Failure Analysis & Prevention

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Lecture - 30
General Procedure of Failure Analysis:
Determination of Type of Fracture I

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention, in this subject so far we have talked about the fundamental sources of the failure and they are after we started the general procedure of the failure analysis and nowadays we are talking about the general procedure of the failure analysis, where in we have talked about the various aspects, but in this presentation we will be describing on.

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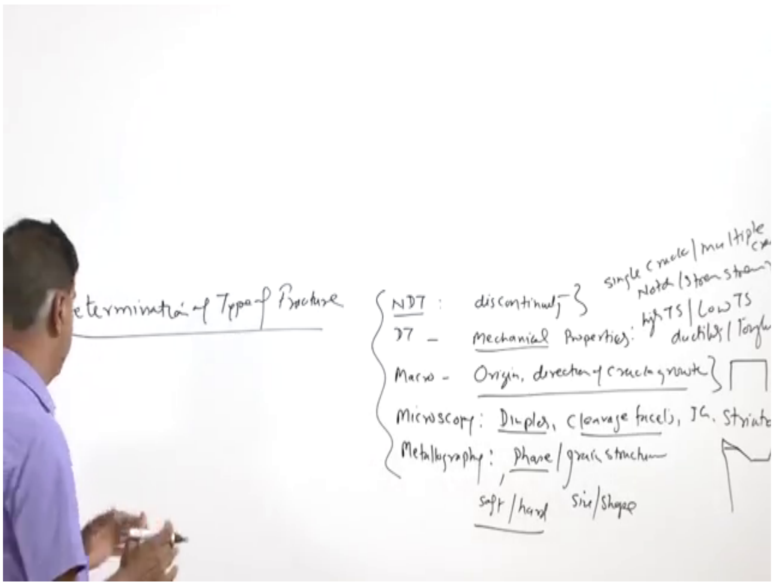

How to determine the type of fracture determination of type of fracture, so it is obvious that this one will be related to those cases where the suppression or the fracture of the component takes place during the failure you know that we have.

Talked about the NDT non destructive testing which is used for a determining the discontinuities, whether they are present at the surface or within the or inside the surface of the or underneath the surface or below the surface of the component.

Destructive testing where the mechanical properties been evaluated in terms of hardness toughness tensile strength and the then we have also talked about the macroscopic analysis, where in the origin or initiation of the fracture then direction of the crack growth.

In under the microscopy of the fracture surface and thereafter we have also seen the microscopy of the fracture surface, where in primarily we find the surface features like dimples cleavage facets cleavage facets intergranular fracture and fatigue fracture through it is creations of.

So, it is creation are the microscopic features on the fracture surface, apart from that under the metallography which is a very important aspect related with the filler analysis. Under this is used for determining the phase and the grain structure which is present in the failed component.

So, basically we in front of us now we will be putting the information related with all these things, which have been completed for determining the type of fracture which has are taken place.

So, there can be a single crack or there can be multiple cracks identified through the NDT or it can be the notch or any other form of a stress raiser a stress raiser. So, actually this information will be used to identify if it is the fatigue fracture or the tensile brittle fracture or ductile fracture or the fatigue has taken place in the corrosive environment or the fatigue has taken place in the dry conditions mission to the fratigue fratique fatigue conditions.

Similarly, the mechanical properties it is of the high tensile strength or it is of the low tensile strength, similarly the high ductility and the toughness. So, accordingly the material behaviour can be expected if it is of high strength low ductility low toughness, then it will tend to fail in the brittle manner and if it is of low yield strength high ductility and the high toughness.

Then it will fail in ductile manner provided it has experienced some other effects, it has been subjected to the a special kind of the changes or unique changes during the service whether it is high temperature or the low temperature or the a structural instability has occurred in the material.

Then the origin and the direction of the crack growth; So, this is very important we have to keep the microscopy and metallography also in mind say the kind of the fracture surface which has been created.

If the fracture surface is flat or it is showing the shear fracture like this or the fracture surface is showing the cup and cone kind of the fracture like this.

So, this will be indicating the we will also be indicating the kind of the fracture it would be there. So, microscopy will show the general features present on the fracture surface in form of the extent of deformation which as taken place, the kind of a stress conditions which were present and weather whether it is the slant fracture or the flat fracture or the cup and cone kind of fracture.

So, all these things will be indicating the kind of a the fracture which has taken place primarily in terms of the brittle or the ductile fracture, microscopy indicates the micro fracture mechanisms microscopic fracture mechanisms like the dimple fracture indicates the ductile fracture, cleavage facets indicates the brittle fracture inter granular fracture also is a type of the brittle fracture and the striations correspond to the fatigue fracture. So, and thereafter the matallography from the metallography will be able to know that in a given material what are the different types of the phases.

Whether these phases are soft or they are hard or there is a mixture of the hard and soft or hard phases are present in the soft matrix or vice versa. Similarly the size and the shape of these the phases which are hard or the soft and how are they distributed means where they are present that will also affect the way by which the cracks or the voids will nucleate and then subsequently they will grow.

So, information about the micro structural aspects and they are the. So, means the phase structure and the grain structure combination. So, phase structure or grain structure all this information is used to determine the type of fracture in comprehensive manner. So, we will be using the information gathered from all these a steps in order to determine the type of the fracture which has taken place.

Now, we will elaborate that what are will be the unique issues and what are the features which are used to interpret the type of the fracture which has taken place or which can be determined which can be used to determine the type of the fracture in a given situation.

So, basically the grouping or the classification to determine the type of the fracture is not based on the not based on the kind of the deformation, microscopic deformation which has taken place.

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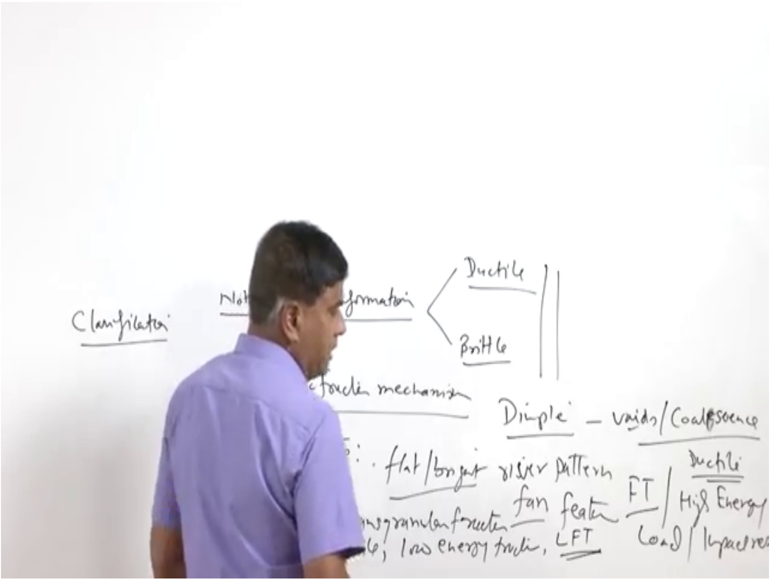

It is the classification is not based on the deformation because, the simple the ductile fracture indicates the lot of deformation prior to the fracture. While the brittle fracture show limited deformation prior to the fracture, so this is a one thing, but the microscopic fracture mechanisms are basically used to classify the type of fracture, which has taken place.

And for that what we have to keep in mind is that the presence of the dimples, will suggest the formation of the voids and their correlations will indicate will indicate the ductile fracture and which also indicates that material is a fracture tough and it is the high energy fracture.

It will take lot of load these load carrying capacity will be good, at the same time it will in it will absorb means the impact resistance will be good and it will be it will show good elongation; So, the presence of the dimples.

So, this is one thing similarly the presence of the cleavage facets cleavage facets on to the surface. I will show through the slides how to recognize and what interpretations can be made through the different microscopic features facet cleavage facets indicates.

So, this is basically the bright the flat bright microscopic surfaces, which basically appear in form of the river patterns or this is also called the fan shaped features on the surface.

This indicates basically the transgranular fracture, which is basically a brittle fracture occurs with a limited deformation, but there can be other in unique situation there can be lot of deformation.

But the finally, the fracture occurs through the cleavage facets. So, that will be classified as a brittle fracture, then a transgender fracture and heats considered as a low energy fracture offering the low fracture toughness, limited fracture toughness and limited ductility in the material may be yield strength may be high for such kind of the fracture conditions. So, material show limited ductility limited impact resistance and may be it has a high yield, a strength and the tensile strength of the material.

Now, we will we will talk about the possible the features which can be there and what kind of interpretations can be made with regard to the microstructure of the material. Say in a in a metal system in poly crystalline metallic materials.

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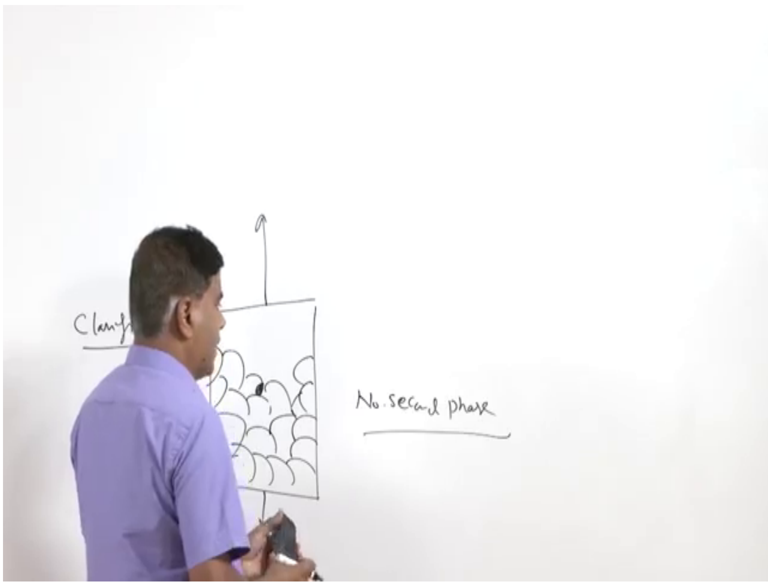

We may have just like this we may have a single phase. So, number of crystals of the same phase, so here no second phase particle, so in this case the material will show extensive ductility because, because there is no second phase where from the voids.

Can nucleate due to the differential change in the dimensions and which can lead to the cracking.

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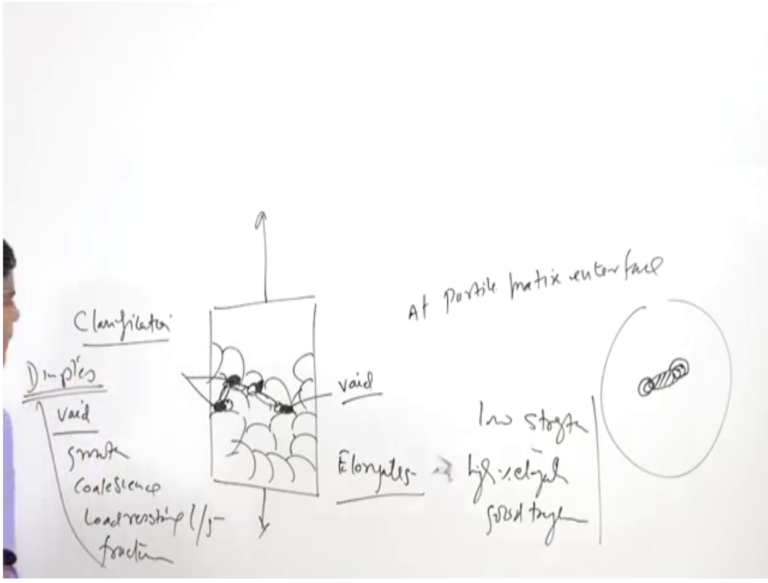

So, when such kind of the systems we have it elongates or it deforms elongates significantly. So, offers the high percentage elongation, it offers the good ductility good toughness, but may be the low a strength of the material.

But in case when it has number of the second phase particles means here and there we have some hard particles located in the material and in that case when the load external load is applied.

So, these hard faced particles these hard second phase particles they do not deform by the same magnitude as the soft matrix. So, because of the differential deformation differential change in dimensions one will be deforming more than other, this situation leads to the formation of the wide, wide is formed at particle matrix interface.

So, if this is the particle and all around it has a matrix then somewhere wherever the stress concentration is high the gap is created this is this is what happens. So, but the gap creation in case of the a spherical fine particles become difficult as compared to the course and elongated particles. So, if the particle is of the needle type, in that case near the tips the stress concentration is high. So, the wide formation between the particle and the matrix means the second phase and the matrix becomes easier.

So, the voids are formed and once the voids are formed at all these locations then they will be growing and consequently all these coalitions of all these voids will be taking place and which intern will led leading to the separation of the component under the effect of the external load.

So, basically in this kind of the mechanism voids first nucleate at the particle matrix interface and then they grow and after the growth their coalescence occurs. So, once the collisions occurs then it reduces the load resisting cross sectional area, resisting cross sectional area and which eventually causes the fracture or the suppression of the surface.

This mechanism typically is known as dimples wherein the fracture surface features wherever the particles are there say in this matrix.

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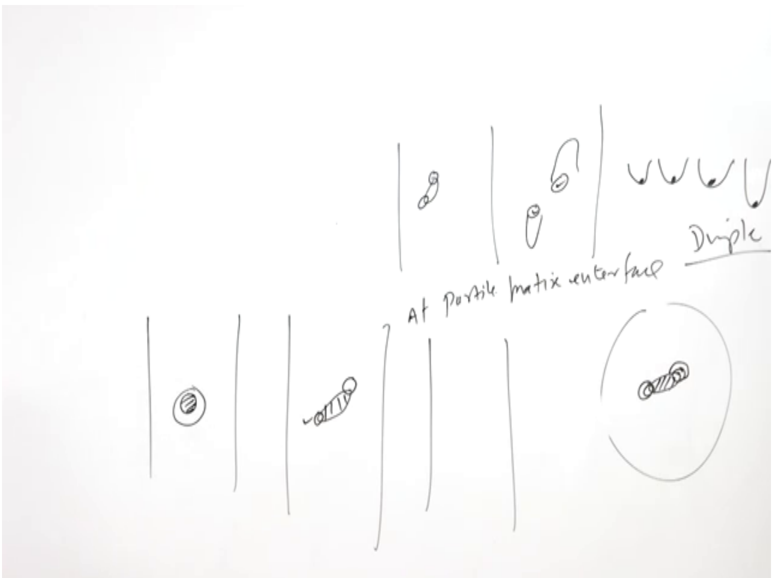

This is one particle and here the voids are being nucleated under the effect of the external load they will be growing the works will be growing like this around the particle and these particles when the fracture occurs, eventually due to the coalescence of these voids what will we finding number of the conical shaped of the different sizes and shapes dimples.

Dimples are the conical shaped features which are present on the fracture surface and of course these particles hot particles will be present at the root of these dimples.

So, their analysis can be performed to see analysis the particles present at the root of these dimples can be performed, to see what these are made of.

So, there can be different situations under which the void nucleation takes place and there are three types of situations where the dimple formation and their subsequent growth, takes place one is where the second phase particle and it is subjected to the external loading. So, one void is nucleated all arounded and in the second case.

When the particle is of a needler shape or it is elongated obviously, the nucleation takes place in the area of high stress concentration.

So, obviously, in that case the locations where a stress concentration at the tip of the second face particle is high the white nucleation takes place and in the third case where the plane a strain conditions exist the void nucleation occurs in different way which I will be showing in this diagram.

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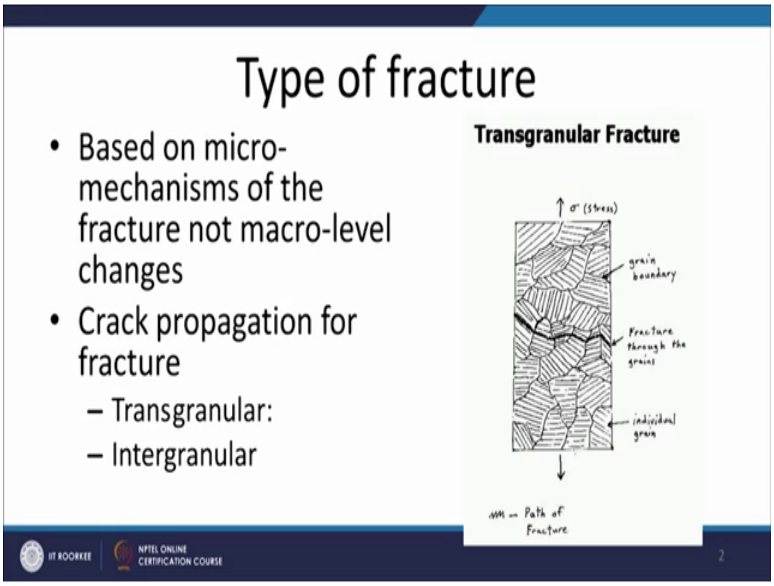

So, now will be going a sequence lead through the various aspects related with the fractures, so what will be seeing first that the fracture broadly can be grouped in two ways, one is that the way by which crack grows during the fracture.

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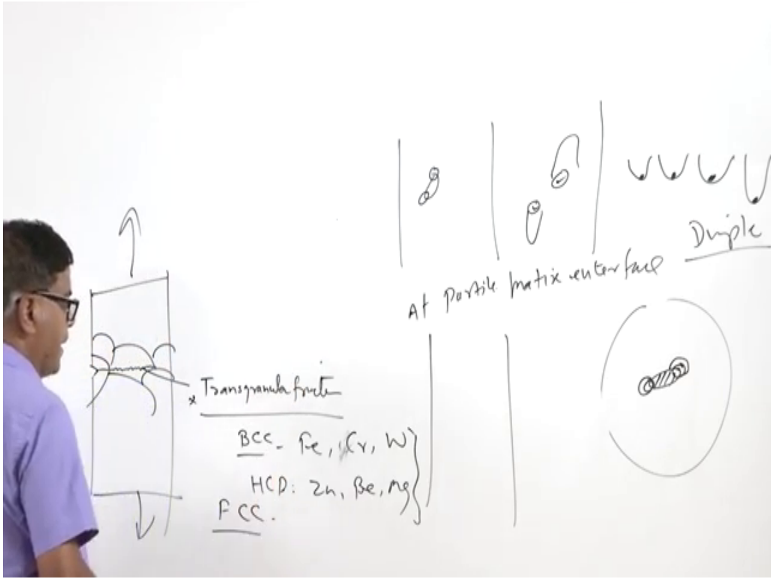

So, there can be a situation where these the these are the different grains present and if we have one crack here and it has grow, so irrespective of the phases and the boundaries if it grows perpendicular to the direction of the external load.

Then in that case so it does not follow any particular direction, but it grows perpendicular to the external loading and not along the particular direction, then and the rather the crack grows across the grains it does not follow the grain boundaries.

So, that is the kind of this kind of fracture is known as the trans granular fracture, where the crack grows across the grace not the grain boundaries this is one thing and in this situation mostly the crack grows perpendicular to the direction of the external loading. Then this kind of the fracture is mostly observed in the BCC metal systems like iron chromium tungsten, while in case of and HCP hexa gunnel closed.

Packed metals like zinc beryllium magnesium because, these metals have the limited slip system; So, in these cases mostly the crack get tends to grow on in trans granular manner, while the FCC metals are immune to the trans granular fracture or this is the one we of talking about the fracture and the second one.

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When we find that crack follows preferentially, the direction of the crack growth follows a particular direction during it is journey. So, like say here the crack is growing. So, the crack will be growing along the grain boundary in this case like this. So, when the crack follows the grain boundaries of the particular metal in that case we find that grain boundary 1 of 1 grain or then of another grain and then of third grain this is the kind of surface which we find at the grain boundary. So, this 1 grain this is second grain and this is third grain.

So, in the fracture surface basically we are able to see the grins. So, when the crack follows the grain boundaries then we call inter granular fracture, most of the time we find mixed kind of fracture mix mode of fracture where we can see the dimples.

We can see the cleavage facets we can also sees the intergranular fracture due to pulling out of the certain heart phases. So, a combination of all these fractures is observed in the real fractures and that is why they will look more complex I will talk about 1 additional thing like in a metal system.

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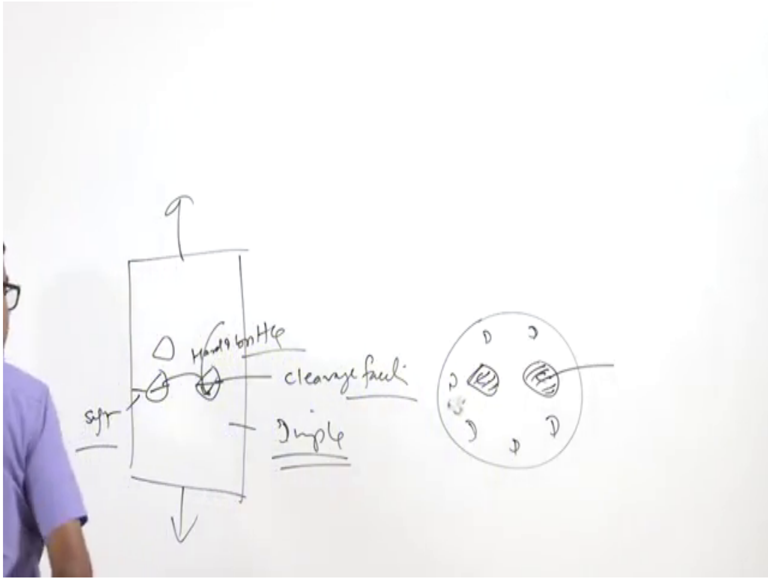

Where a few hard particles are present here and there and if the trans granular fracture is taken place. So, there are two possibilities one is like say the crack may grow in trans granular manner here and this is say compared to be soft matrix and then through this one through the this is the soft matrix and these are the particles which are hard and brittle.

So, it is possible that the soft matrix may fail in the dimple soft matrix may have the dimples on the fracture surface. While the hard and brittle particles where if the if their fracture takes place. So, they will be showing the cleavage facets.

So, we can see a combination of on the fracture surface they are certain zones where cleavage facets are present in the and in the rest of the areas we have mainly dimples here and there and here the cleavage facets at certain locations in localized manner and if under the external stresses instead of getting fractured these particles they get pulled out.

So, pulling out will be leaving some vacant spaces on the fracture surface, so these areas may look dark and so, that will be the location where from these hard particles have been pulled out and they have not fractured.

So, the metal systems having the hard and brittle carbide particles or the like silicon carbide in aluminium matrix silicon particles course polyhedral say primary silicon particle and aluminium silicon matrix, all these will be fracturing either in the cleavage facets minor or they will be getting pulled out under the influence of the external loading.

So, what we can see in this diagram classification is based on the microscopic mechanisms of the fracture is not the macro level deformation, like macro level changes which are taken place in form of the deformation.

So, what it shows that this is the direction of the crack growth, in case of the transgranular fracture where the crack growth follows the crack grows across the grains the means through, the crack propagates through the grains and it does not follow any boundary or a particular direction.

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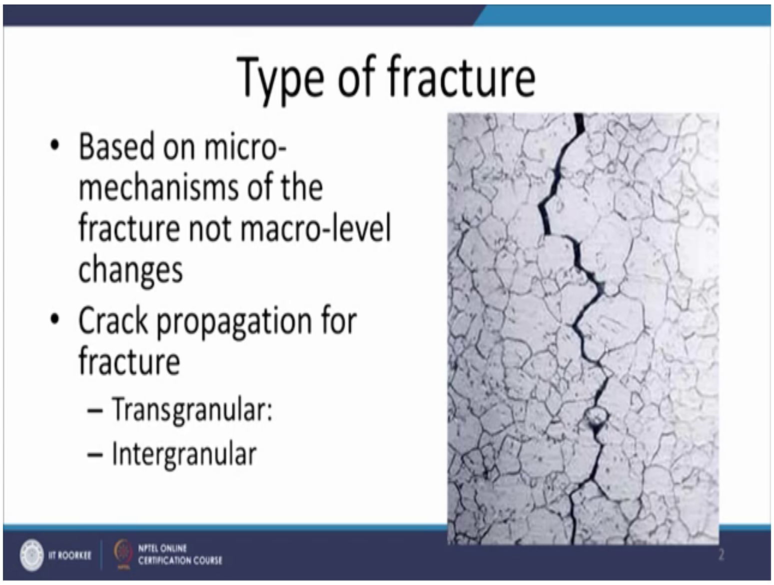

And that this kind of fracture is known as transgranular and this is the fracture where the crack has grown along the boundary of the grains and that is why this type of the fracture is termed as inter granular fracture.

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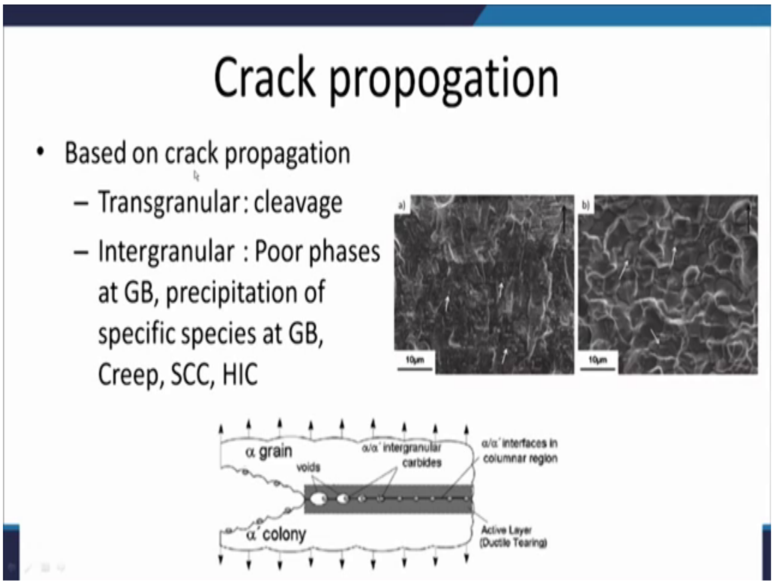

Now, based now how the crack grows during the, during it is growth, so the crack propagation based on the crack propagation we can have the transgranular fracture which is in form of the cleavage facets or intergranular fracture may happened under the certain conditions.

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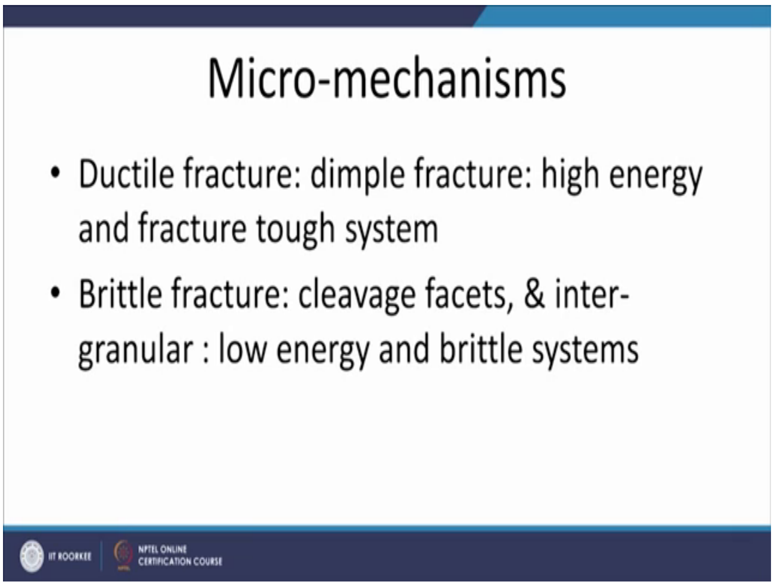

Wherein; like the poor phases are present in the metal like there will be certain cases, why the crack will grow, preferentially along the certain grains.

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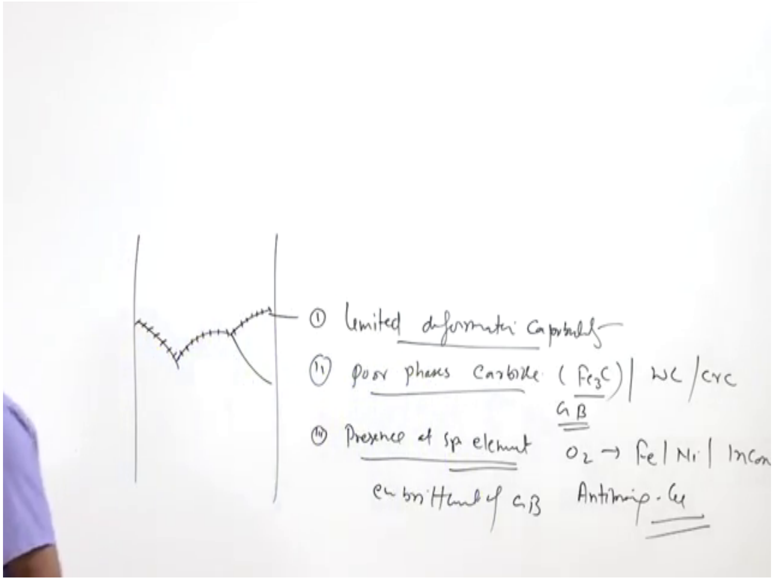

So, if the grain boundary is weak, then crack will prefer to grow along the grain boundary and it will lead to the intergranular fracture, there can be three situations for the this kind of the fracture to occur one is the metal system, which is presented the grain boundary has the limited deformation capabilities. So, it is very brittle limited a deformation systems or limited deformation capabilities.

The second is very poor phase or phases like carbides in case of the iron carbon system sorry the cementite is present as a network in the steel, since cementite offers very low strength and very high hardness.

So, it will tend to fail easily and it lowers it also lowers the tensile strength of the a steel. So, presence of the poor phases in form of the carbides tungsten carbide or chromium carbide especially at the grain boundary this also weakens the grain boundary area and it causes the intregranular fracture preferentially and the third one like some special elements are present primarily at the grain boundary.

So, presence of specific elements at the grain boundary also leads to the weakness of the grain boundaries. For example, presence of oxygen in iron and the in can nickel alloys like in conel, this causes the intergranular fracture similarly the antimony in case of the copper alloys causes the intergranular fractures.

So, these are the three things either the metal system presented the grain boundary has the limited deformation capability, the phases are very poor in terms of the load carrying capability and so the ductility, so they provide the easy site for the nucleation of the voids and subsequently their coalescence can lead to the intergranular fracture and the presence of a specific element.

So, this will be leading to the embrittlement of (Refer Time: 28:58) will be leading to the embrittlement of the grain boundary area to cause the intergranular fracture. So, from here we can easily see these are the cleavage facets which are present and indicating the direction in which the crack has grown.

While in this particular case where in the we can see the grain boundaries sorry we can see that individual grains all these are the individual grains, suggesting the intergranular fracture. So, a steal can fail in transgranular way or the intergranular way if some undesirable phase precipitation or element precipitation has taken place at the grain boundary, then it will be leading to the intergranular fracture.

So, this is also indicating that how the one grain boundary if the weak phases are presented the grain boundaries, then how the fracture will be facilitated. So, what these are shown these are the second phase particles. So, if these are the all these are second phase particles present at the grain boundary under the influence of external loads.

So, just ahead of the crack tip already what we can see we can find the excessive deformation in this area, that deformation will be differential of course, the particle will not be deforming it the same way in the same way as the matrix. So, more deformation of the matrix will be leading to the formation of voids the void size will be larger here the voids will be formed here and here also of the reducing in size and then the continuous growth will be leading to their coalescence and the suppression.

So, here the grain growth at the boundary is taking place or in the in the direction it is taking place in such a way that, wherever the particles are there voids are formed and subsequently they are subsequently their coalescence leads to the fracture. So, in all these cases we will be finding the dimples both the sides.

So, like as I have said ductile fracture primarily involves the dimple fracture, which is a high energy fracture of tough system shows this kind of the fracture, while the brittle fracture shows the clevis facets and the integranular fracture which indicates the low energy fracture and are found in brittle systems.

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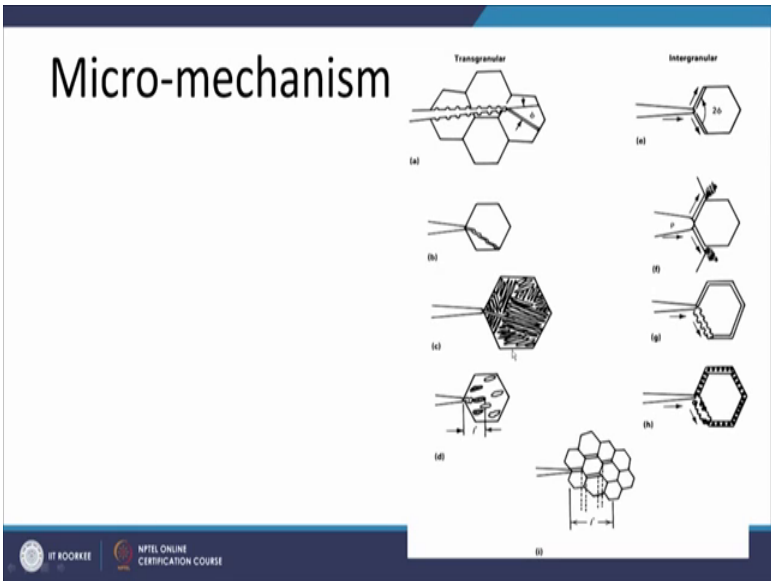

So, this is this is the systematic way by which the crack grows in the case of the transgranular fracture, the crack grows a through the grains, but here the crack grows along the grain boundaries preferentially.

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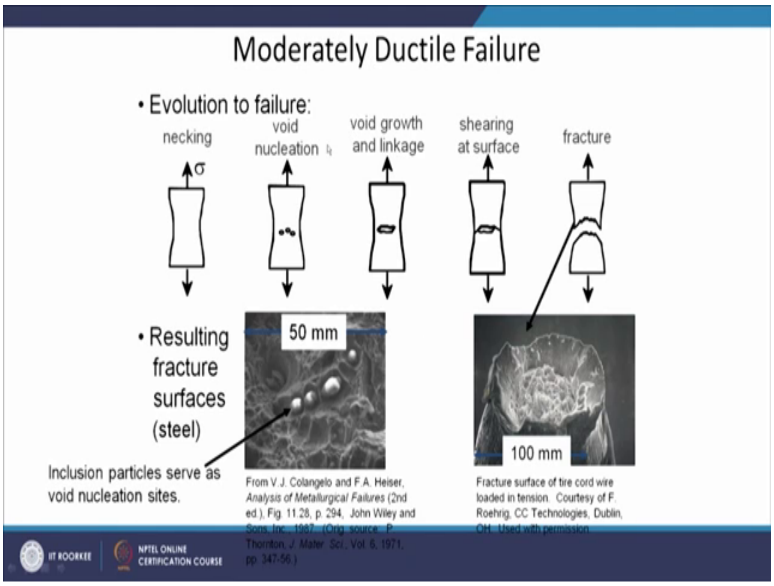

Then we can say how the ductile fracture is observed in a typical design test of the material, this is what has been shown here. So, evolution of the failure in case of the evaluation of the ductile failure in case of the tensile test; So, under the influence of external loading there will be deformation there will be necking.

So, this necking's when the necking is starts we find that some of the voids are nucleated at the second phase particles and subsequently their coalescence leads to the growth. So, the void growth and the linking leads to the reduction in cross sectional area and then subsequently the shearing of the subsequently the fracture takes place.

So, when we see such kind of the fractures this kind of fracture typically shows the flat fracture at the centre and the shear fracture at the near the surfaces. So, here we if we see this one the flat fracture which is basically typically indicator of the ductile fracture, but here the flat fracture zone is being formed by the nucleation of the voids and their subsequent growth is leading to this zone and that is why it is important to understand the microscopic mechanism of the fracture.

The central fracture surface is in a is formed by the void formation and their growth and what we can see at the root of these void some hard particles are present some precipitates are present, which will be facilitating these the formation of these dimples and these dimples we can see here the large sized dimples and fine sized dimples. So, both kind of the dimples are present on the fracture surface.

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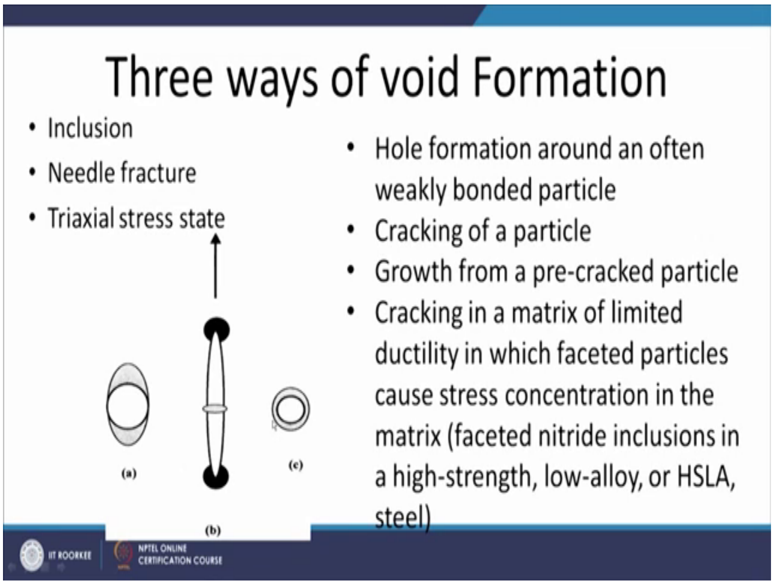

As I have said these are the three ways of the wide formation the this is the second phase particle, this is another second phase particle and this is third second phase particle. So, when the second phase particle may be present in form of the inclusions or these may be in form of needles or tri axial stress state exist.

So, in that case in all these three cases how the void formation takes place. So, the second phase particle when inclusions are present and the material is deforming, then we will see the void is found of both the sides and this eventually causes the formation of the dimples, but in case of the needles shaped constituents are come needle shaped second phase particles the voids are formed at the tip of the needles.

So, that so where so that void can be formed on at these locations the stress concentration is high, when the tri axial stress state exists in this case.

So, in this case the void will be formed all around the second phase particles, so these are the different situations where such kind of the void formation takes place. So, it may happen around the whole.

So, it is basically the whole or void formation often around the weakly bonded particle or this also can happen when the cracking of the particles takes place growth of the pre crack pre cracked particles or cracking in a matrix of the limited ductility in which faceted particles causes their stress concentration. So, presence of such all these hot particles will be leading to the formation of the voids.

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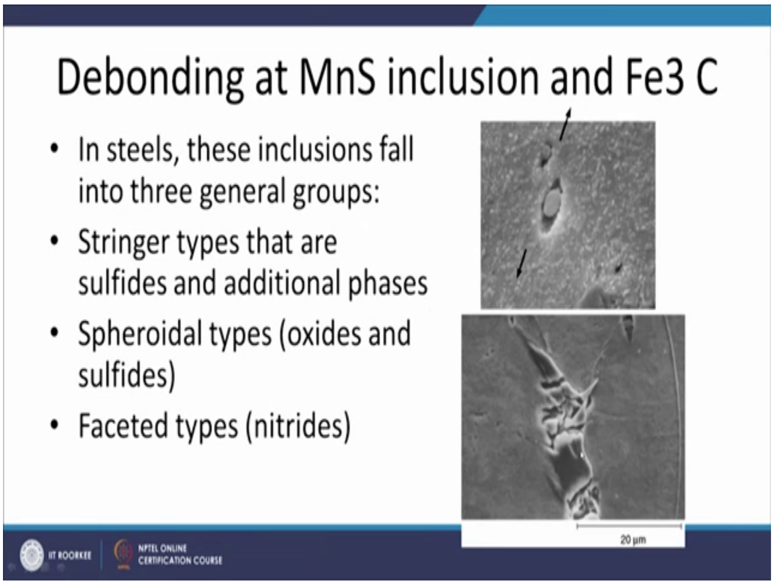

One typical example here is how the voids are found in the real system, this show this shows the two micrographs in one case where manganese sulfide inclusion is getting is acting as a nucleus for or a as a site for the nucleation of the voids.

So, both the sites we can see the voids are being formed around the manganese sulfide inclusion and when we will see that in the hard brittle particle is present at the boundary and it gets fractured in that case also the voids will be formed somewhere like iron carbide is present in this case and it is a fracture facilitates formation of the voids and the gaps.

So, there are three situations a stranger type that are sulfides and other phases a spheroidal type of the inclusions may be there of oxides and sulfides and faceted particles in form of the nitrides. So, wherever the second phase particles are present this will be acting as a site for nucleation of such voids and subsequently their good will be facilitating the dimple fracture.

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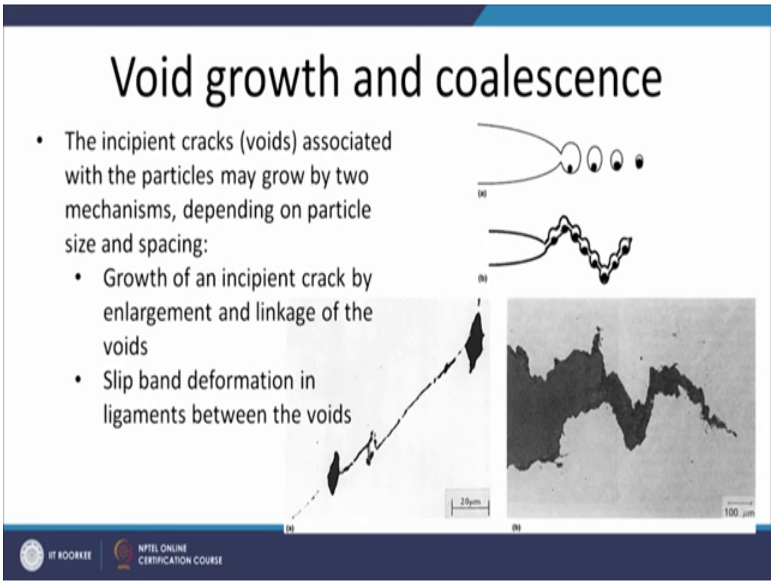

What we can see here the inclusions present number of inclusions are present and under the influence of the external load the voids will be formed and subsequently their growth will be leading to the subsequently their growth and coalescence will be leading to the generation of the fracture surface.

So, this is the one case where growth of incipient cracked by enlargement and linkage of the voids takes place, but when the these inclusions are presented the different locations in that case there can be change in the direction of the fracture also.

So, the slip band formation in the ligament between the voids also can take place say this is the 1 location where void is being found and this is another location. So, in between the slip can occur and the sheer fracture can be absorbed. So, this is the kind of thing can be seen in this fracture surface also.

Where continuous change in the direction of the fracture surface as per the presence of these inclusions and their void formation and their coalescence will be leading to the zigzag shape of the fracture surface. So, the location where these are present will also be affecting the kind of a the way by which the fracture grows or the track grows during the fracture.

Now, I will summarize this presentation in this presentation basically I have talked about the role of the different factors in identification of the type of fracture, which includes the mechanical properties microscopic features microscopic features and the micro structural aspects also and information about all these aspects will be helpful in determining the type of fracture in more effective manner, but in this representation primarily I have talked about the ductile fracture

Thank you for your attention.