the voids which are taking place for the growth of the crack.

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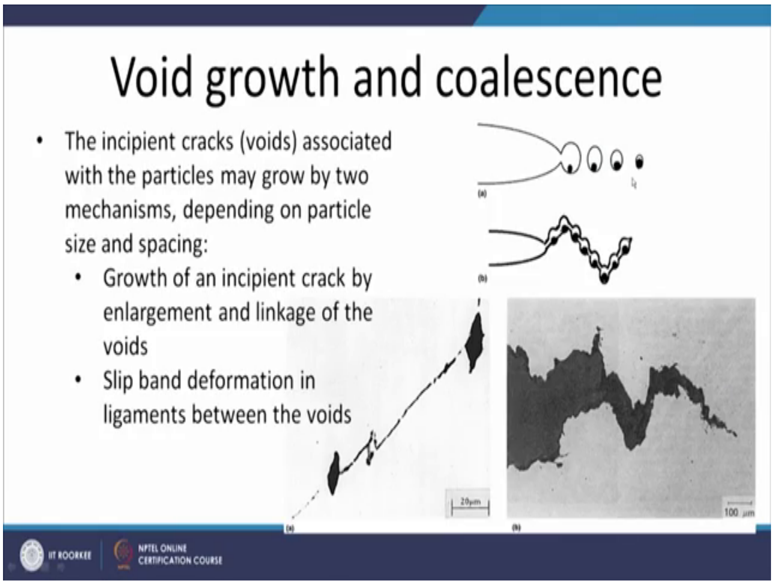

So, in this case the growth of incipient cracks by enlargement and linkage of the voids and when and the slip band deformation in the ligament between the tool, so this is the another case where the void nucleation and growth is taking place at the two different levels, but in between them the slip are deformation takes place and which eventually of course, the fracture will be occurring or subsequently due to the growth of the crack.

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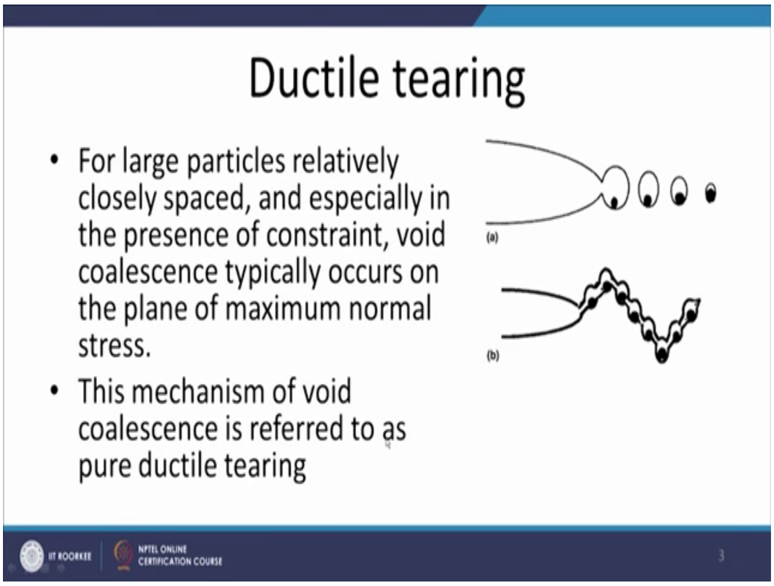

So, for the large particles which are relatively closely spaced especially in presence of constraint, the void coalescence typically occurs on the plane of the maximum normal stress. So, maximum normal stress, so this is the particular case but in this mechanism of the void coalescence is referred as pure ductile tearing. So, in this situation where large particles which are closely spaced and the system is under the presence of the constraint means the tri axial stress state is there then micro void, means the void coalescence typically occurs in the plane of the maximum and normal stress and this is returned as the ductile tearing.

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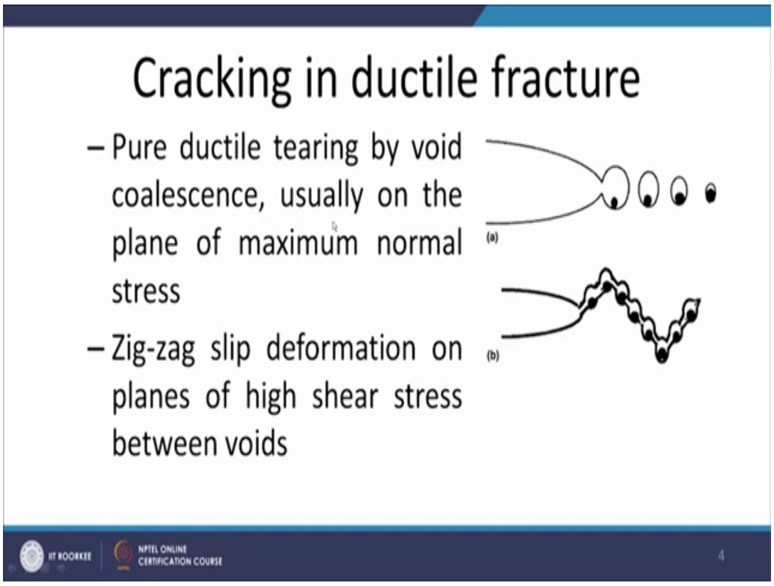

So, pure ductile tearing by void coalescence usually on the plane of the maximum normal stress and the Zig-zag slip plane deformation on the plane of high stress occurring between the void; So, between the voids prepare if the voids are being formed at different planes then in between them slip deformation will be occurring in the plane of the high shear stresses, so that is the second case.

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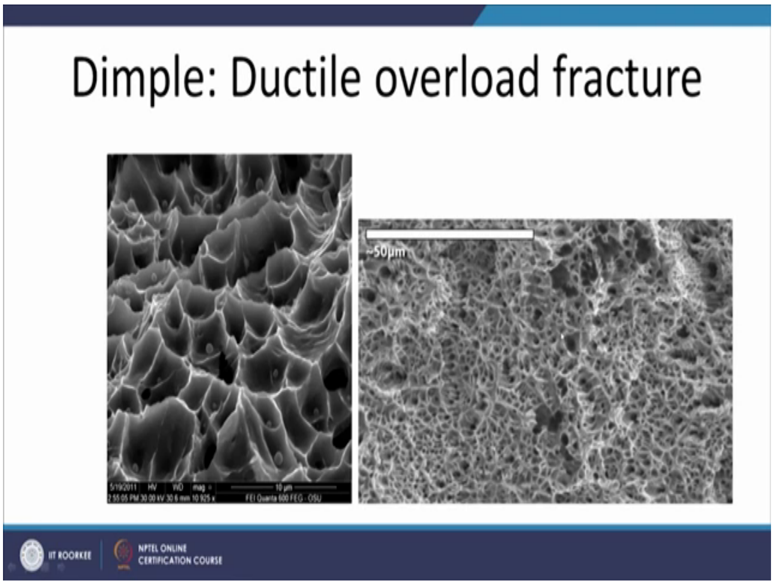

When we see that the typical dimple formation takes place and the dimple formation takes place and the it causes the fracture, then the dimple morphology we can see from this diagram. Here only on the conical shaped the features present on the fracture surface and at the root of some of these dimples we can see some of the inclusions are present and which act as a site, where from such kind of the voids nucleate and there subsequently grow.

So, if we compare it with the another diagram here we can see a very fine dimples which are very shallow as compared to this case, although there is a difference in the magnification; but if the two fracture surfaces have one is having large means course dimples which are shallow or which are deep and the another the fracture surface having the fine dimples and the shallow dimples, then that will indicate their different loading capabilities load carrying capabilities and the ability to get deform.

So, those which show the fine dimples and the shallow fine and shallow dimples they show high load carrying capacity with a limited ductility as compared to the others, where law course dimples and the very deep dimples are present that will indicate the low yield strength and the high percentage elongation.

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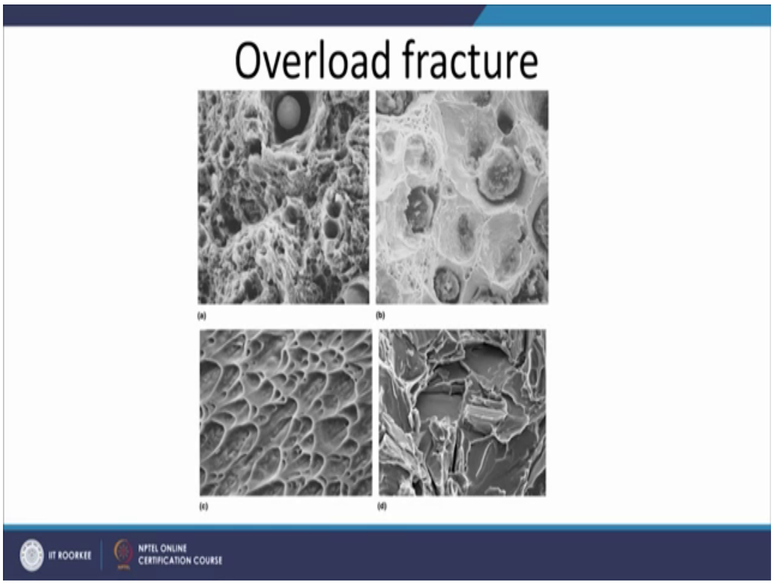

And this is also an indicator of the overload fracture. When overload fracture under the tensile conditions the dimples grow perpendicular along the direction of the external loading, but when the load is shear type then the dimples elongate in the direction of the loading, that is what we can see here the direction the dimples are oriented in one particular direction and they are not perpendicular to the surface.

This is the typical case of the shear loading which may be in form of tensile sorry toughness test or any torsional test, here this is the another overload fracture and we can see the inclusions and the second phase particles at the bottom of these dimples. So, all these three cases are of the dimples, in these two cases the load is a normal and here in this case load is the shear type.

So, this is the typical example of the cleavage facets where the transgranular fracture we can see and indicating the limited ductility and the limited toughness of the material. So, this is the transgranular cleavage facet transgranular fracture having the cleavage facets.

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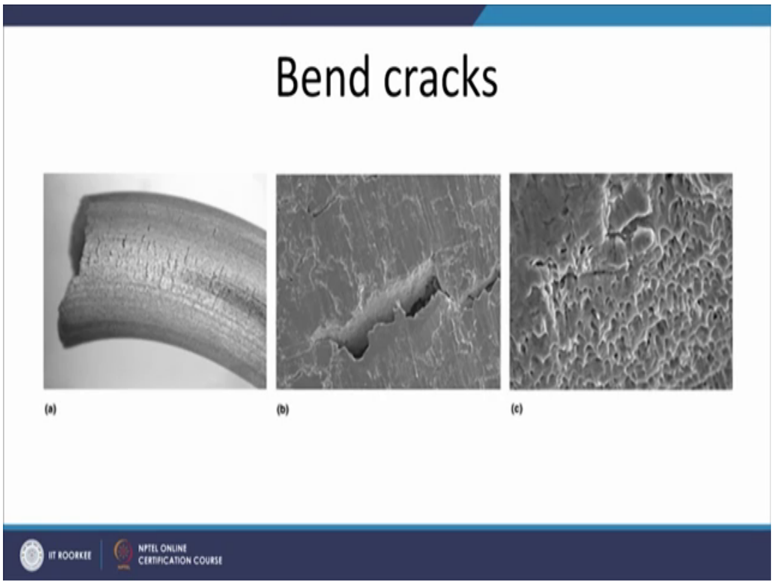

Now, we know that when we bend the one surface is subjected to the tensile stresses and the inner side surface is subjected to them compressive stresses. Of course, the cracks will be nucleating on the outer surface experiencing the tensile stresses and when we try to see the have the closer look of those cracks which are being formed under the bending conditions, we will see that the cracks are elongated in one particular direction.

So, this is also another example where the dimples will be formed on the fracture surface which will be elongated as per the direction of the loading.

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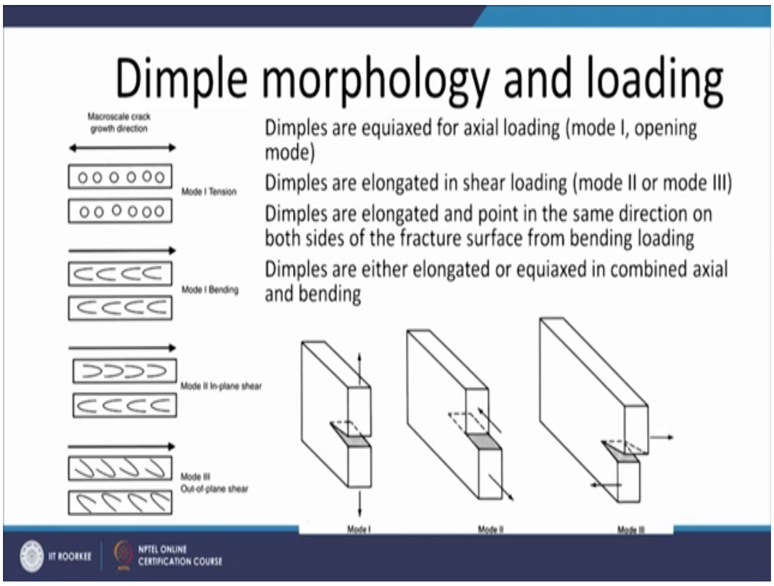

This diagram is schematically shows the how the dimples are formed on a how they get oriented for the different types of loading different modes of the learning. So, in case when the dimples are formed under the mode one loading that is the tensile loading. So, in that case the dimples grow perpendicular to the fracture surface in the direction of the external loading, but in case of the mode 2 and mode 3 dimples are elongated in the direction of the shear loading in mode 2 and mode 3, so this is mode 2 and this is mode 3.

So, in that case in the in case of the mode 2 this is the shear 1 where the opposite surfaces will have the dimples elongated in the particular direction, but they will be they will be in like say this is like a mirror image. So, they will be oriented in opposite way, so dimples are elongated in this particular case towards the left side and here in they are oriented towards the right side.

So, now similarly here when the mode 3 which is also the shear loading, but out of the plane shear loading; So, in that case the similar kind of the pattern will you followed the as per the direction of the loading dimple will be oriented in the direction of loading, but they will also be out of the plane means they will be incline to the direction of the surface.

So, here this is the direction in which fracture has taken place, but this crack these dimples will be elongated in as per the kind of the. So, with respect to the shear load the dimples are inclined because, this is the out of plane shear. While in case of the bending what we can see the dimples are also elongated, but the direction of the elongation in both the fracture surfaces is same.

So, here in this case that along the orientation of the in mode 1 means, the external surface is experiencing the tensile loading, but under the bending conditions the both the fracture surfaces in this case will be having the oriented. The dimples oriented in one direction in this particular case say for in this particular case what we can say and they are oriented from left to from the right to left and the same is the trend for the other surface also this is one top surface and this is the bottom surface which has a fractured. So, the dimples are either elongated or equiaxed in combined in axial and the bending loading.

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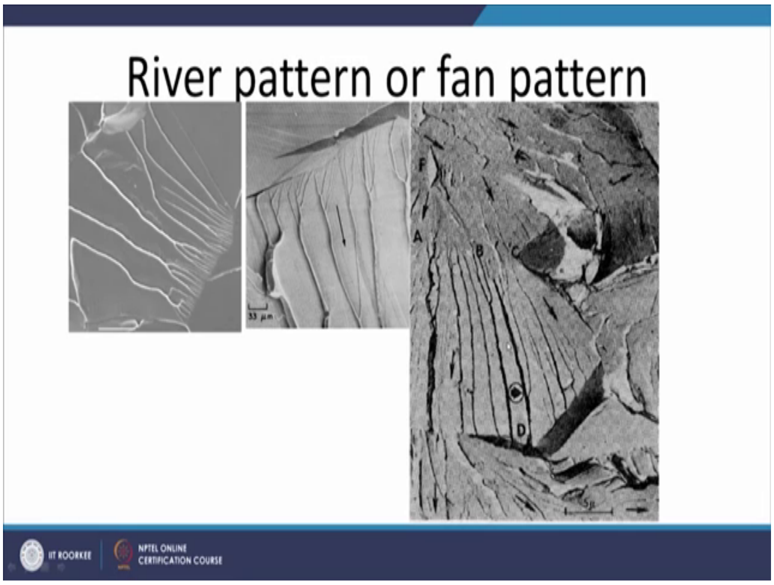

Now, as I have said when the material shows the limited ductility under the limited load limited toughness. So, the poor fracture toughness in that case, the transgranular fracture is particularly experienced and that happens through the cleavage facets. So, the cleavage facets these are the typical features of the cleavage facets which appear in form of the river pattern or the fine pattern. So, this will be having a number of the flat surfaces with the river a pattern. So, this is the river pattern and these fine marks are indicating the tributaries which are merging into the main river.

So, if we assume that the these are the tributaries and merging into the main river, then the direction of the crack growth is in the downstream. So, these are the tributaries all these are merging in this main river. So, this is the direction of the crack growth also up and what we can say this is the these are the another set of the tributaries and all are merging into this main river. So, this is the another plane on which the crack is growing.

So, these different the flat surfaces are indicating the different plane of plane on which the cleavage or facets are growing or the crack growth of crack is taking place; similarly in this diagram all these are the tributaries and they are merging in this mean river. So, this is the direction of the crack growth this the same analogy can be given to other fracture surfaces.

So, when we see the river like pattern or fan kind of the pattern this indicates the presence of the cleavage facets and indicates the trans granular fracture in a system having the limited ductility limited fracture toughness and maybe high strength or high tensile strength. So, low fracture tough brittle metal systems of limited ductility show this kind of behavior.

A real system so that is just for example, I have shown in the earlier slide previous slide here these are the simply these are the simple features of the cleavage facets.

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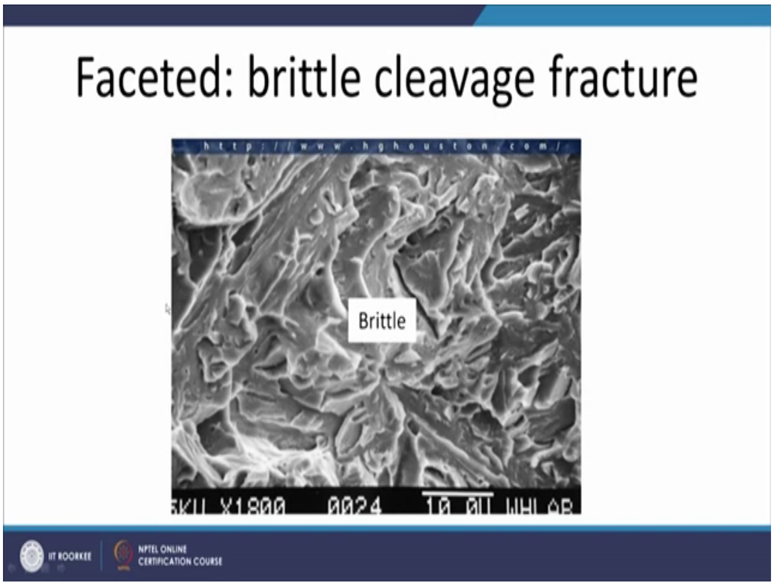

But in real systems we find a mix of all because the real systems are complex in nature. So, what they will be showing a lot of flat fractured features saw and bright assigning features also mix of all we will be able to see on the fracture surfaces in which has failed in brittle manner.

So, this is the typical brittle fracture surface which is having the cleavage facets on to the fracture surface indicating the brittle fracture.

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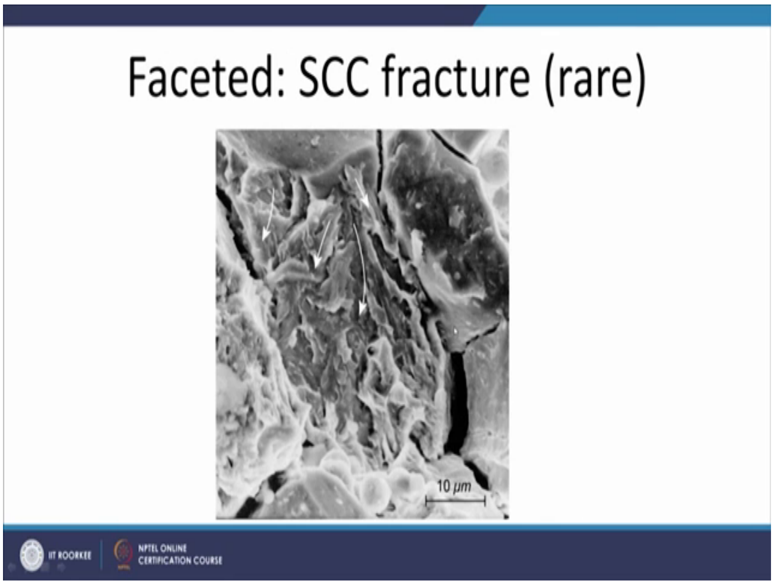

This is another case where a stress corrosion cracking and the growth of crack in through the cleavage facets. So, you faceted a stress corrosion cracking fracture this kind of thing is a very rarely observed, in this case the grain boundaries have been eaten out or grain boundaries have been damaged, but they still whatever the grains are there those have experienced the cleavage facets and the brittle fracture in this particular case.

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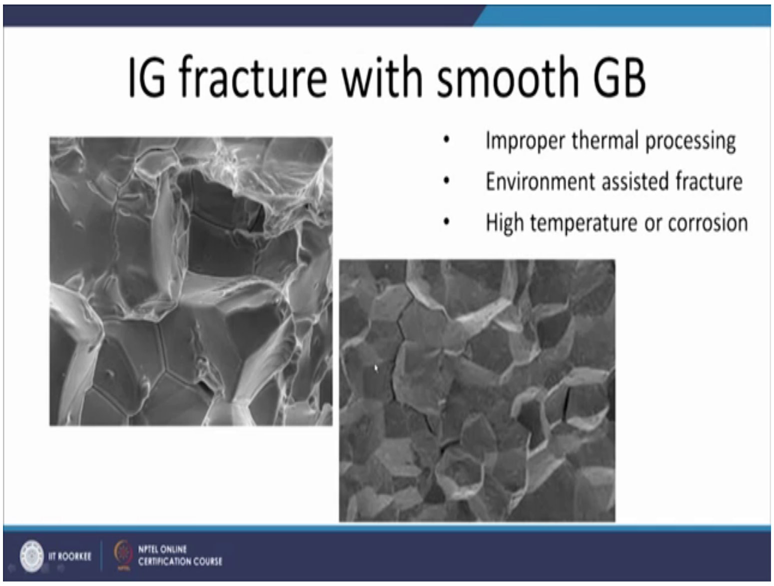

Now, as I have said that when the grain boundary area is a poor in terms of the v limited slip deformation system or the presence of the weak phases or presence of the a some special or specific elements like oxygen in conel and iron and antimony in case of the copper.

So, these constituents weaken the grain boundary areas and such kind of the conditions are favored by the thermo mechanical inappropriate thermal, thermo mechanical processing or thermal processing of the component or the environmentally assisted like and the hydrogen has got segregated along at the grain boundary area and which leads to the embrittlement and facilitates the fracture in inter granular manner.

Similarly, the high temperature exposure leading to the precipitation of the undesirable phases at the grain boundaries undesirable precipitates at the grain boundaries and weakening the material. So, the high temperature exposure leading to the development of the uninst unfavorable micro structures or the corrosion where grain boundaries are eaten out due to the corrosion localized corrosion attack that the grain boundary or environment. So, these are the two examples of the environmentally assisted fractures or thermal exposure has been given under such conditions where.

So, unfavorable heat treatment we can say this like temper embrittlement at to 300 degree centigrade or 400 degree centigrade or 500 degree centigrade different the steels are sensitive for embrittlement under the different temperature conditions. So, that also leads to the precipitation of someone desirable precipitates at the grain boundaries and which weakens the material and causes the inter granular fracture.

So, in this case what we can see is the grains are very smooth like this we can see and these are the ball shape we can see these are like football shape different footballs are segregated together sometimes the secondary cracks can also be seen at the grain boundary area. The primary crack is one which is responsible for suppression of the surfaces through all the grains and, but there are some additional secondary cracks are also present between the grains.

So, it is easy to identify the presence of the inter granular fracture because, this will be showing this kind of the this the inter granular fracture will be showing the presence of such kind of the grains indicating the inter granular fracture. But identification of the cause of the inter granular fracture is more difficult because a presence of some fine amount of the elements or weak phases at the grain boundary or poor deformable systems at the grain boundary will promotes the inter granular fracture.

So, there detection of the cause is difficult, sometimes at the grain at the grain we find that sometimes the inter granular fracture is coupled, either with the dimple fracture or with the brittle fracture. So, if we are brittle at the grain boundary area and localized manner if the brittle constituents are present then they will be failing in brittle manner. Similarly, if the grain boundaries are having some of the ductile metallic systems then they will be facilitating the dimple fracture.

So, these two are the examples of the inter granular fracture, where this is the low magnification this is the high magnification micrograph showing the inter granular fracture where grains can be seen, but some of the features are there in transgranular or other the cleavage facets

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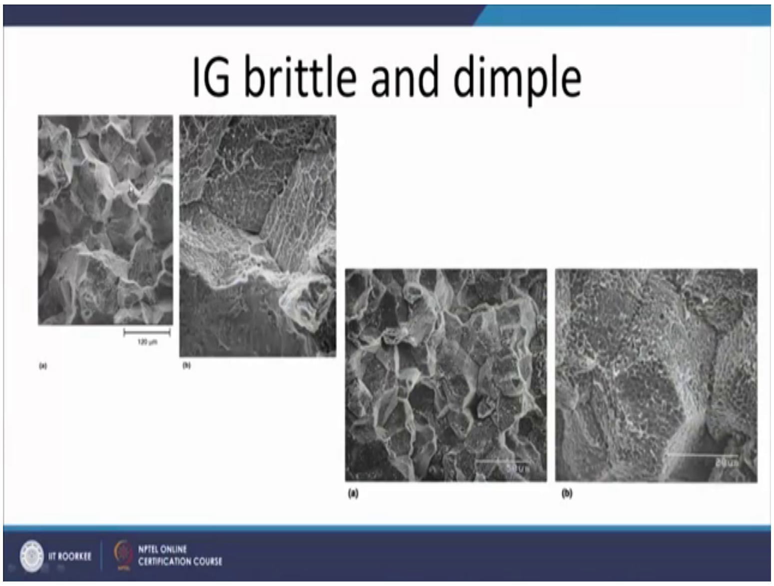

But here in this case the grain boundaries are having showing the grains are having we can see all these grains and these grains are in addition to the appearance of the grains there are some dimples are also present on the fracture surface. So, we can have a combination on the inter granular fracture or the brittle fracture as per the kind of phases which are presented the grain boundary area.

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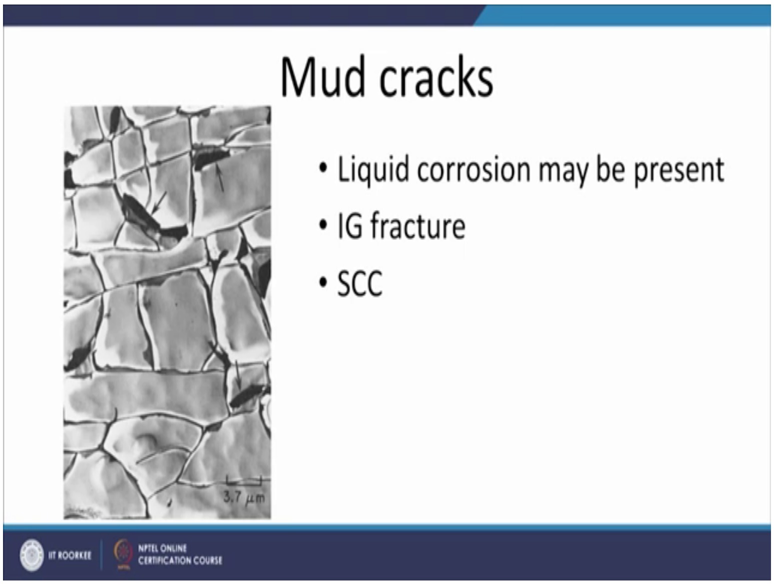

Now, as when the component is subjected to the liquid corrosion like, sensitive for a particular kind of the metal system like a liquid the liquid zinc or liquid magnesium steel may be adversely affected. So, in these are the typical examples of the corrosion crack.

So, where the corrosive media is able to attack the grain boundaries or particular phase in very localized manner or the crack is growing in a very selective manner along certain phases or the at the boundary. So, that we will be promoting the stress corrosion cracking or inter granular fracture because grain boundaries are badly affected because, of the presence of the corrosion media.

So, such kind of when such kind of the reactions happen that will be leading to the very poor kind of the structure of the material. So, that is why these are called as a mud crack and where the corrosion products are present at the grain boundary and they darken those areas just like a mud that is way these are called mud cracks.

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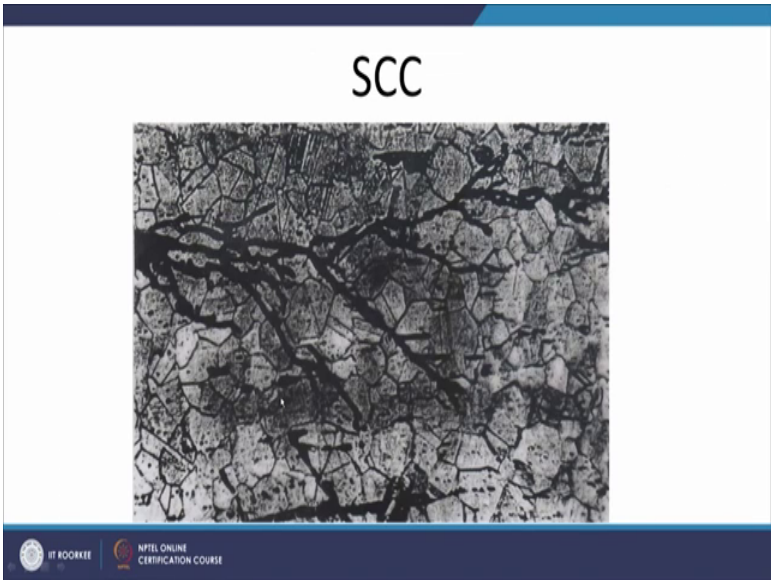

And we know that the stress corrosion cracking is the another one wherein stress corrosion cracking happens and it is very dangerous also because, the metal systems which are subjected to the tensile load and the component is also exposed to the like mild corrosive media.

So, under these conditions the presence of any crack, so the tensile stresses will be facilitating the growth of crack and the corrosion attack will also be facilitating the growth of crack, but when both are present the rate of the crack growth is very fast. So, the point is how this crack grows in typically when we find when we see presence of both the to work in very synergic manner and reduced the life of the component drastically because of the combined effect of the two, but the point is how the crack how the fracture is facilitated in under such conditions.

So, the failure of the component in presence of the tensile stresses and the corrosive media is termed as stress corrosion cracking, so a stress corrosion cracking the in which way the fracture or the crack propagation takes place that is what is to be seen so, it has been observed that it can be trans granular or it can be inter granular also.

So, there is no fixed way with it is also possible that the grains the crack can grow across the grains irrespective of the grain boundaries. So, it will be crossing and the propagating, but if the grain boundary area is sensitive, then crack can follow particular grain boundary and then accordingly the growth will be occurring along the grain boundary zone.

So, the stress corrosion cracking where crack growth can be trans granular or inter granular as per the kind of the weakness of the material some of the corrosive media offers, the poor offer some of the med corrosive media attacks very badly to the grain boundaries while in other cases that crack growth is facilitated through the trans granular growth of the crack.

There is a typical example wherein like a stainless steel austenitic stainless steels when these are exposed to the some of the like the chloride hence like sodium chloride solution also, the corrosion attack under the tensile load conditions takes place in very branch the manner growth of the crack. So, this particular example shows the stress corrosion cracking where the number of cracks are growing, but few are growing to cause the fracture.

So, this when the branch the growth of the crack is observed in the failed component suggests the, the occurrence of the stress corrosion cracking, but in the different metal systems this growth happens in different ways some of the cases it is completely inter granular.

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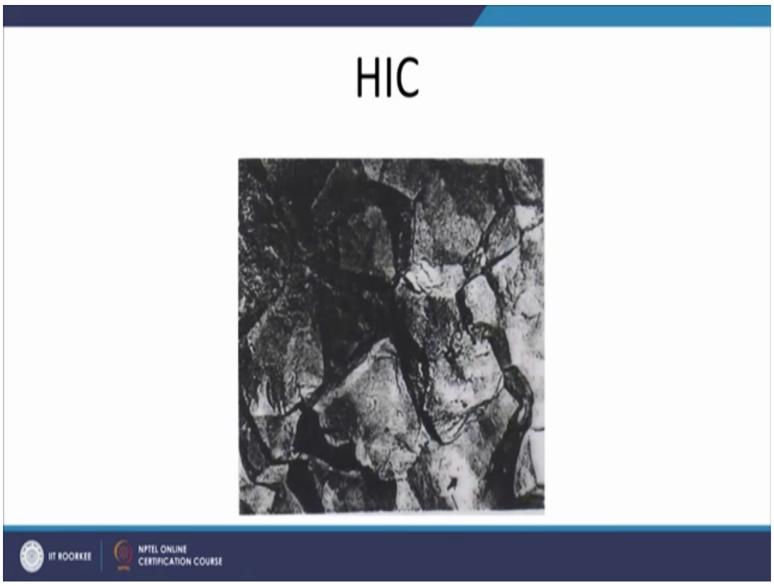

While in other cases it is trans granular or mixed of both these happen. I have some information about the case in the metal systems and the way by which they are subjected to the stress corrosion cracking.

So, here like a high strength aluminum zinc magnesium alloys, they are sensitive even for the atmospheric conditions and even under the atmospheric conditions the stress corrosion cracking can takes place; like austenitic still and the nickel alloys and in conel systems they are sensitive for the chloride and hydroxyl hydroxyl ions and then low carbon steel low carbon steel becomes sensitive for sensitive in the hot concentrated nitric nitrates hum HNO 3 nitric acid and alkaline solutions alkaline solutions.

Similarly, the copper zinc systems you know they are sensitive for sc in ammonia environment and the high strength steels are sensitive for the cracking stress corrosion cracking in case of the means in presence of the hydrogen environment.

So, like there are some special cases the for the growth of the crack in case of the aluminum alloys and in case of the low carbon steel the stress corrosion cracking occurs through the inter granular growth of the crack. Where in case of the high strength steels mainly inter granular, but sometimes it is a with the few of the cracks will be growing in the alpha aluminum also in case of the oh sorry alpha iron.

So, in high strength is steels it is mainly the inter granular with some of the cracks growing through the alpha iron that is the ferrite and in case of austenitic stainless steel it is branched growth of the crack the like this and in case of the high strength steels hydrogen induced cracking, means the hydrogen embrittlement and hydrogen induced cracking and the fracture due to the hydrogen induced cracking is also inter granular.

Here this is an example where the separation of the grains is occurring under the pressure of the hydrogen during the hydrogen induced cracking.

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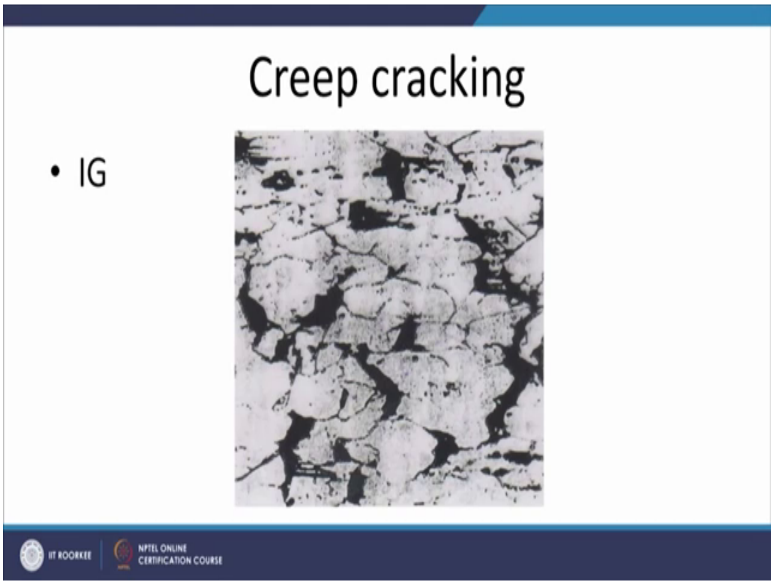

So, if this is basically inter granular growth of the crack as we have talked about the creep, we know that at a high temperature near the stress structure conditions the grain boundary sliding takes place which leads to the formation of the voids between grains and this indicates the occurrence of the creep.

So, when the separation of the grain at the grain boundary takes place under the effect of the external loading. So, this kind of the separation is occurring basically at the grain boundary that is why this is inter granular fracture.

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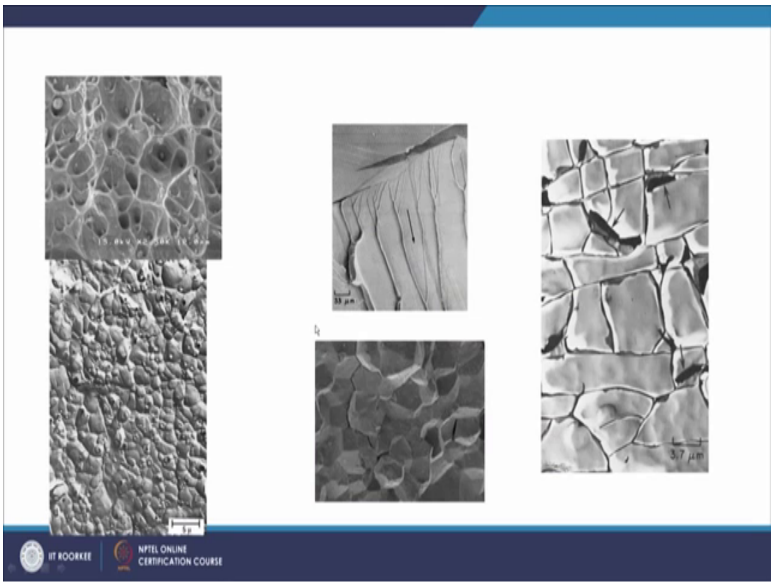

So, now all such kind of the fractures I have been clubbed together at one place fracture surfaces, this is the dimple fracture and sometimes we see the conical projections also for the dimple fracture and this is are the cleavage facets and this is the inter granular fracture and this is the mud cracking when the corrosive media attacks the grain boundaries in selective manner.

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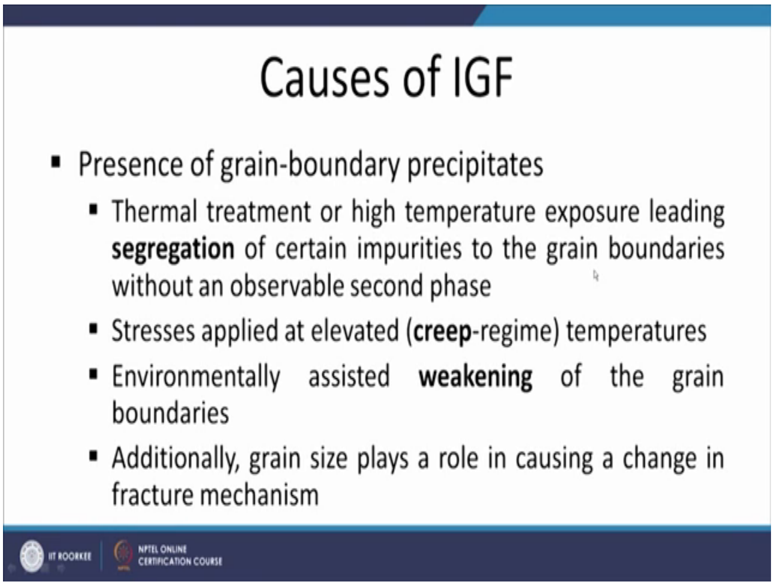

Now, the causes for the inter granular fracture indicates that sort of some poor phases are presented the grain boundary. So, this may happen in the following forms like thermal treatment or high temperature exposure leading to the segregation of the certain impurities at the grain boundaries and then the stress applied at elevated temperature leading to the grain boundary sliding also leads to the inter granular fracture, and in case of the environmentally assisted weakening of the grain boundary like precipitation of the some undesirable things at the grain boundaries.

It reduces their deformation probabilities or increases the localized attack of the corrosion media or the void nucleation and their growth.

So, all these will you facilitating the facilitating the inter granular growth, additionally the grain size also plays a role in the changing in the mechanism of the fracture ; especially at the high temperature if the grain boundaries are fine then it will promote the inter granular fracture through the creep. That is why the coarse grain structure is normally used for those components which will be used at a high temperature.

So, far we have talked about in this presentation the how to determine the dimple fracture cleavage fracture and inter granular fracture and what are the what are the important causes for the inter granular fracture and how the cracks grow in case of the dimple fracture and how the growth of crack occurs in case of the ductile fracture besides the cleavage fracture.

Thank you for your attention.