Failure Analysis & Prevention
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Lecture - 04
Fundamental Sources of Failures: Deficient Design II

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention and we are talking about the fundamental sources of the failure to understand, how to undertake the failure analysis if a failure has taken place. So, there are different directions in which investigations can be undertaken based on the initial the indications and the directions. So, we have talked about under the fundamental sources of the failure we are talking about the deficiency in design.

And due to that how the in one in or other different ways by which failure can take place.

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So, deficient design under this we have talked about the stress concentration which causes the localized increase in stress magnitude and that sometimes causes the premature failure of the component due to the high stresses through nucleation and growth of the cracks and this is especially important in case of the brittle materials because the brittle materials maintain the sharpness of the crack tip and so, the stress concentration is maintained or that remains high.

So, how to take care of the stress concentration related failures and what are the factors that affect the stress concentration due to the geometrical features, either, they are present intentionally or unintentionally. So, the factors that affect the geometrical features include the size.

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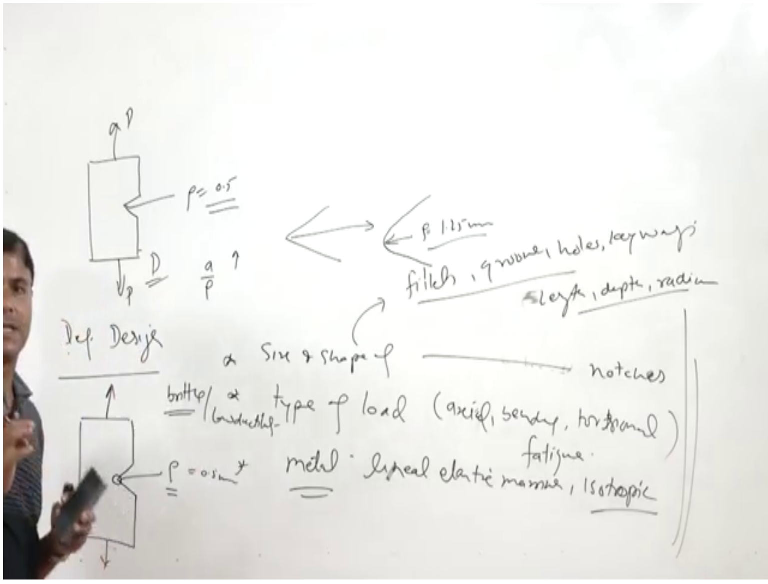

And the shape of the notches in the material, but not the size of the component and the material so, but not the size of component and its material this is the initial stage.

But if the material is brittle, then the stress concentration will remain high and if the material is ductile and due to the stress concentration high stress concentration initially whenever there is a blunting of the crack tip the stress concentration is reduced due to the increase in the crack tip radius. So, the size and the shape of the notches is one then the type of the loading whether it is axial or bending torsional loading or the fatigue loading is also there or the fatigue or the fluctuating load then there is another factor like this particular shape of the notches; so, like here all though we have talked about the size and shape of the notches.

So, in the shape whether it is in form of the fillets or it is in form of the groups holes groups holes keyways there are these can be in the different forms. So, depending upon their dimensions like the length depth and the radius at the corners of these geometrical features that will be affecting the stress concentration, then there is the metal aspect, it is assumed that the metal behaves in linear elastic manner and it is isotropic. So, these are the things if the material is like say if we take any case here this is the component having a notch and crack tip radius is say point five mm and subjected to the external load. So, whenever there is external load the stresses will be more localized near the tip of the notch or tip of the crack. So, since the radius of the crack tip directly affects the maximum magnitude of the stresses because here it was the length by root t or the that is the crack tip radius. So, if crack tip radius.

So, if finer is the radius greater with the stress concentration. So, if the material is brittle and of the low ductility then under the external stress condition external load conditions the crack tip does not blunt it remains sharp and so, a stress concentration remains high, but in case of the ductile systemsm if the same crack same geometrical feature is present in form of the notch having the radius rho point five under the external load conditions the crack tip for the ductile metals it will tend to get blunt.

So, blunting of the crack tip will a simply increase the nose radius of the crack tips. So, increase in radius of the crack tips like say from 0.5 to 1.25 mm, then it will lead to the reduction in the stress localization and the maximum stress at the at the tip of the crack will be reduced. So, it will reduce the tendency for nucleation and growth of crack and which eventually will reduce the failure tendency.

So, this apart from the size, say the mechanical properties of the material and the type of loading also affects the a stress concentration like say somehow some of the types of the loading.

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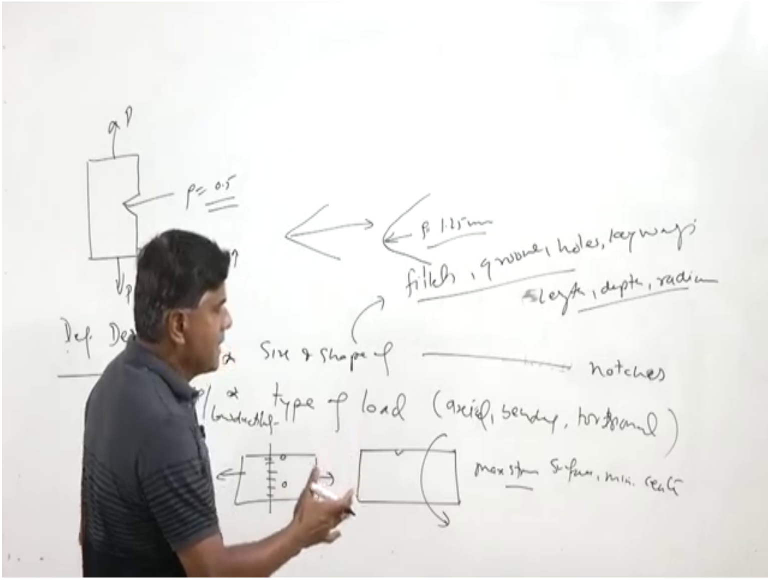

Wherein like in case of the torsional load the maximum stress occurs at the surface and minimum at the center. So, presence of the stress raisers at the surface are more dangerous on the other hand as compared to the case when we are having the axial loading. So, the stresses are uniform all across all across the cross section and in this case since the stresses are a uniform. So, whether it the cracks or the geometrical undesirable geometrical features are present or the notches are present inside or outside, they will not have that much adverse effect especially under the tensile load conditions axial which is of axial type means acting in longitudinal direction.

So, torsional stresses at the bending stresses are more harmful for the stress raisers. So, if they are present or means a stress raisers are more harmful for the tensile and the torsional and the bending stresses if they are present at the surface as compared to that at the center or as compared to the axial load conditions.

So, we need to be more careful with regard to the stress raisers especially in case when these stress raisers are present at the surface and the component is expected to work under the torsional and the bending conditions and similarly, if the component is to be made of the low ductility and the high hardness high strength material. So, high yield strength materials show limited tendency for plastic deformation and which in turn decreases the tendency for blunting of the crack tip and so, the crack tip remains sharp and which increases the stress concentration.

So, the factors like geometry of the a stress raiser the type of metal the type of loading these are some of the important aspects that must be logged into while taking decision about the presence of the stress raisers and how to take care of them, there are certain methods which have been proposed although this is not the exhaustive and complete list there can be so many ways also to reduce the stress effect of stress concentration.

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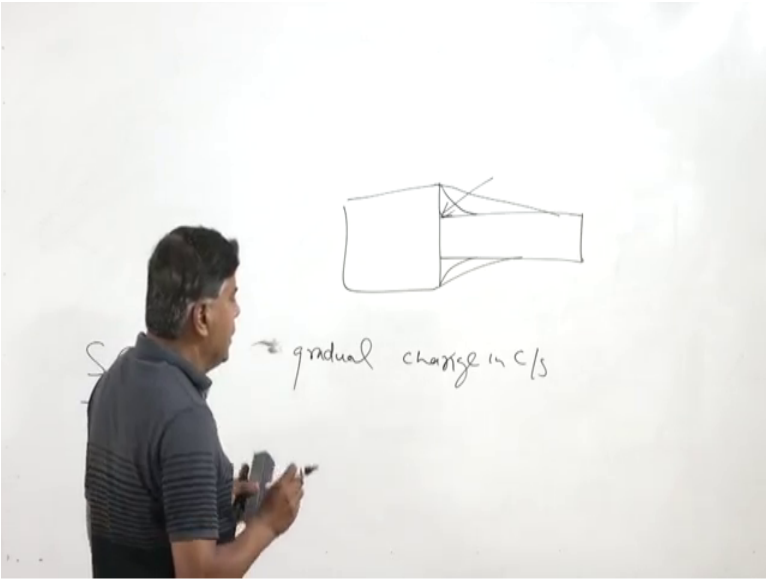

So, a stress concentration effect can be reduced through the use of through the gradual change in cross section we need to adopt all those methodologies which will help to have the gradual change in cross section like say a change in from large diameter to the smaller diameter in which way the change is been acting accumulated, either, we are giving the gradual tipper like this or we are giving a continuous curve or some fillet is given.

So, all these are the approaches. So, efforts are always made to have the change in to have very gradual change in cross section. So, that the effect of the stress concentration can be reduced either by giving suitable taper or by giving the fillet radius or by giving the continuous curve this will help to reduce the stress concentration.

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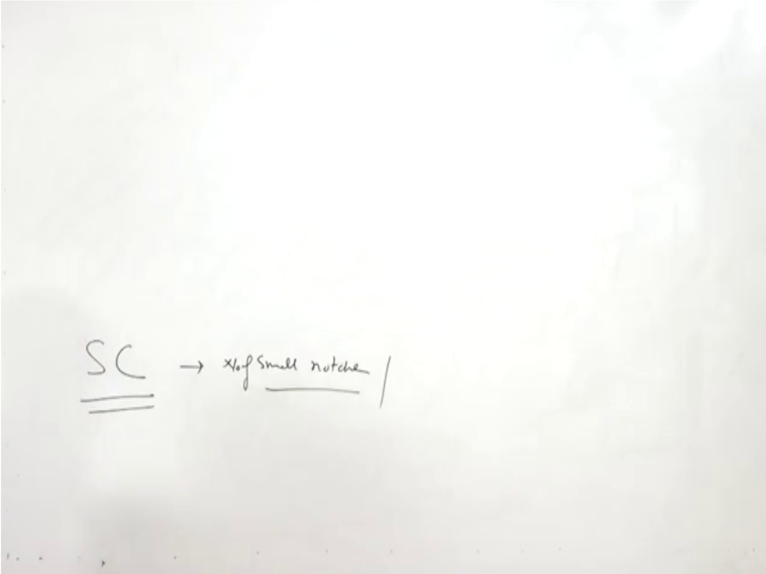

And it is always good to have the number of small notches or geometrical features as compared to the single and the big one which will be more dangerous more harmful for the components s better to have the more number of a small notches, if it is workable as compared to the case when we are using a single notch which is big and very wide.

So, third approach is use of the narrow notches rather than wide notches, if the projections need to be used and there is one more approach where the suitable stress relieving groups are made especially at the locations where the sharp change in cross section is taking place this is one there is one typical example like.

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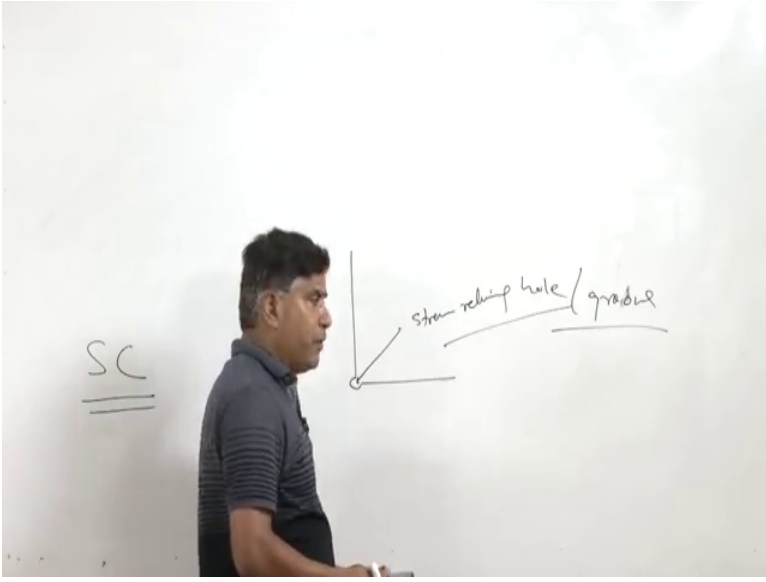

If this is the kind of junction where change in cross section is taking place then people drill a hole like this.

So, at the junction this is a at the junction the junction becomes curved and smooth. So, this is called s this a typical example of a stress relieving hole or the group a having the having the particular fillet or radius or a smoother surface to have more uniform and less localized flow of flow lines of the stresses. So, these are some of the things which can be done in order to reduce the effect of the stress concentration. So, that the component can perform for long even in the presence of the a special geometrical features now. So, if the failure has taken place due to the stress raises or due to the stress concentration then how to establish this.

So, to establish the to investigate the failures occurring due to the stress raisers or due to the stress concentration we need to understand the design criteria.

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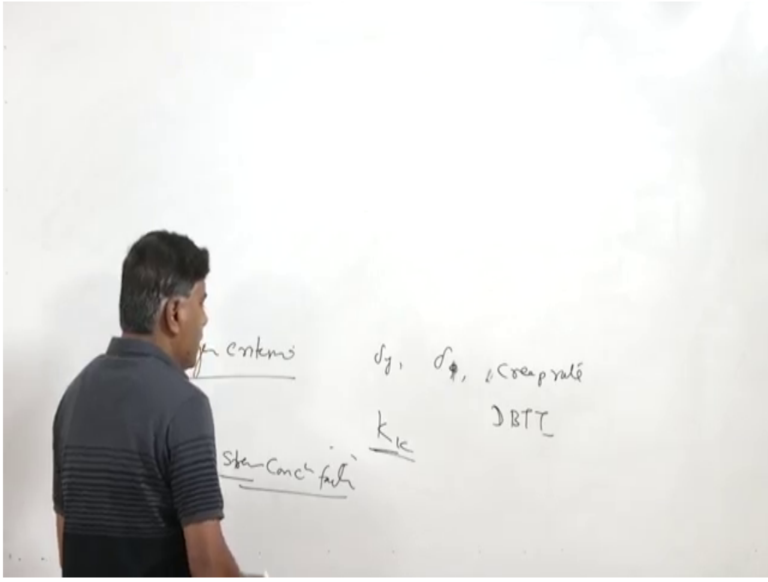

Need to understand the design criteria this is the first one whether the design was based on the yield strength or the fatigue strength or endurance limit or it was based on the some creep raped or it is based on the ductile to brittle transition temperature or it is based on the fracture toughness stress concentration critical stress concentration factor like k 1 c.

So, the suitable design criteria is to be identified to see what kind of the stress concentration factor has been considered in the design whether it was 1, 1.2, 1.5 so, that these geometrical features can be taken care of in order to understand in reality how the how the geographical features have been incorporated in the design.

So, design criteria we need to understand then size and shape of geometrical features and location where they are present. If the geometrical features are present within the in the inside at the lowest stress areas or non load carrying areas, then they may not be that harmful compared to the case when the geometrical features are present in the high stress areas they are more harmful.

So, they will have more tendency to cause the failure then the type of loading since that torsional and the bending for the torsional and bending kind of the loading the geometrical features are more harmful as compared to the surface geometrical features are more harmful as compared to the case as compared to the case, when the axial loading is applied or geometrical features are surface geometrical features are also harmful for the fatigue load conditions, then what are the mechanical properties of the material whose failure has taken place like.

If the motel ductility is too high and the hardness is low, then contribution of the stress raisers will be less as towards the failure as compared to the case when the ductility of the material of hardness is high toughness is also low. So, under those conditions geometrical features will have or stress raisers will have a more contribution towards the failure.

So, this needs to be investigated miss mechanical properties need to be investigated what type of the loading and which failure has taken place what are the geometrical size and shape of the geometrical features like the size of the crack or the filets or the radius, what has been used which kind of the stresses for which the component what are the kind of stresses for which component has been designed and then what are the metallurgical properties of the material.

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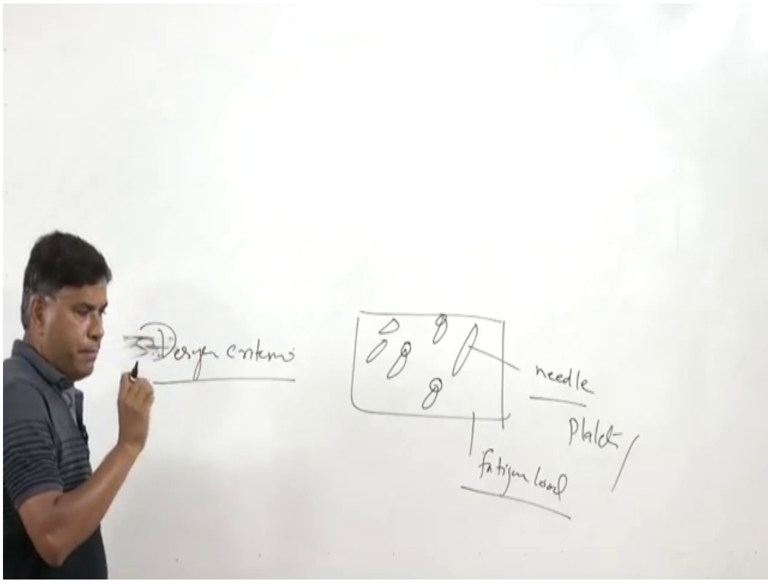

Say like say sometimes despite of everything being fine if the material metrological properties are unfavorable like the component, a is made of the material having large number of high aspect ratio micro constituents in form of a, like say in needles or the platelets or the then these will cause the higher stress concentration at the tip of the micro constraint in the matrix interface and which will easily nucleate the cracks especially under the fatigue load conditions.

So, the micro constitutes means morphology of the micro constituents also play a big role especially if they of they are of the high aspect ratio, then they will be nucleating the cracks and their facilitating their growth easily especially under the dynamic loading conditions and then stress analysis also, we need to carried out to see that in presence of the given stress raiser, what will be the maximum stresses would have generated and whether the failure of the material under those condition should have taken place or not.

So, for this proper f e analysis kind of thing can be carried out to see if the stress localization will be within the limits for the given component or not or the crack should have nucleated under those conditions in order to establish if the stress raisers really have contributed towards the failure sometimes, the fracture analysis approach is also used which is very simple one like if the material is of the high strength high hardness.

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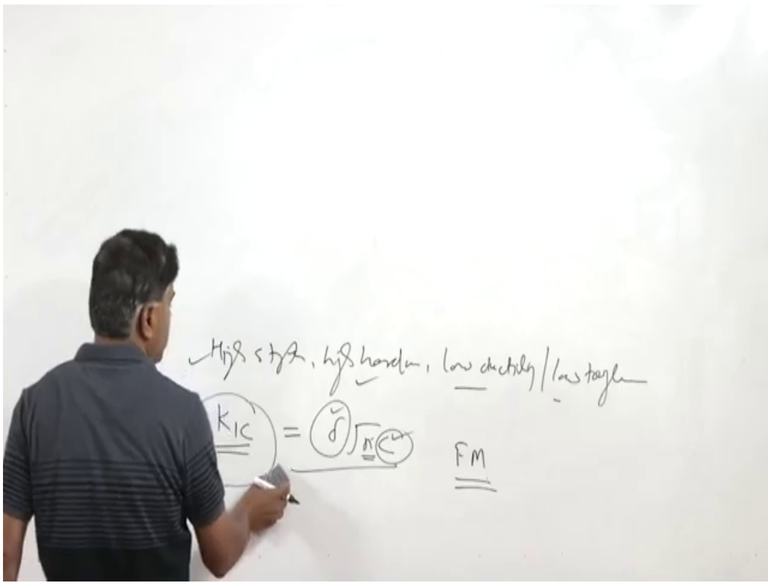

And a low ductility and low toughness if the material is of the high strength high hardness low ductility and low toughness, then it will also be important to consider the fractured mechanics approach which considers the fracture toughness of the material stress concentration factor or critical stress intensity factor of the material like k 1 c the fracture toughness of the material considering like sigma root pi c. So, sigma is the nominal stress c is the crack length and the pi is the constant.

So, this is the material property this is the applied strengths and this is the notch size or the crack size or the discontinuity size which is present in the material. So, under the given conditions if the if the failure should take place or not that can also be established through the fracture mechanics approach. So, basically these are the analysis part to see the role of the stress raiser like the notches cracks if they are present in the material. Now will take a few examples are related with the failure analysis for the special conditions like the.

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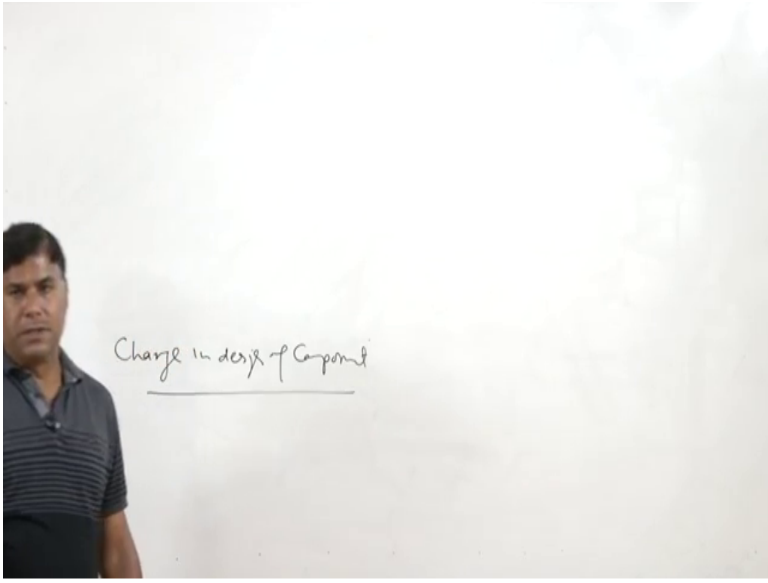

The change in design of the component without giving full consideration to the various possibilities which can happen like; so, this the this example basically is related with the spindle which was used in the military vehicle the geometry of the spindle we can see here.

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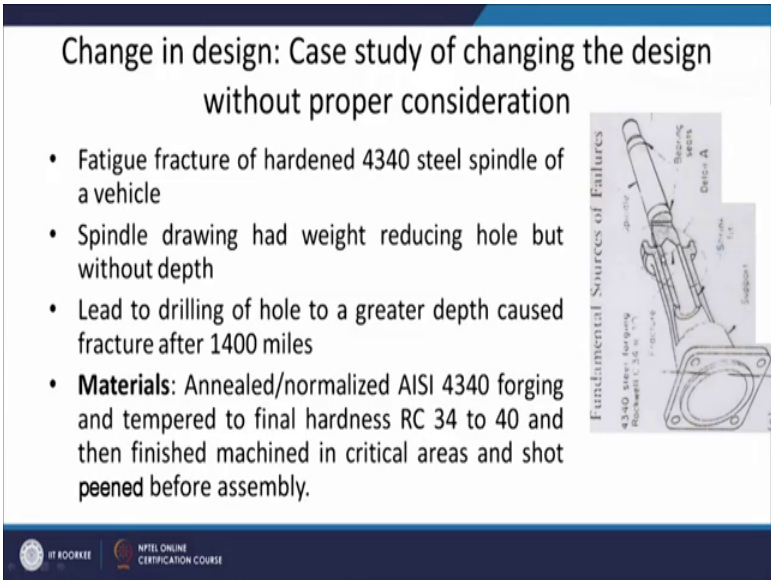

So, here actually this is a an spindle which was which is related with the military vehicle. So, here according to the drawings according to the design one hole was supposed to be drilled like this hole was supposed to be drilled for reducing the weight of the spindle, but they did not mention the depth of the hole because it did not play any big role except reducing the weight. So, as a result of this operators used to drill the whole of the different depths. So, in one of the case is what had happened in that the operators drilled two deep hole.

So, the hole the root of the hole raised in the high stress areas and once the hole reached in the high stress areas that nucleated the cracks and cause the fatigue fracture of the spindle this is the particular case study where the due to the change in design unintentionally by drilling a hole of greater depth it lead to the premature failure of the spindle during the service.

So, this the case study is related to the fatigue fracture of the hard and 4340 steel spindle of a vehicle the spindle drawing had a weight reducing hole, but unintentionally they left the dimension of the hole to be drill to be drilled because it was simply weight reducing hole and this situation led to the drilling of hole of the wearing dept in one of the cases the hole was drill to the greater depth and that cause the failure of the spindle after 1400 miles and to know about.

So, this is about the introduction of the item which has failed and when it had failed the spindle was made of the annealed and un yield normalized AISI 4340 forging and forced and tempered to the final hardness of the RC that is the Rockville C scale hardness 34 to 40 units there after finish machined in critical areas and short peened before assembly in order to relieve the residual stresses are to remove any the feed marks and induce the residual compressive stresses.

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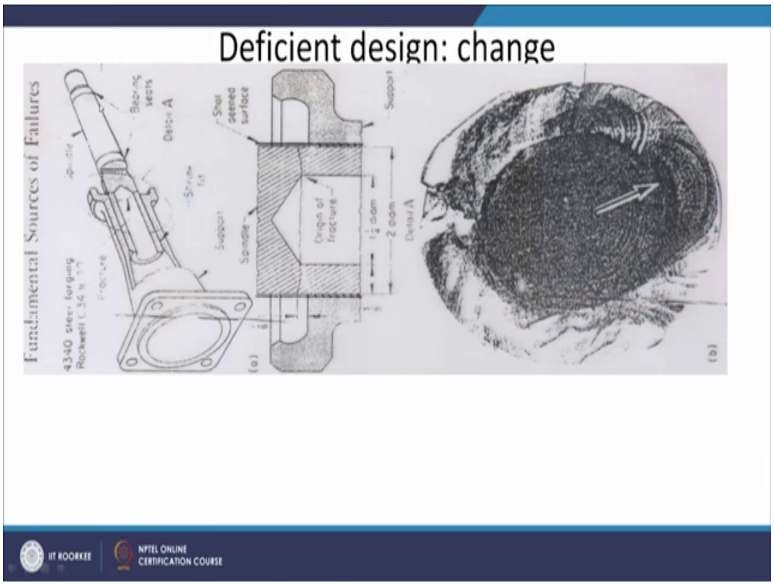

So, this was the complete the case where there was a spindle and the this location geometry where the change in cross section was taking place this is the bearing support area and the enlarged view of this root of the hole can be seen here this is the location where change in cross section was taking place. So, the hole was drilled too deep and it reach to the high stress areas where change in cross section was taking place. So, this led to the nucleation of the crack at the periphery of the this hole at the root. So, and this led to the growth of nucleation and growth of the crack all around the periphery and cause the fatigue fracture.

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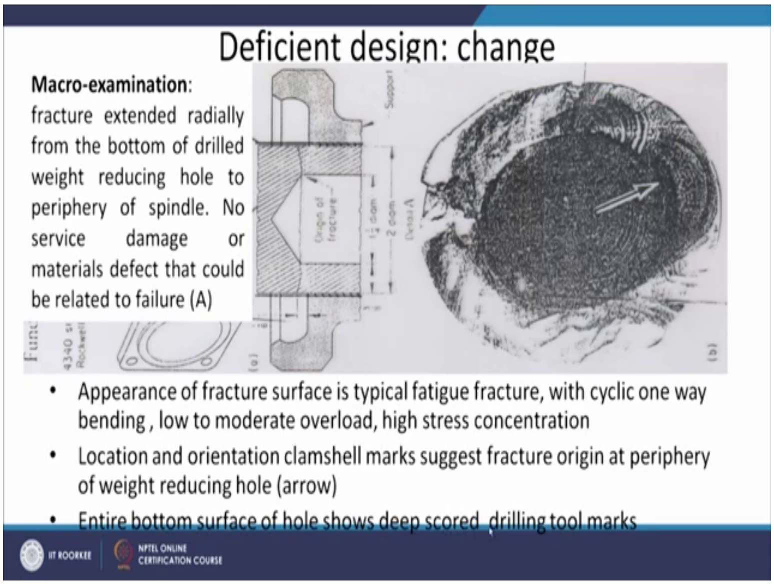

So, if we see the macro examination of the field component showed that fracture extended radially from the bottom of the drilled weight holed from the bottom of the hole a drilled for weight reducing to the periphery of the spindle.

So, bottom of the hole is this that is what we can see all around the periphery and it grown outward direction all around the periphery and the no service no service damage or the material defect was observed in this from the figure itself can be seen everywhere there is a metallurgical failure and there is no presence of the defect in any of the region of the failed component. So, there is no service damage or the material defect which is the apparent at the fractured surface.

So, appearance of the fracture surface is typical fatigue which we can see here like we can see the concentric marks at this location also this concentric marks at the arrow location suggests the fatigue typical fatigue fracture with cyclic one way of the bending because it was it has grown in one direction there after this is the final stage fracture zone. So, initially the crack grows in one direction and when the stresses become too high then the sudden fracture takes place due to the overloading.

So, load to the moderate a load to the moderate overloading and the high stress concentration things can be seen here location and orientation of the clam shell marks suggest that fracture origin at the periphery of the weight reducing hole. So, this is the origin where from it initiated, then it had grown in this direction and thereafter southern fracture in other areas had taken place due to the overload entire bottom surface of the hole shows the deep scoring drilling marks. So, the deep scoring drilling marks can be seen here this is not the fracture location fracture took place the metallurgical fracture took place in all around this area only and, but these are the feed marks which are present at the bottom of the hole.

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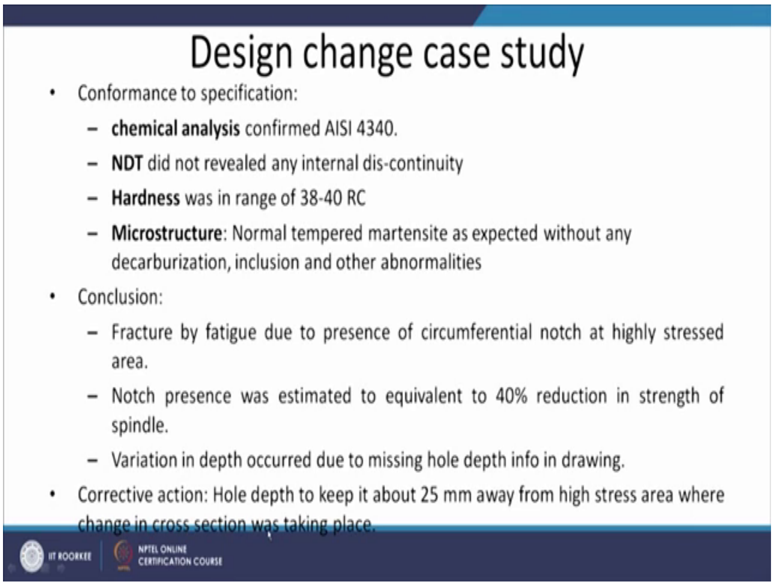

So, in order these this is about the macro examination the macro examination suggesting the beach marks and the fracture due to the overload and the beach marks or clam shell marks initiated from the root of the hole where there were feed marks conformance to the specification means we need to confirm really the material of the spindle was same as recommended or not whether properties, it had our acceptable or not whether the microstructure was proper or not.

So, it is also required it was also required to carry out the chemical analysis and chemical analysis suggested that are confirmed that material was made of the a I s I 4340 and it did not reveal any internal discontinuity and hardness was found in the range of 38 to 40 RC as per the specification and the microstructure also did not reveal any deficiencies or discontinuous in form of decarburization inclusions or other abnormalities.

So, it was a concluded that fatigue occur the fracture occurred by the fatigue due to the presence of circumferential notch at the high stress areas which happened; obviously, due to the drilling of the hole to the greater depth and notch presence was estimated at equivalent to the 40 percent reduction in the strength of the spindle means at the junction there was a notch of the weight reducing hole which reduced the strength to the tune of the 40 percent and variation in depth occur due to the missing hole depth information in the drawing.

So, it was the mentioned the depth of the hole was mentioned in order to avoid such kind of failures in future. So, this was correct action which was recommended as a result of this failure analysis of the spindle the hole depth to keep hole depth should be kept about 25 m m away from the high stress areas where change in cross section was taking place. So, this in this is study what was found that the stress concentration was found too high at the bottom of the hole where few feed marks were also present in due to the drilling and they reduce the strength or load carrying capacity of the spindle and which caused the failure of the spindle by the fatigue.

So, the recommendation was that hole depth should be kept hole root of the hole or bottom of the whole should be kept away about 25 mm away from the location where the change in cross section was taking place or what is the area of the high stress concentration.

Now I will conclude this presentation in this presentation I have talked about the factors that affect the stress concentration and what can be done in order to reduce the stress concentration and one case study related with the unintentional change in the design of the component led to the development of the high stresses and so, the failure of the component or that is the spindle took place from the location where stress concentration was high very prematurely.

Thank you for your attention.