Failure Analysis and Prevention
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Lecture - 25
General Procedure of Failure Analysis: Macroscopy of Fracture Surfaces – II

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention. And we are talking about the general procedure of the failure analysis, and under this general procedure of the failure analysis we have started the Factography. you know that Factography is used for determining the environmental and loading conditions under which the fracture of particular component has taken place. At the same time, it also helps to rule out various possibilities whether there has been overloading whether the material had required properties are not or whether the discontinuities have played any role in fracture or not.

But there are certain specific features which are observed on the fracture surface which are used to make very useful inferences about the fracture.

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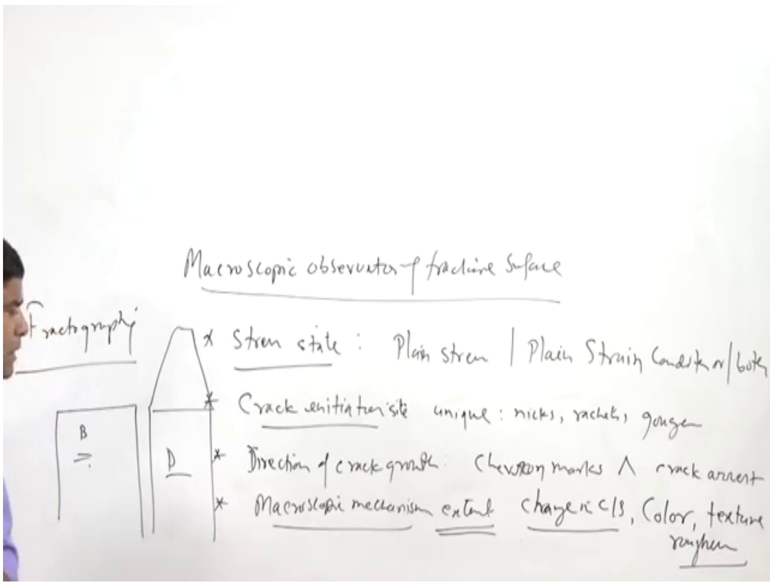

So, about these inferences, which are obtained from the macroscopic observation of the fracture surface, macroscopic observations of fracture surface? So, what information actually we can gather through the various features which are present on the fracture surface is like the; stress state under which the fracture has taken place. So, there can be rest assisted like the plane, stress conditions or there can be plane strain conditions or both.

So, we are both partly partially stressed partially plane stress and partially plane strain conditions. So, this is a one information which we can gather from the macroscopic observation. Another is about the crack initiation site, where from fracture has triggered; that is what can be identified through the various features present on the fracture surface. And these features are basically unique as compared to the remaining fracture surface and which may be in terms of like the nicks, the rachets and, the gauges and likewise very uniqueness we will be able to see in at the location where from fracture is initiated.

So, the fracture initiation site this is second.

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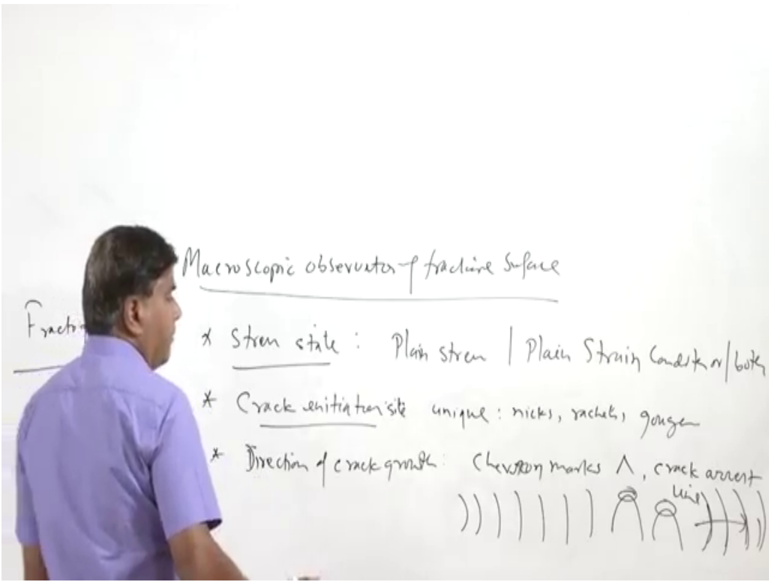

And the third one is the direction of the crack growth; means the how in which direction the crack has propagated during the fracture of the component. So, the direction of the crack growth or crack propagation for this purpose basically we use the 2 types of the features which are present on the fracture surface, one is like chevron marks the chevron marks these are like inverted v shape features which are a indicating the direction in which the crack has grown. And the then there we have the crack arrest lines crack arrest lines, these crack arrest lines are in form of striations in case of the cyclic loading and these are the u shape in case of the static loading or monotonic loading.

So, these u points the direction in which the crack has grown or subsequently the increasing radius of the these concentric circles or restorations in the fatigue fracture surface indicates the direction in which it has grown and it is easier to identify the direction in which the crack has grown in case of the fatigue fractures because their spacing between these iterations will keep on increasing with the increase in the growth of the crack. And thereafter will have the sudden fracture zones which can be easily distinguished from as compared to the remaining area of the fracture surface.

So, the crack arrest lines, which are u shape in case of the monotonic loading and the concentric circles in form of like striations in case of the cyclic loading. And the chevron marks are there in like v shape features present on the fracture surface in case of the brittle fractures. So, these will be indicating the direction in which the crack has grown or crack has propagated during the fracture. And then there is like various other features in form of like say the macro scopic mechanism extent. The extent up to which the plane stress conditions are there a stress extent up to which, plane strain conditions are there or stress the extent up to which, the fatigue fracture is there or there after overload fracture is taking place.

So, the extent of particular operational mechanism leading to the fracture can be identified through the various features which are present on the fracture surface and this may be in terms of like the change in cross section, change in cross section this is one thing; then there can be the possibility of the change in color, change in texture or change in surface roughness.

So, these features indicate as soon as there is a change in operation mechanism of the fracture there would be change in the color there would be change in the surface texture and the surface roughness or the change in cross sectional area of the component. For example, like there is no changes in cross sectional area of the component for the brittle fractures, while in case of the ductile fracture that there is significant reduction in cross sectional area.

So, this is what we can say ductile fracture and this is brittle fracture. Similarly, the 2 will be indicating entirely different kind of the texture color and the surface roughness of the fracture surface. So, these unique features we will be talking in detail to see that how the inferences can be made from the microscopy of the fracture surface.

So, first of all we will take up the how to I determine the stress condition under which the failure has taken place.

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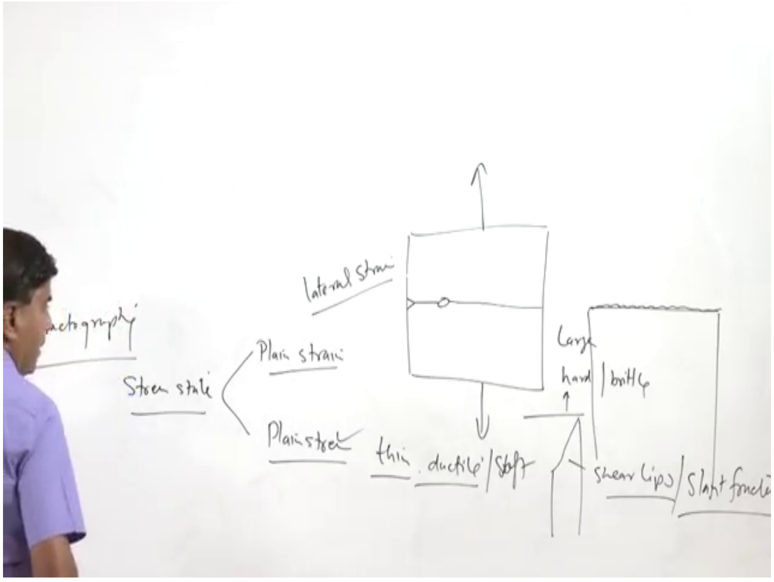

So, stress state is the one whether it is the plane strain conditions or the plane stress condition. When the component size or section is large and the material is a hard and brittle, under these conditions whenever load is applied literally there is hardly reduction in the cross section and mostly in this case if there are discontinuities or some of the defects under those conditions the cracks will grow rapidly and the fracture surface will be created normal to the perpendicular to the external loading without any reduction in cross sectional area of the component since, there is no lateral strain in the component due to during the a due to the external loading.

So, this is the situation where the plane strain condition will be existing and there is no thinning, necking or reduction in cross sectional area will be observed. The fracture surface will be the typical square perpendicular to the external loading while in case of the plane stress conditions plane stress conditions will be involving a lot of the lateral strain and reduction in cross section and this kind of conditions exist when the sections size is thin or the material is a ductile, and it is soft. So, under these conditions the material will be showing the slant fracture surface. this will have the shear lips in this form and the surface will be slant with respect to the externally applied load.

So, shear lip and the slant fracture surface itself indicates that the there is a plane stress condition. So, now whenever there can be a combination of these 2 situations also, where in like the component can have the mixed mode of fracture both plane stress and plane strain conditions exist in.

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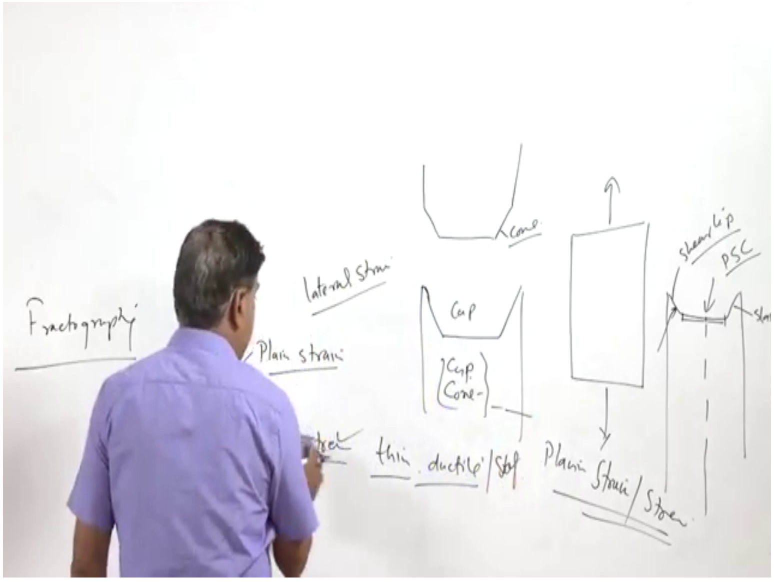

Like a tensile sample like this when subjected to the external loading and the failure occurs, when failure occurs what we find that fracture surface is of these kind of feature wherein at the center of the specimen the there is a flat fracture surface and at the sites near the surface there is a slant or fracture surface or shear lips are present.

So, in this case we have the plane strain conditions in the middle, plane strain conditions in the middle and the plane stress conditions near the surface of the component because when the crack grows the crack and the fracture begins from the center and as it grows towards the side. it is the stress strain conditions is relaxed and it approximates to the plane stress conditions near the fracture surfaces; that is why we have the flat fracture surface at the center and the shear lips at the corner.

So, this feature is basically similar to the. So, this is one part and if we see the opposite part it will have again the fracture surface often the opposite features. So, here this one is similar to the shape of cup and this is similar to the shape of cone. So, that is why the this type of the fracture is called cup and cone fracture, which is basically mix of the plane strain at the core and the plane stress conditions at the surface.

Ah this is the case when the fracture starts with the growth of crack from the center, where the plane strain conditions exist, but there can be other situations also where the fracture initiates from the surface.

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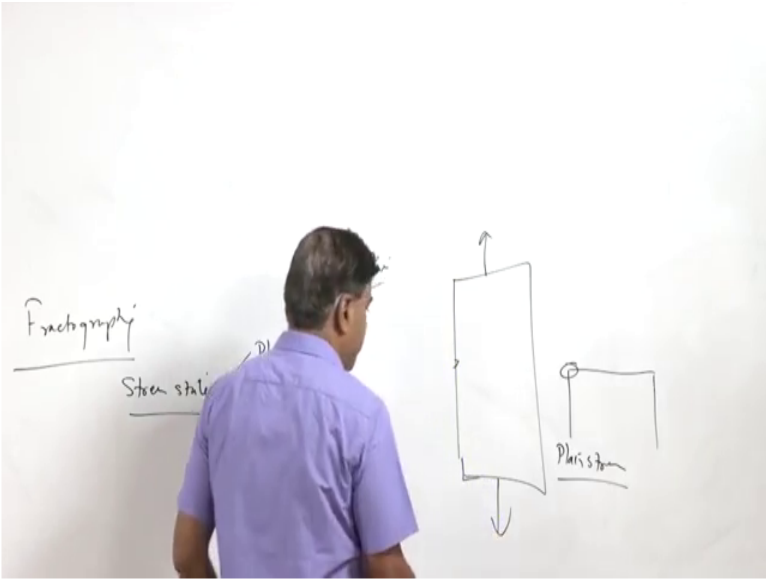

So, in this case what happens like if the fracture initiates from the surface even under the static load conditions in that case even under the plane stress conditions, we do not find any shear lip and the fracture surface is again the flat.

So, when the fracture initiates from the surface means the fracture is initiated from the surface even in the plane strain condition, a plane stress conditions we do not find such kind of the shear lips or the slant fracture surfaces. So, these are the features which are used to identify or determine the kind of the stress state under which the fracture has taken place. So, that is what we can see in these photographs what we can see here.

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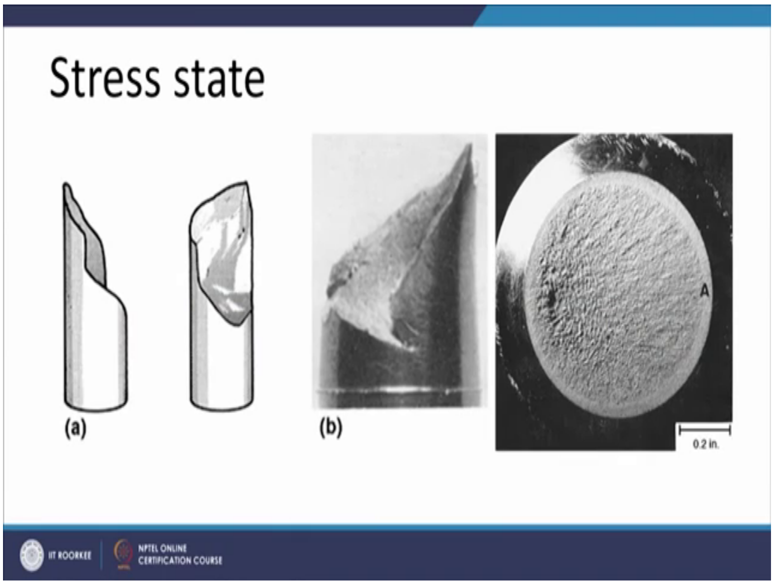

Ah in this case this is the slant fracture surface, this is the corresponding another part and if we see the real sample slant fracture surface is indicated with the help of this diagram. And when there is no re major reduction in cross sectional area the surface is perfectly flat with respect to the normal or the externally applied load. So, this is the plane strain condition the plane strain conditions exist at the core and the plane stress condition exits at the surface. So, we get the cup and cone features. Another so this is what information we can get from the whether the fracture has taken place in to the plane stress and plane strain conditions.

Now, if the failure has taken place due to some other region rather than fatigue rather than the fracture then we will see that a lot of deformation.

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Or change in dimensions of the component has taken place and that is what can easily be observed, in form of the visible distortion and visual distortion suggest that there has been loading beyond the indistinct limit of the component and it can be identified through the buckling or the necking in the component, which we can see that the component has lost itself shaped and this is also the failure of the bearing cage. So, in this case all the fracture has not taken place, but the comparts have deformed very badly and which can be identified through the like the necking or buckling when the stresses are more than the yield strength limit.

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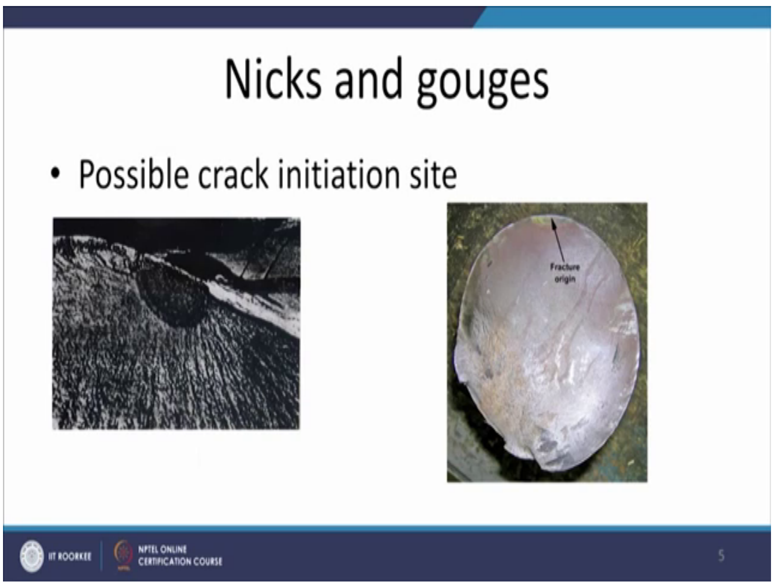

Now, as I said among the various other things or various points about which information can be gathered from the microscopy of the fracture surface, the one is about the fracture initiation site.

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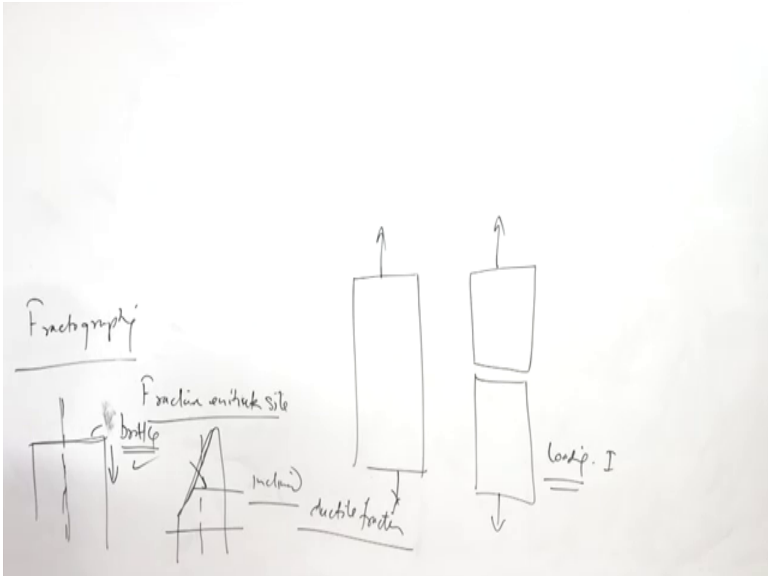

Where from fracture has initiated. So, the nicks and gauges are the 2-ah typical the features the rachets are the other ones which will be indicating the location where from fracture initiates that in it gives entirely different kind of the fracture morphology texture, zone, color and that is why it is comparatively easy to identify the location where from fracture has initiated.

So, like say this shows the nicks, wherein or the fingernail kind of the feature. This is the location where from fracture has initiated and it has completely different morphology than the other locations. These are the other locations where which indicates that the crack has grown from this particular location in the directions. So, all the lines will be converging towards the fracture initiation site these are the chevron marks indicating the direction in which the crack has propagated. Similarly, in case of the fatigue fracture this is the location which is indicating tempere completely different surface morphology surface feature as compared to the other locations.

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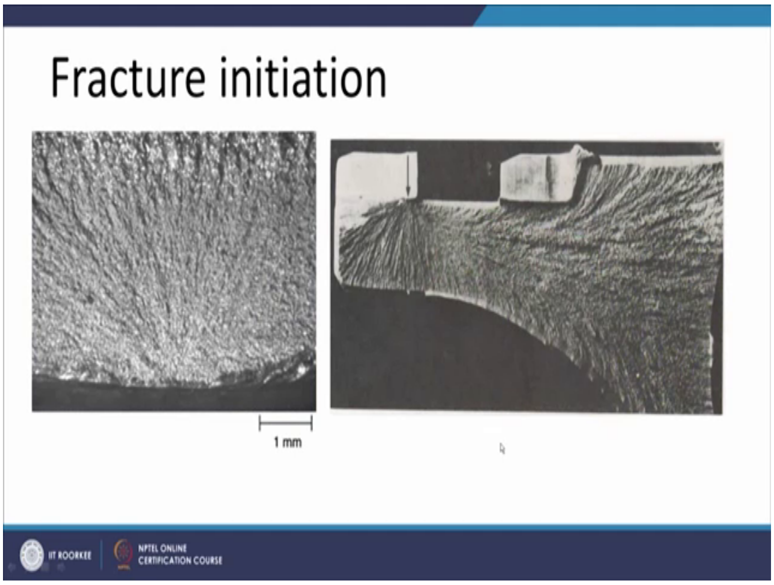

Ah now, the fracture initiation sites can also be seen in these 2 diagrams where in like this is the one location where, where all these the lines are converging. So, then if we see this feature also all these lines are pointing towards the one direction and that is where the fracture has initiated. So, this is the area where from fracture has initiated. And this needs to be investigated further to see why the fracture has initiated from this zone whether there was some kind of the crack or some kind of the weakness in the mechanical properties or some other reason like the stress raisers were present at that location. So, definitely there must be some reason why the crackture fracture has initiated from that location and that should be investigated in order to find the possibility as a cause of the fracture.

So, similarly here if you see this is the fracture surface and this all these are pointing towards this direction. And here if we see all these are indicating also in one direction. So, that is this location you know which is indicating that the location where from fracture has initiated. So, it is a if we see carefully the fracture surface, then the presence of the surface features and morphologies then the failed component will be pointing towards the location where from it has initiated and that it becomes the area of the interest for further investigation to see if there is a disk deficiency in terms of the mechanical properties or a stress problem was there of the stress raisers or something like that; should be investigated as per the possible indicators.

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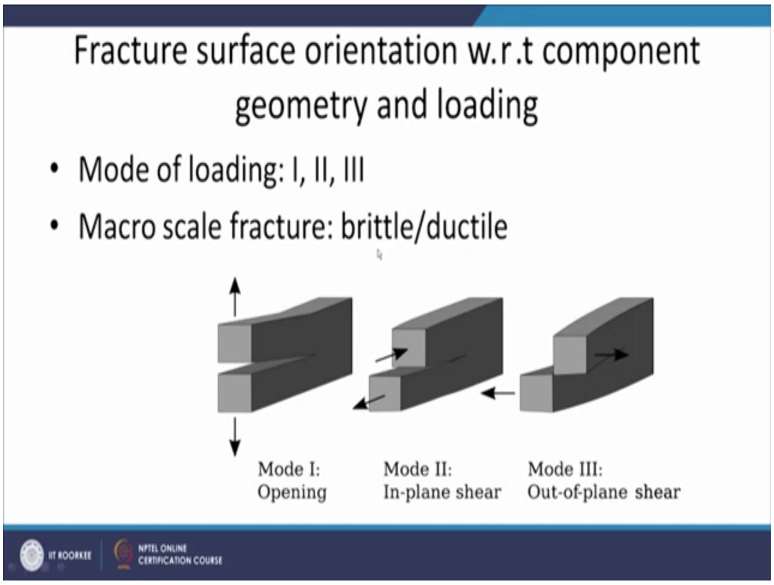

Now another information which can be gathered from the surface orientation of the fracture surface orientation with respect to the geometry of the component and the loading. So, here what we can see the fracture surface orientation like this is the component so the fracture surface may get filled like this so here this is the case of the loading one or the loading of mod 1.

So, fracture surface helps to indicate this is the macroscopic feature which can easily be observed which kind of the loading was there, whether it was the tensile or the shear type. So, if we see when the fracture surface grows perpendicular to the direction of the external loading then it indicates the mo loading mod 1 or mod 1 that is the crack opening mod this is the case of the tensile loading.

While in other case other 2 cases mode 2, where the fracture surface ah, where the movement of the one part of the component takes place in direction parallel to the fracture surface indicating the in-plane shear. So, basically this is the case of the shear loading and where the fracture component or the part of the fracture component is moving parallel to the fracture surface and that too in the plane of the shear. And this is also the case of the third is the third case of the regarding the mod of the loading, the third case is the also related with the shear loading where the deformation or the fractured part of the component is moving with respect to the fracture surface in parallel, but out of the plane of the shear.

So, in these 2 cases mod 2 and mod 3 where loading is shear, and this is the case of the tensile loading where mod 1 loading is tensile and depending upon the fracture surface orientations we can identify; whether the component has been subjected to the shear load or the tensile load it has been or in the shear loads whether it has been the mod 1 loading or a sorry mod 2 loading or mode 3 loading as far whether as per the case if the movement of the sheared out component has been in the direction parallel to the fracture surface and in plane of the shear or it has been out of the plane of shear.

Now, the another important of information which can be gathered from the fracture surface orientation, with respect to the component geometry and loading is that it also indicates whether the fracture of the component has been ductile or the brittle one. So, if the fracture surface of the component is perpendicular to the direction of the component a perpendicular to the axis of the component or perpendicular to the loading axis of the component then this is the case of the brittle fracture, and in case of the shear or slant fracture this one is inclined indicating the ductile fracture.

So, whether there is a brittle fracture or a ductile fracture that also can be identified through the orientation of the fracture surface with respect to the loading access or the geometry of the component, fracture surface is inclined with respect to the axis of the component this is this can vary right from let us say it can be 45 degree or the slant angle can vary significantly, while in case of the brittle fracture with respect to the externally applied load and axis of the component fracture surface is normally perpendicular in case of the brittle fracture.

So, the ductile fracture will have the slant fracture surface and the brittle fracture will have the square or perpendicular fracture surface with respect to the externally applied load. now the load and the fracture orientation surface is also vary depending upon the type of load, the fracture orientation can vary significantly.

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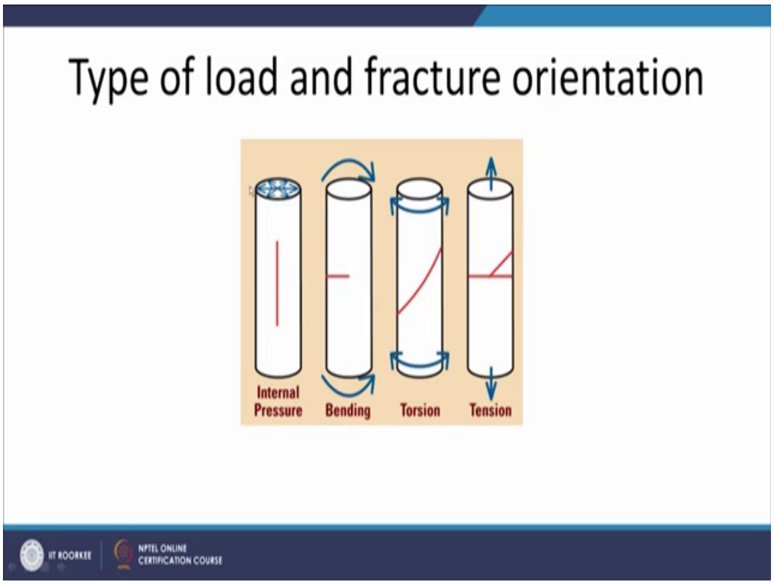

For example, here what it shows when there is internal pressure. So, in case of the internal pressure, the fracture will be in longitudinal and that is indicated through this red line, when there is a bending type of the load there will be the circumferential fracture means the orientation of the fracture surface will be circumferential in case of the torsional there will be slant fracture surface. And in case of the tension it can be both where a flat fracture surface or the slant fracture surface, as per the case of the type of the fracture whether it is ductile and the brittle. So, there can be both flat fracture or the slant fractures in case of the tensile loads so depending upon the type of loading the fracture surface orientation can vary significantly and that is what can be schematically understood from this diagram.

Now, as far the macroscopic feature of the fracture surfaces concerned like says ah, this is the component which is subjected to the external loading.

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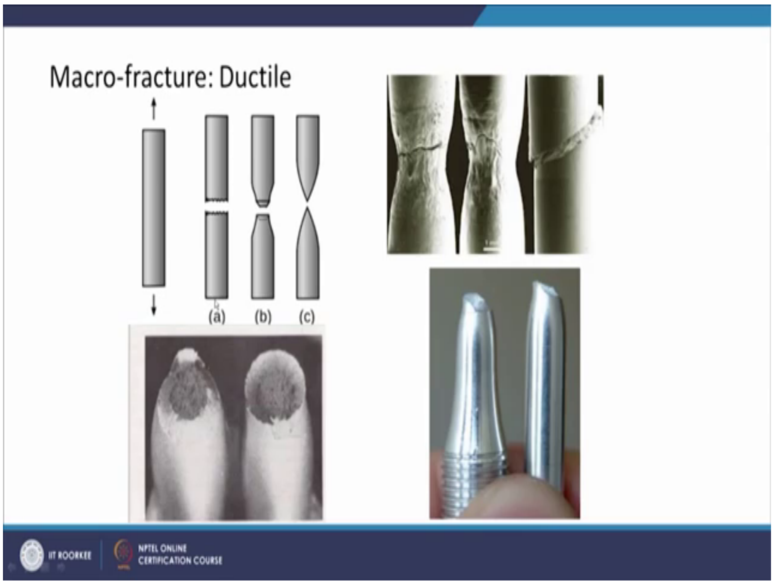

So, the a is the case of the brittle fracture, where the fracture surface is perpendicular to the axis of the loading. This is the case of the somewhat ductile fracture means partially ductile fracture in this case a at the center the we have the at the center we have the brittle fracture; that there is the flat fracture and at the sites we have the slant fracture.

So, this is the mixed mode of the fracture and this is the case where the metal is completely ductile and a reduction in cross sectional area is close to the 100. So, this is a completely ductile fracture. So, the mixed mode fracture where both the flat fracture is present at the surface at the center and the slant fracture is present at the sites; that is what can be seen from this diagram and the corresponding the cone is here, where the slant fracture is present in this area and flexure flat fracture is present in this at the center of the specimen.

So now this is the case of the slant fracture and this is the case of the in this case there is a no necking hour, while in this case in these 2 cases there has been some necking and the fracked their fracture surface will be indicating if there has been the mixed mode or there it was just the slight fracture surface.

So, this is how we can say in case of the ductile mode of the fractures there is a reduction in a cross section as well as the presence of the shear lips, especially near the fracture surface, but if the fracture is initiated from the surface then their would not be any shear lips and, but the fracture will be the slant and this will also be indicating the ductile fracture.

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In case of the brittle fractures as I have said there is no change in cross section of the component. And so, here you can see whatever is the cross-sectional area here the same is here there is no reduction in diameter. At the same time ah, the fracture surface is also perpendicular to the externally applied load and. So, these are the 2 important features apart from the color texture and the roughness that about that we will be talking later.

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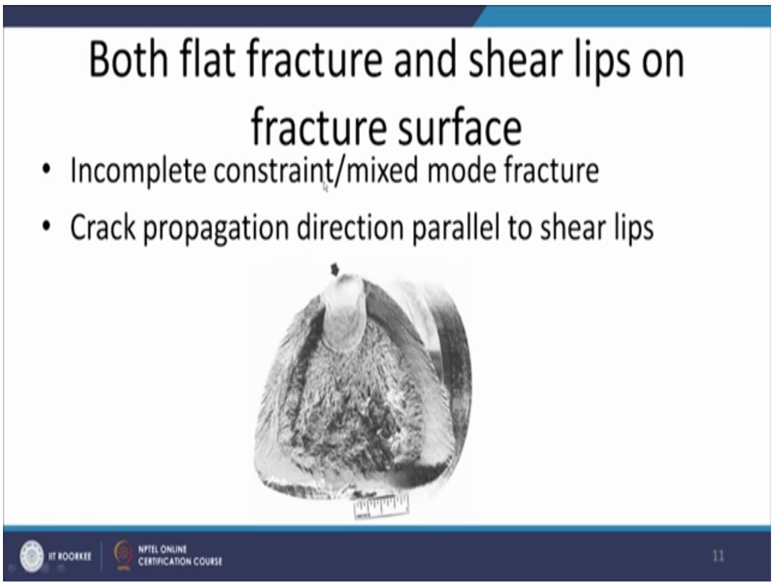

The case where the both flat fracture and the shear lips are present on the fracture surface this is called a mixed mode fracture and this is the situation where the strain is incomplete the actually plane strain conditions exist at the center. Here in this case and the plane stress conditions will be existing at the near the surface.

So, that will be corresponding to the shear lips, while at the center the plane strain conditions exist. So, this is the flat fracture zone. And in this case the crack propagation direction and takes place parallel to the shear lips. This is what also we can see in this case you see if we see there are 3 zones basically one is the shear lip area second is this flat fracture zone and third is this one, which is also different with regard to the features present in the rest of the fracture surface area. So, this will be indicating the site of the fracture initiation.

So, this is how we can make the interpretation about the stress conditions under which the failure has taken place, whether the failure is ductile or the brittle. So, here now I will summarize this presentation. In this presentation I have talked about what information we can gather from microscopic observation of the fracture surfaces, and how to read and how to make the interpretations from the broken component with regard to the stress state in which failures fracture has taken place or the kind of the fracture it is whether it is ductile or the brittle fracture.

Thank you for your attention.