Failure Analysis & Prevention
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Lecture – 27
General Procedure of Failure Analysis: Macroscopy of Fracture Surfaces- IV

Hello. I welcome you all in this presentation related with the subject Failure Analysis and Prevention. And under this subject we are talking about the General Procedure for the Failure Analysis and when a component face, then how macroscopically, we can get the information about the conditions of the failure or the kind of the loading which has been there where from fracture has initiated.

So, for this, we have certain kind of certain the macroscopic features which help us to make lot of inferences about the loading conditions were from fracture has initiated in which direction it has grown. So, we have talked about talked about certain some of the features like the chevron marks radial marks or the kind of the macroscopic changes in the cross section or the deformation takes place and how the inferences about the stresses state can be made about the conditions under which failure has taken place.

So, now in this presentation we will be talking about few more the features related with the macroscopic study of the fracture surfaces.

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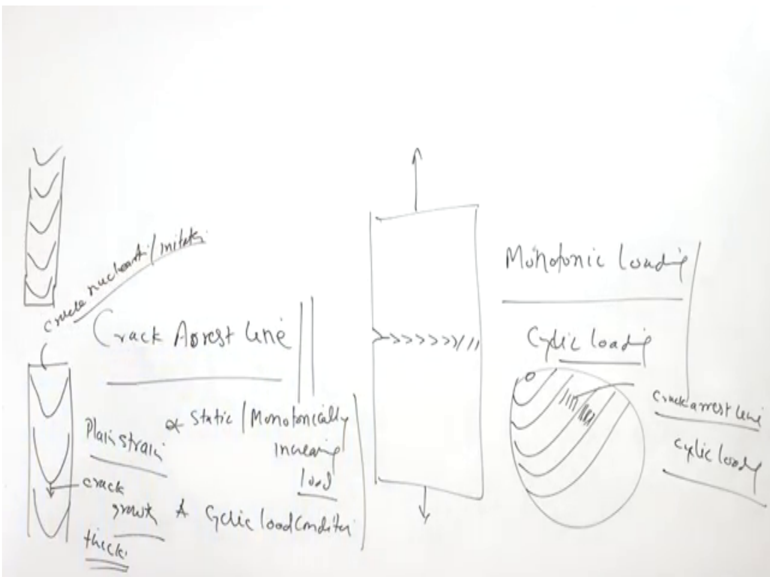

So, one feature is like crack arrest lines we know that whenever a fracture occurs the fracture is preceded by the growth of the crack. So, like say this is the notch and here crack has an nucleated then under the effect of the external loading depending upon the type of the material and the loading conditions the crack will be growing in different way.

So, when the crack grows and thereafter certain fracture takes place what we see the features which are obtained on the fracture surface under the static or we can say monotonically increasing load. So, this is one type of the loading like say in presence of the notch when the tensile load is applied the crack and nucleates and then it grows in particular manner and another case is where like the crack grows under the cyclic load conditions.

So, in both the cases the growth of crack leaves some of the marks behind onto the fracture surface and those marks are termed as the crack arrest lines. So, crack arrest lines in case of the monotonic loading monotonic loading or different then one what is observed under the cyclic loading conditions again the kind of the stress state which is present that also offers some indications through the presence of the crack arrest marks when the crack arrest marks under the monotonic loading conditions they are of the typical kind like say this is one the thick plate.

So, here, the crack arrest marks will be there in u shape like this. So, the tip of the u is offering the direction in which direction of the crack growth so; obviously, the direction opposite to that of the trip tip indicating the crack nucleation or initiations site where from it has started or triggered. So, this is one case such kind of the features are less when the plate is thick means when the plate when the when the plane strain conditions are present means it is not exactly plane strain conditions, but when the when the situation is approximating to the plane strain conditions then we find a fewer such kind of marks.

But when the plate is somewhat thinner, we find more marks of this kind because the growth of the crack is more frequently arrested by the material and we find lot of a such kind of the marks. So, there are two points as far as the crack arrest line under the monotonic loading conditions may exist that we get the u shape feature and the lines pointing in the direction of the crack propagation.

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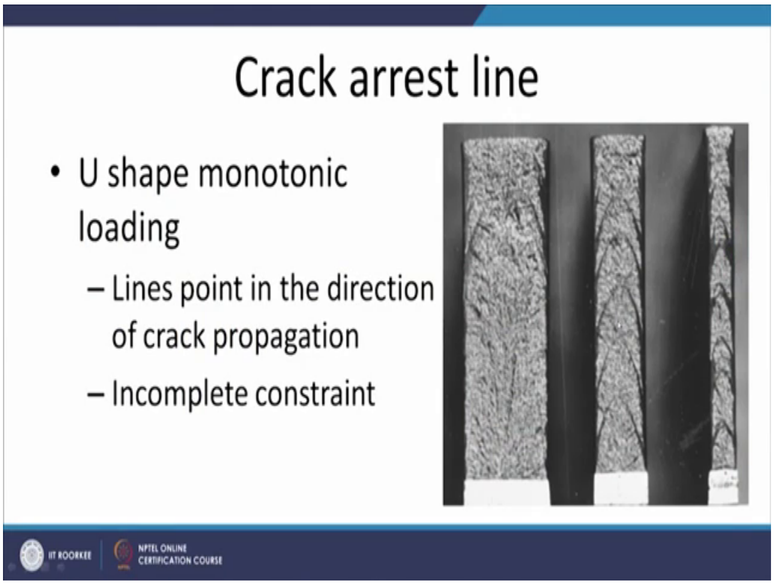

So, like say here these u shape inverted U shape lines are indicating the direction in which the crack has grown and you see. So, the presence of these a indicating the presence existence of the incomplete constraint means as the thickness increases when the plate is thin we find more such kind of the u inverted u shape marks and when the plate is somewhat thicker, we get somewhat fewer marks and very few marks when the plate is thick.

So, the presence of these marks indicate that the incomplete constraint exists and so, here, this is the situation nearer to the plane a stress condition and as the thickness increases we approach towards the plane strain conditions, but a still if these marks are present that will indicate the incomplete constrain. So, it is obvious that with the increase of the thickness the plane strain conditions were possibility for a plane strain condition will be increasing and that will be increasing the constraint also.

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So, a presence of such marks indicate incomplete constraint while under the cyclic load conditions the presence of these concentric circles in form of the beach marks or microscopically these are present in form of the is creations at which can be seen at a high magnification. So, these are also the crack arrest lines in form of the beach marks or these creations and which will be indicating the presence of the cyclic loading and the direction in which the crack is growing.

So, the circle the center of such concentric circles will be the location where from the crack has initiated. So, this is what we can see in this diagram also what it shows that there are number of the crack arrest line in this component which has fail similarly there are number of crack arrest lines which have failed and it is also indicating the direction in which the crack has grown and the origin is somewhere here where from all these have initiated.

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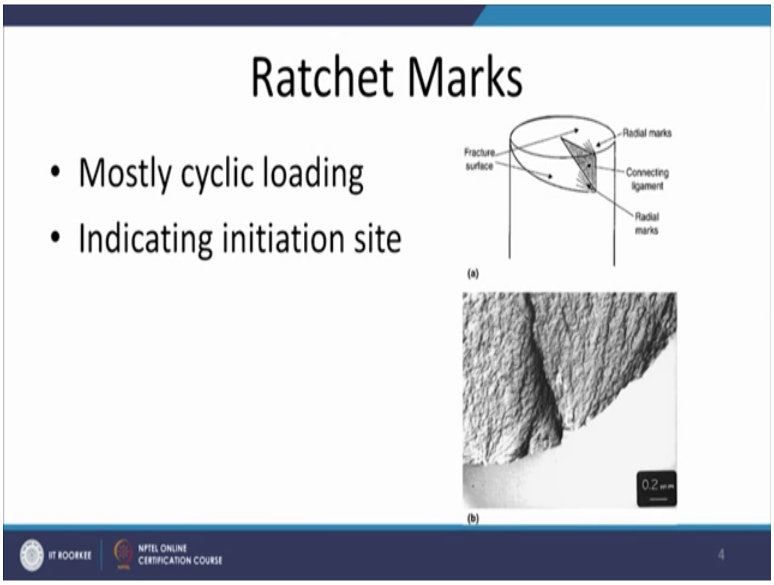

So, all these concentric circle circular lines indicating the presence of the crack arrest marks on the fracture surface then another mark which indicates the fracture initiation site and this is observed mostly under the conditions of the cyclic loading and the ratchet marks can be seen even macroscopically. This is because a very and this kind of feature can be seen through the naked eye also and this is indicating the presence of the ratchet marks which suggests the where from the site where from the fracture has been initiated and it is commonly formed under the conditions of the cyclic loading.

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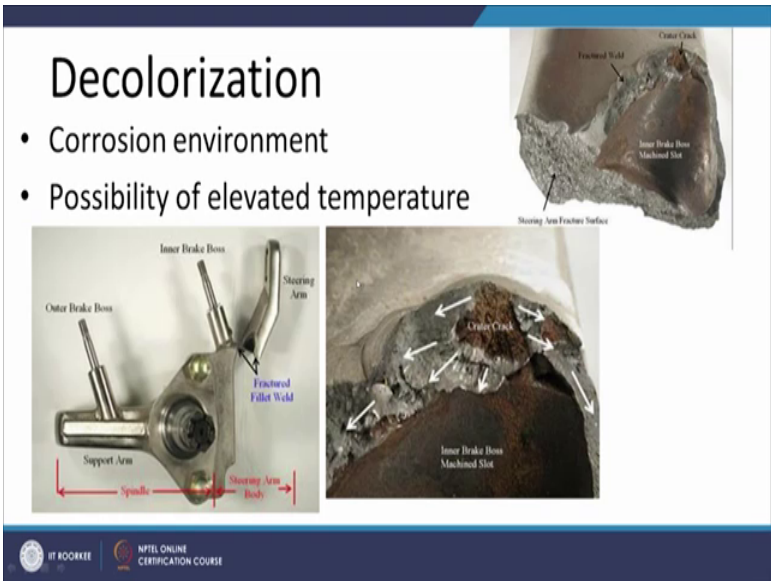

Now will be coming across the other aspect related with the fracture where we have talked about the texture color and the surface roughness and what kind of the inferences can be obtained from such kind of the surfaces decolorization or change in color itself indicates either the component has been exposed to the corrosive environment or it has been exposed to the high temperatures because of which oxidation has taken place.

So, these are the two possibilities if there is any change in color of the metal during the service. So, that will suggest the possibility these two possibilities like presence of the corrosion environment in which component has been exposed or the possibility of the elevated temperature. So, that oxidation would have changed the color like say this is one particular example where the failure had taken place of the steering arms which was welded and what it shows that the in the weld joint there was a crater the crater had a lot of the corrosion features because of the different color this what we can see.

So, the macroscopically if you see from a distance then what we can see the fracture occurred from the weld zone and this is the location of the crater where was we can see some corrosion features and the bright shining surface indicates the freshly fractured surface. So, it will be indicating that the surface was exposed to the corrosive or environmental conditions for certain period of time with the change of color. And if there is some freshly fractured surface then it will be the bright and the shining. And the reflective means the bright in color and it will not be a dull there is one more possibility that if this surface was exposed.

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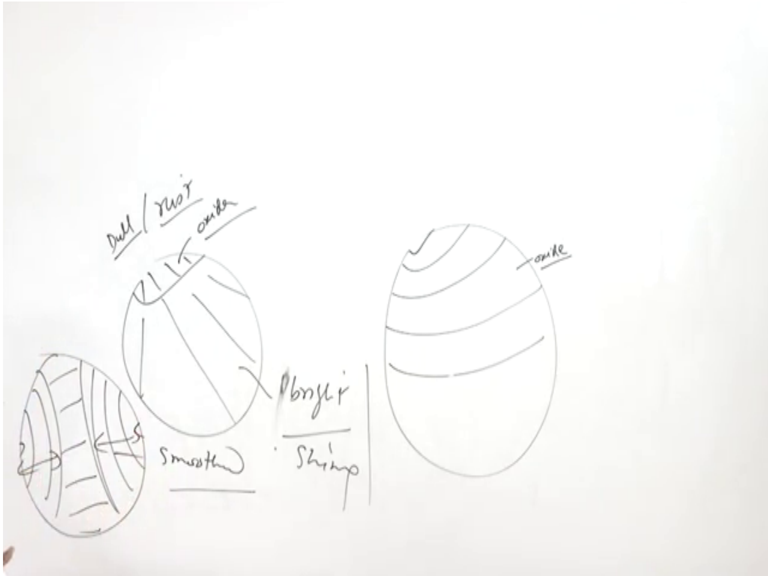

In the environmental conditions for long, then it will get oxidized and another one which will be filling catastrophically under the overload condition. So, this will be comparatively bright and shining.

So, this will suggest to the possibility of the freshly fractured surface while if they when a particular region where we can see that it is dull and there is a presence of oxide or rust as per the metal it will indicate, it has been there for certain period of time because of his rusting or oxidation has taken place there is one more aspect which is that by measuring the thickness of the oxide like if this is the crack which has nucleated and then it is growing slowly like this.

So, by measuring the by measuring the oxide thickness layer and using the oxidation kinetics of that material we can estimate for how long time, this surface was exposed to the environmental conditions where sometimes measurement of the oxide thickness layer helps to estimate the kind of the period the period for which the surface was exposed to a particular kind of condition through the a measurement of the thickness, because once we know the thickness then using the oxidation kinetics of that metal we can determine for how long time, this surface has been exposed to the environmental conditions.

So, we can also see there is a surface having the oxides off of course, in fatigue conditions the location where crack has nucleated will be exposed for longer period as compared to other surfaces because if the surface will be formed sequentially and the third zone will be formed suddenly in the third stage of the fracture. So, the; obviously, the oxide thickness layer will be maximum here and then it will keep on decreasing because of completely shorter period of the exposure to the environmental conditions or the corrosive environment.

So, means the decolorization indicates either oxidation or the corrosion exposure of the component to the corrosive conditions.

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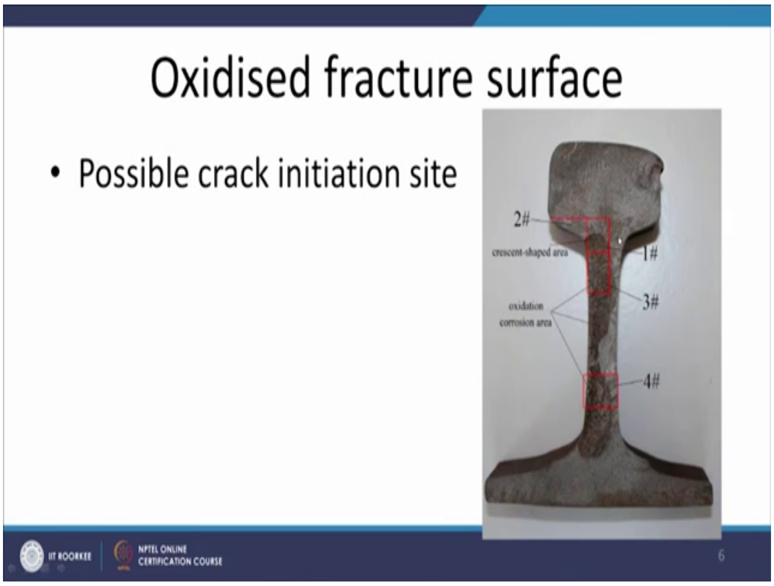

Then oxides oxidized fracture surface also indicates that the there two possibilities were a related with the oxide oxidation or oxidized fracture surface one is the location where from the crack has been initiated because the wherever from crack initiates that is exposed to the environment and that gets oxidized.

So, if there is a dull or rustered surface that will of course, indicate the location where from it has been crack has been initiated and by measuring the oxide layer thickness we can estimate that the estimate when the crack was initiated and for how long time this surface was exposed to the environmental conditions because of which oxidation has taken place. So, this surface also has. So, these are the freshly fracture surfaces which are the bright one as compared to the others which are dull.

So, the most dull surface is this way which is suggesting the possibility of the initiation of the crack other surfaces which are somewhat less dull will indicate that these surfaces have not been exposed for that long to the environmental conditions or for corrosive conditions then another one is the reflectivity of the fracture surface.

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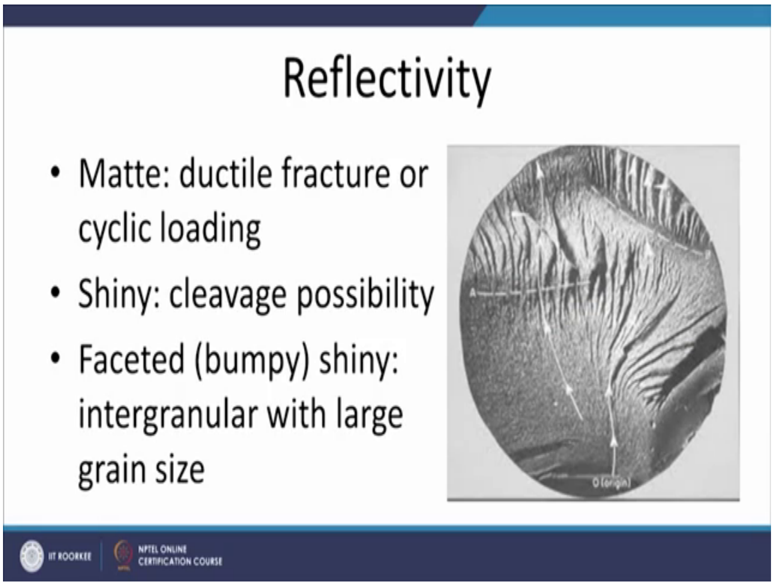

So, there are few surface features like the matte fracture surface which is which we can observe under the two conditions when either the material is ductile. So, ductile fracture is somewhat dull and matte a surface is observed as compared to the flat and in the shining fracture surface which is observed under the brittle fracture condition. So, the cleavage fracture possibilities exist cleavage brittle fracture possibilities exist in the fracture surface is flat.

And shining and dull fracture and the cyclic load condition possibility exists when the matte surface the reflectivity is of this surfaces of the matte a type and the faceted or against a bumpy signing surface now indicates that the fracture surface has been intergranular and with the large grain size. So, basically these two are the common features the matte surface indicates the ductile fracture and the signing surface indicates the brittle fracture which occur which occurs to the cleavage micro fracture a mechanism.

And faceted signing surface indicates the intergranular fracture with the large grain size and a lot of information can be obtained from the surface roughness of the fracture surface.

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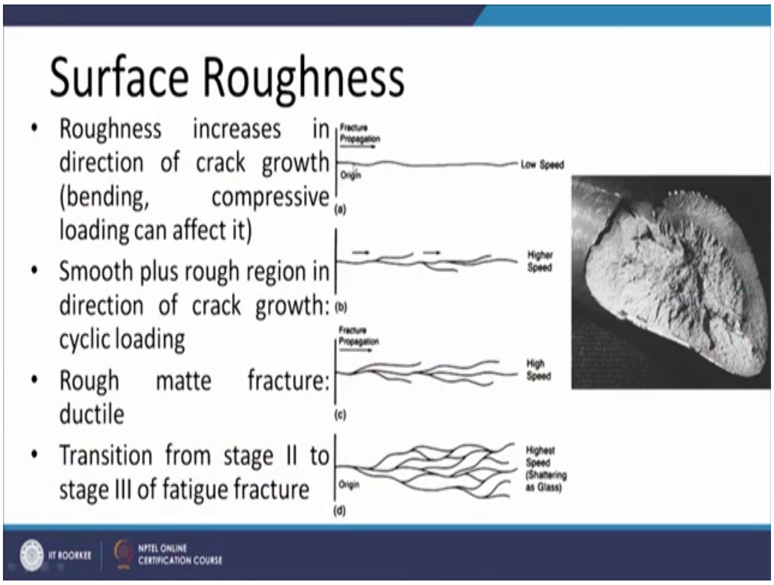

So, for that what we need to see we need to see just this diagram in the like say, this is the origin for the crack new origin of the crack nucleation and it grows gradually with the time at a lowest speed, then the surface is very smooth and ups and downs are less.

So, in the direction of the crack propagation from the origin to the end of the end where the complete fracture is facilitated the low speed fractures indicate a smoother fracture surface when the fracture propagates at a higher speed. Then will see some what are rougher surface and when the fracture proposition from the crack initiation or the fracture initiation side at a higher speed. Then we see the fracture is further rougher and when the fracture occurs at very high speed like the shattering of the glass then will see the with the growth of the fracture the roughness will keep on increasing his growth of crack roughness on the fracture surface will keep on increasing.

So, these are some of the schematics showing the way by which surface roughness is affected when the crack grows at a different speed on the on the fracture surface. So, what we can see here roughness increases in the direction of the crack growth that is what except in one case in all the cases, we can see the roughness grows in the direction of the crack growth. However, the bending and the compressive load conditions can effect because in both the cases there is a possibility for the compressive loading.

So, the fracture surface can get closed. So, the closer of the fracture surface under the compressive loading will is smoothen the fracture surface is smooth plus rough region in the direction of the crack growth is observed in case of the cyclic loading like say this is what we have seen when the crack grows from all the direction from the two directions under the fatigue conditions then will be seeing the rougher surface will be present at the like in this case the crack is growing from the two directions.

So, the rough surface corresponding to the third stage of the fracture will be at the middle while these two surfaces will be somewhat a smoother because due to the continuous opening and closing of the crack these surfaces will be is smoothened. So, smoother surfaces at the side and at the centre region where you may get the rougher surface. So, a combination of both is smooth plus rough region in the direction of the crack growth can be observed under the fatigue load or cyclic load conditions a rough matte fracture surface is observed in case of the ductile fracture while the transition from the second stage to the third stage is accompanied in case of the fatigue fracture with lot of change in the roughness.

So, in the second stage surface is smooth in third stage surface is rough according to the mode of fracture which may be our dimple fracture or ductile fracture in case of the ductile materials due to the overloading or it may be brittle fractured by the cleavage faceted in case of the brittle material. So, there can be lot of transitions or variation in the surface roughness, but in general increase in roughness increases in the direction of the crack growth.

Now will see the ductile to brittle transition a temperature and how does it affect the fracture surfaces. So, for that what we need to see we know that with the change of the temperature of low carbon steel there is a lot of change in the impact resistance which is indicated through the sharpie or IO test in terms of the energy absorbed the energy absorbed may vary significantly from say 140 joules at twenty degree centigrade at room temperature or like this.

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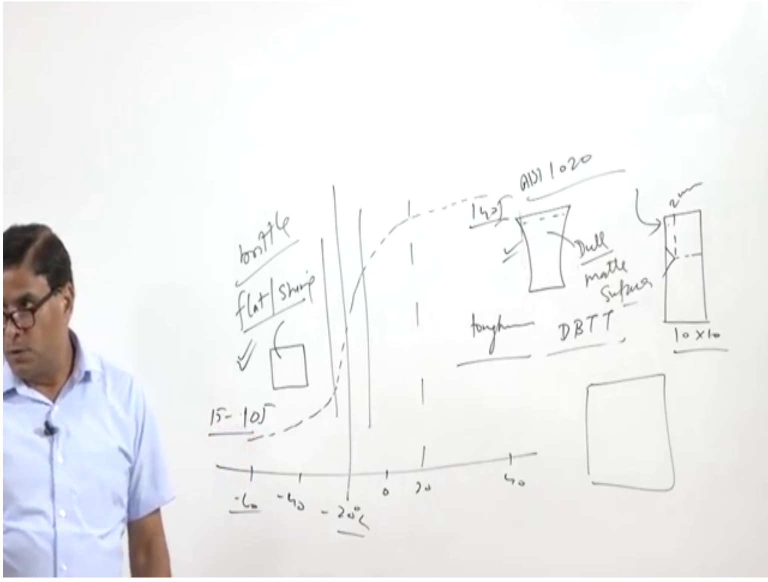

So, at room temperature say, it is 20, then 40 and here somewhere 0, then minus 20 minus 40 minus 60. So, what it suggests that as soon as we come down below the minus twenty there is very sharp drop in the toughness value which say has been for simple carbon steel AISI 1020 of 140 joule which may get reduced to almost like say the 10 to 15 joule 15 to 10 to 15 joule.

So, such a large drop in the impact resistance or the toughness of the material is termed as ductile to brittle transition temperature and when it happens we will see lot of variation in terms of the fracture surface morphologies normally or the toughness sample is of the square shape where we make a square cross section you make a notch and 10 by 10 mm cross section is normally used. And here then this is the 2 mm notch which is normally made and then we check the impact resistance using the sharpie or IO test.

So, what we normally get like this is the sample of the 10 by 10. So, in case of the ductile materials in case of the ductile materials, what we see that there is a significant change in the dimension of the component like this. So, like say this is the fracture surface. So, what will see when the fracture is corresponding to the minus 40 degree centigrade for this one the cross section remains by enlarge unchanged and entire fracture surface is flat and shiny.

So, corresponds to the brittle fracture while in other case when at are high temperature what we see that the fracture surface is by enlarge is distorted and it is not anymore the square and it shows that lot of dull and matte surface is present. So, on moving from the high temperature to the low temperature there is a continuous change in the proportions of the fracture.

So, this involves completely shear fracture under the toughness test and this complete completely reminds reflects the brittle fracture. So, how to indicate that the approximate the proportion of the shear fracture or a brittle fracture just by observing the just by observing the fracture surface? So, what we can see here when the fracture takes place. So, at the center we find the brittle fracture and at the sides we find the shear fracture.

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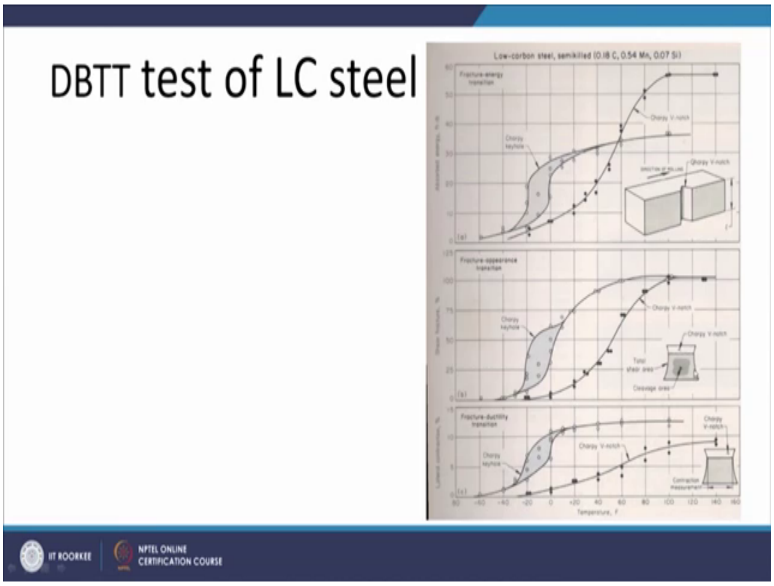

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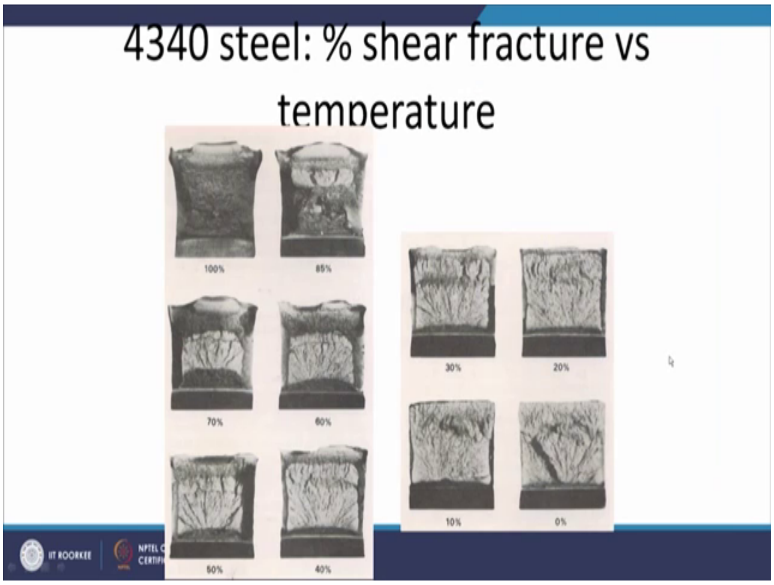

So, how the proportion of the brittle fracture and proportion of the shear fracture change as a function of the temperature say the temperature at 40 degree centigrade the it is completely shear fracture and energy absorbed is 140 joule say, just for example, this for this is still it will be different like say 4340 is still will be for this is still impact energy absorbed will be different, but as we move from the high temperature at high temperature, what we see that it is completely shear fracture, but as the temperature is reduced what we find that in middle there is a brittle fracture which is shiny and this indicates in terms of the surface texture and the color its different from the remaining area.

So, what is it indicates that in between it is the brittle fracture which is about 15 percent and all around that we have the shear fracture as we further lower down our the temperature, then what we find the shear fracture is limited to the 60 percent remaining 40 percent is this is the brittle fracture and remaining is the shear fracture.

So, shear fracture here is 60 percent and remaining 40 percent is the brittle fracture as we come down at further lower temperatures what we see that the shear fracture has been reduced significantly in brittle fracture has increased. So, in the center region all this is the brittle fracture and in these 2 diagrams, what it show it is almost 90 percent brittle fracture and only 10 percent is the shear fracture and here it is completely or the brittle fracture.

So, by seeing the texture and morphology of the fracture surface we can estimate the proportions of the shear fracture and the brittle fractures and now we will see that the when the cracks and develop under the different loading conditions will find the different morphology of the fracture surfaces. So, a specimen subjected to the bending on the external surface where that as a load is acting.

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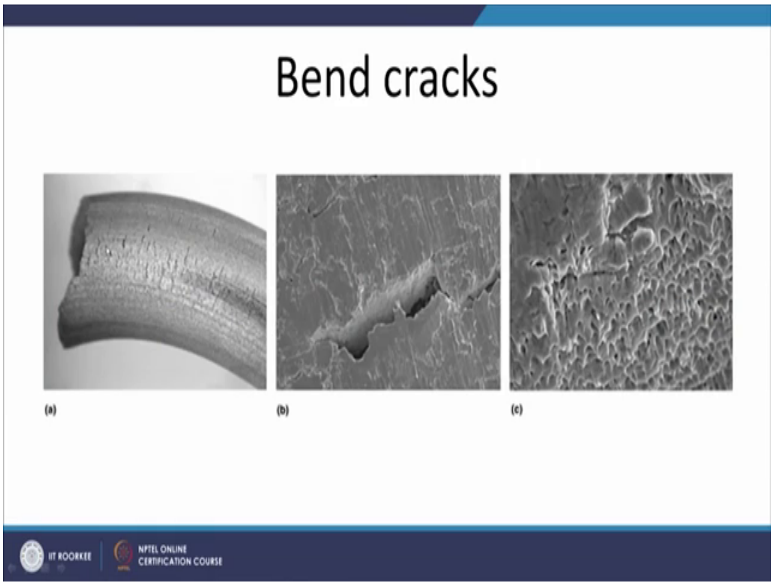

It will be showing lot of circumferential cracks and this is one of the higher magnification micrograph of the such kind of the crack and what it shows that all the dimples which are present on the fracture surface are oriented or oriented in one particular direction that is the direction of the bending will see the more aspects related with the microscopic features of the fracture surface in subsequent slides when we see that the fracture surface is having the rubbing features.

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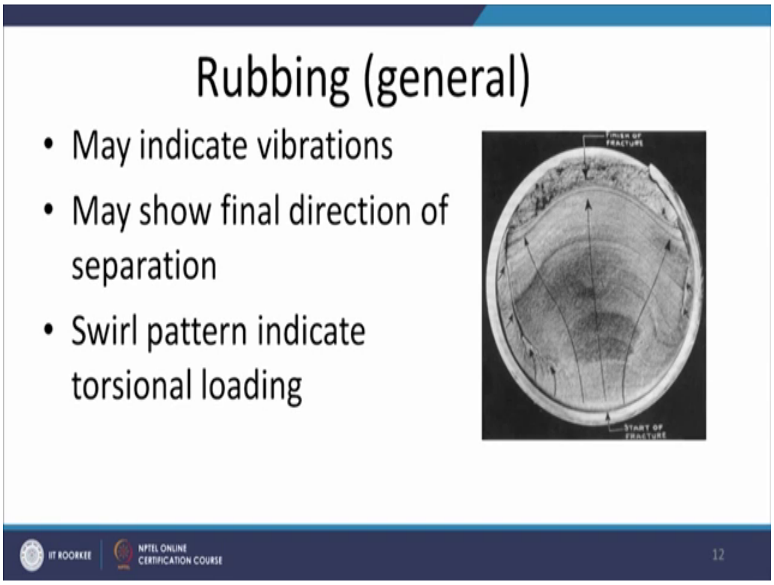

So, the rubbing features indicate that the possibility of vibrations is there or a rubbing sign also indicates the final direction of the separation and when the swirl pattern are present on the fracture surface in then it indicates the presence of the possibility of the torsional loading when the rubbing is localized then it may indicate the crack closer a location in case of the cyclic loading or the presence of the weak beach marks.

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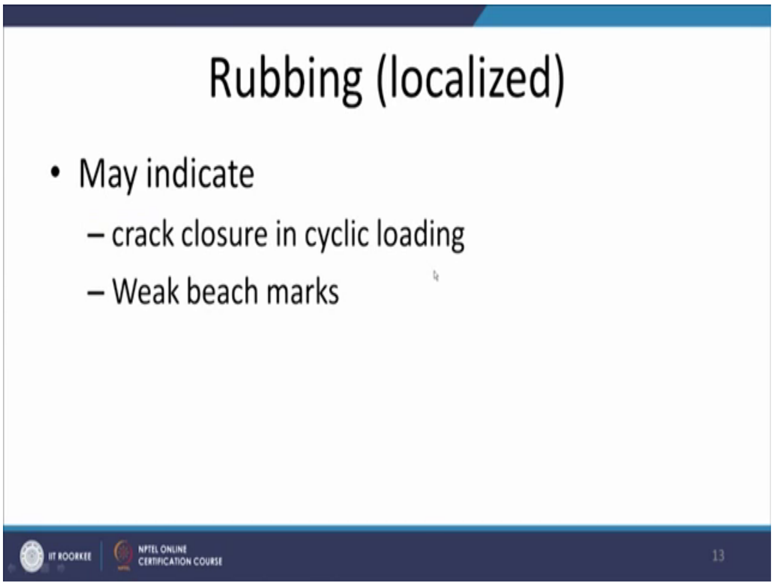

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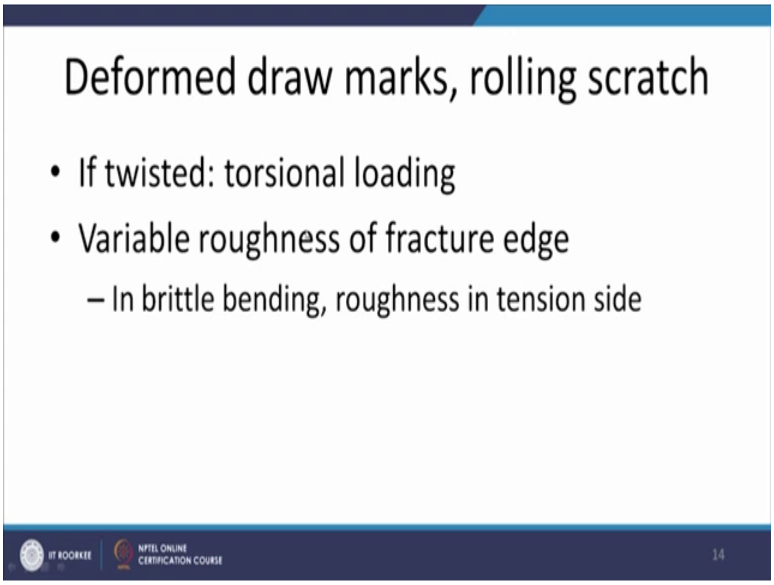

When the deformed component having certain kind of the features like the twisted marks then it indicates the torsional loading and when the surface roughness is varying near the fracture edge then it indicates that in brittle bending conditions roughness is more on the tension side as compared to the other side.

So, this is how now we will compete the macroscopic feature aspect related with the fracture surface and the kind of information which we can gather from the macroscopy of the fracture surface. So, in a now will summarize this presentation in this presentation I have talked about certain additional features are related with the macroscopy of the fracture surface which indicate about the loading conditions the direction where from crack has initiated in the direction in which crack has grown.

Thank you for your attention.