Failure Analysis & Prevention

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Lecture - 05

Fundamental Sources of Failures: Deficient Design III and Upgrading of a part

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, under the failure analysis and prevention subject. We have talked about the two aspects related with the deficient design, and these were there in form of the presence of the stress raisers.

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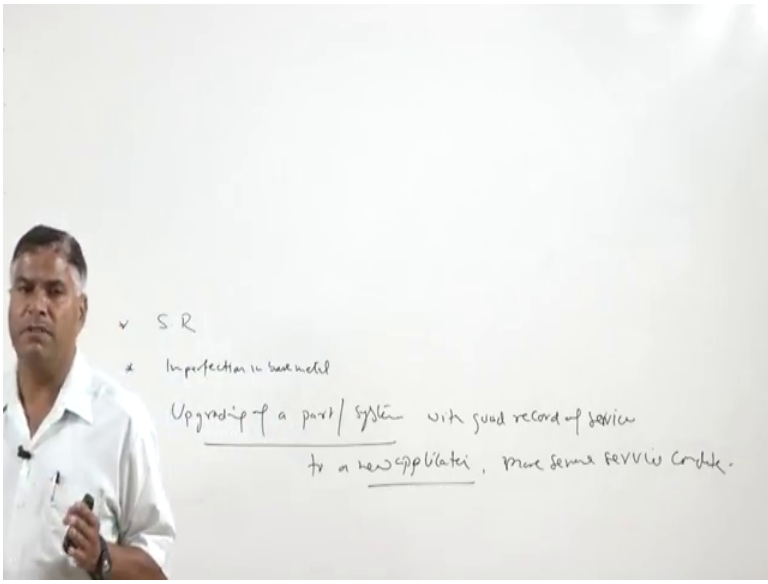

And the second one, about which we have talked, was about the imperfections in base metal.

We will be talking about the few other aspects related with the deficient design. And these may be in form of upgrading of a part or system; which had a very successful record of the performance to the some more severe conditions for different application. So, upgrading of a part with good record of service to a new application; this is one thing or to the more severe service conditions.

So, sometimes we are encouraged so much with the very good performance of some of the systems or the mechanical components that they are also recommended for the different application for the different service conditions. So, which sometimes leads to the premature failure of the component and the reason for this kind of the failure becomes it may be in the variety of forms.

For that we can see that the deficiency it is in design of a component can be in various forms like presence of a stress raisers changing design without proper consideration, duplicating a success full design for more severe loading conditions. About this aspect we are going to talk. There is another aspect related with the deficient design about which we will be talking in this presentation is, designed developed without full knowledge of the stress conditions due to inability to calculate the stress is properly, or due to the complexity of the geometry of the component which is to be designed, or inability to use the proper criteria for the designing.

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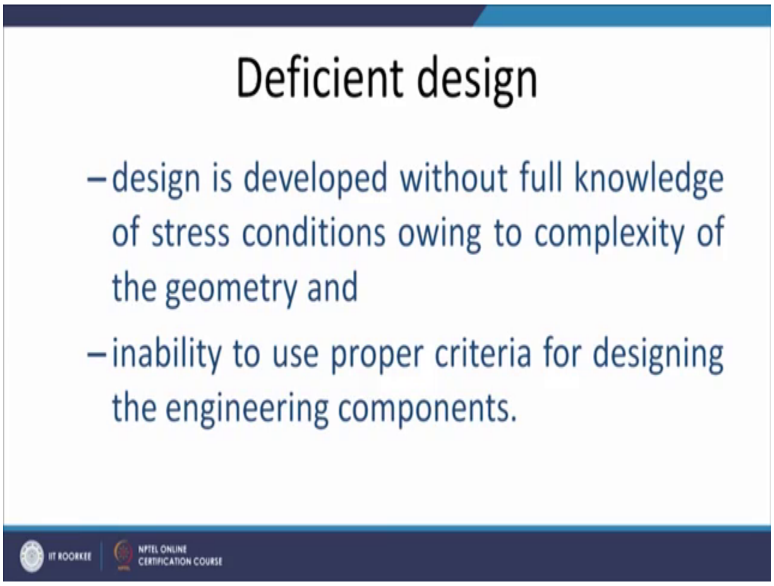

So, under the first one where we have to consider upgrading of a part to the more severe conditions. This can lead to the failure of the component due to arrange of the conditions. One is like the metal is unsuitable for a given application.

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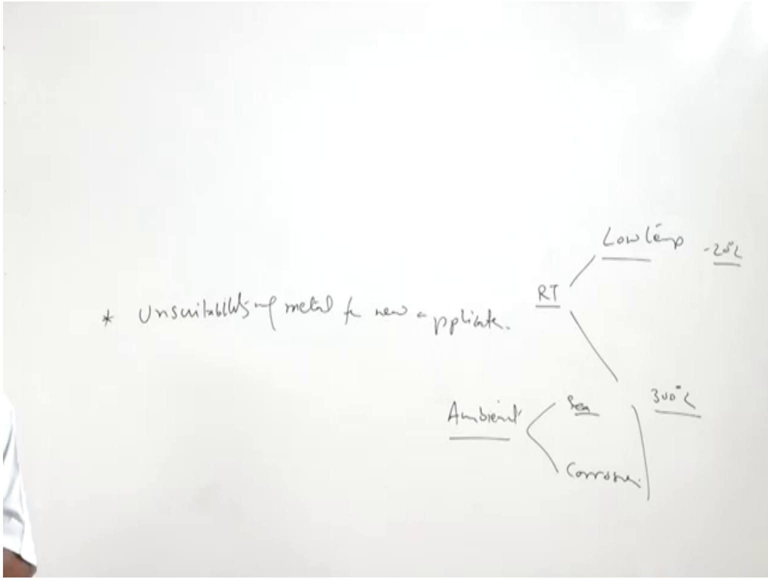

Unsuitability of metal for new application; So, this is one this way unsuitability maybe in form of more severe wear conditions or more severe temperature conditions; like, something had a good record for the room temperature conditions. If the same is used either for low temperature conditions like, minus 20 degree centigrade or high temperature conditions like 300 degree centigrade.

So, the performance of the component may not be the same. Similarly, something had very good record for performance under the normal ambient conditions. Normal ambient conditions, but if the same is placed under the conditions like seawater conditions; where both corrosion and erosion is severe or some petrochemical industry or some like in chemical industry, where the corrosion is dominating.

So, the performance may be very adversely affected. Because the material which had very good record of the performance under the normal ambient condition may not be able to perform in the same way, under the different service conditions, for which it has not been it does not have the required characteristic. So, it is a so, it is not necessary that a product which is having a very good record of the performance, we will also form we will also be showing the similar kind of performance for the newer applications.

So, this is what we can see here unsuitable metal of the component for the new applications may be in form of high or low temperature kind of or we are corrosion or the mechanical performance.

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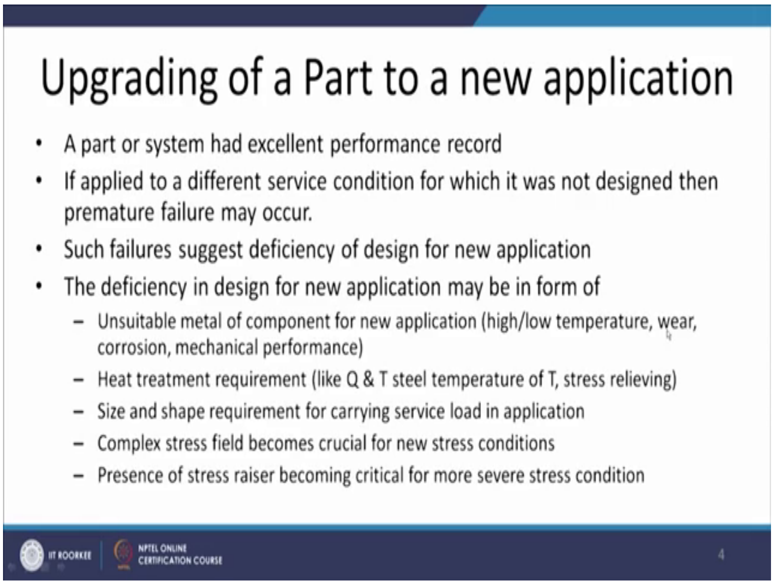

Like, for one application where the toughness may not be important, at room temperature, but the toughness becomes crucial at the low temperature conditions is the same is to be used.

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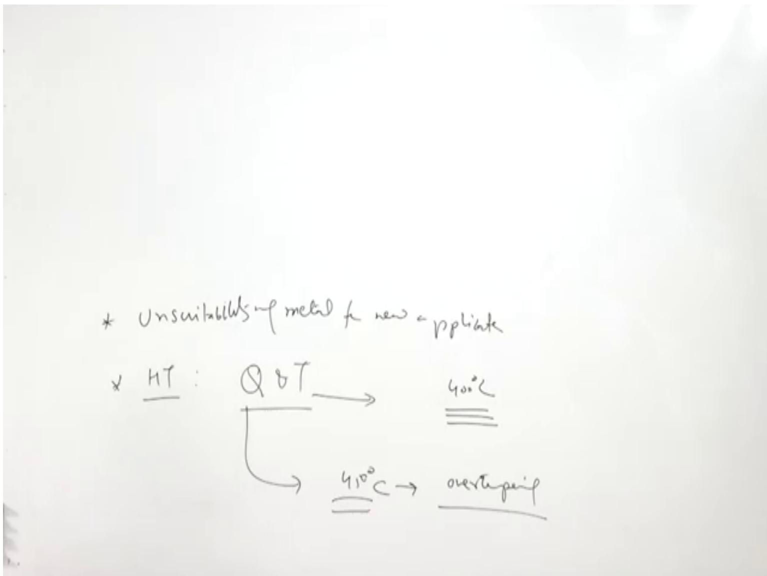

Now coming to another point like the heat treatment requirements; especially this is true for the steels which are subjected to the heat treatment like the quenching and tempering. So, quenching is done primarily for the hardening purpose and tempering is done to induce the required toughness. So, the combination of the strength and toughness can be realized, and this will be this properties will be corresponding to the particular temperature of the tempering.

So, say steel is tempered at 400 degree centigrade. And the steel which had which was quencher quenched and tempered at 400 degree centigrade had very good performance record. But if the same component is to be used under the temperature conditions of the 450 degree centigrade during the service, then it will be during the service itself will be it will be over tempered.

And that will be leading to the degradation in properties of the steel softening of this steel and which may get rid the mechanical performance. And so, premature failure of the component can take place. So, this is one typical example where the improper heat treatment of the component, the composition may be suitable, but the if the heat treatment is inappropriate for newer application, then it also can lead to the a failure. similarly are the stress relieving if in one situation is stress relieving may not be crucial.

But for new application if the stress concentration, if the loading conditions are more severe; than inappropriate stress relieving can also lead to the premature failure of the component. Then there maybe size and shape requirements.

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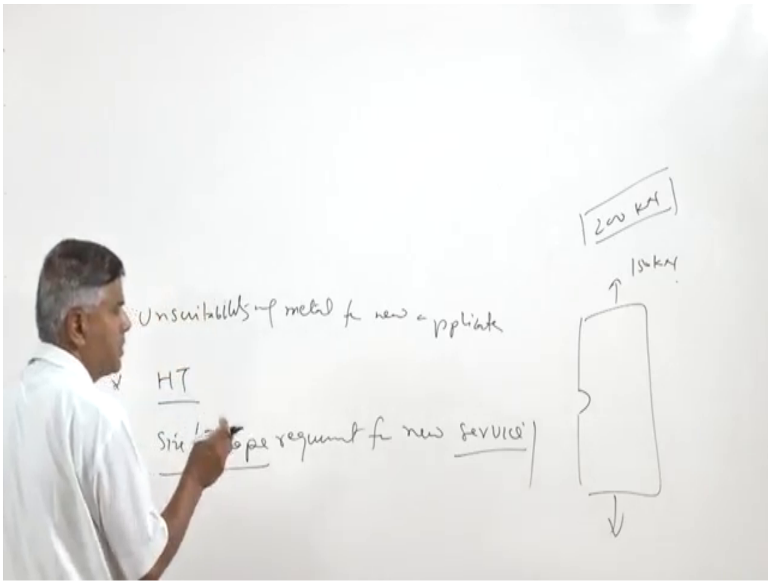

Size and shape requirement for the new service conditions are for new application. Like, if earlier it was being used for carrying the load of the 150-kilo Newton, but in the new service if it is to be subjected to the 200-kilo Newton, then it will be experiencing the more severe stress conditions. So, the no change out the geometrical features which were present in the component; might not have been that up crucial, but under the sea more severe stress conditions these no change and the stress raisers may become very crucial.

So, the similar so, in that in that case, the no chase and the geometrical features may required the different kind of the geometries and the locations; in order to avoid their adverse effect on the performance. So, the size and shape requirements may be different for the newer service conditions. And if without doing that without changing the size and shape for newer service where loading conditions are different, then also it can lead to the premature failure of the component. Similarly, then we have the complex stress field become crucial for the newer stress concentration. sometimes like if the component was being subjected to the tensile stresses. And in the newer application, it finds that it is being subjected to the torsional stresses.

So, tensile stresses are uniformly distributed across the cross section ah, but in case of the torsional loading conditions the maximum stresses are found at the surface. So, the discontinuity is which are present at the surface may be more crucial for the torsional loading, and for the bending conditions as compared to the case when it is a simple stresses magnitude is uniform across the section. So, here while in case of the torsion, the stresses, and in the core or near the center is 0, or it is very less as compared to the case, when tensile stresses, in case of tensile stresses they are uniform across the section.

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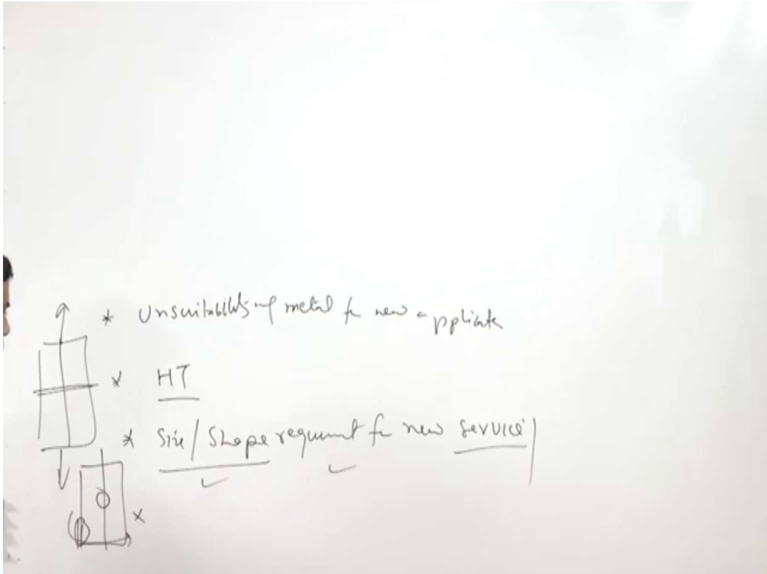

So, depending upon the type of stresses severity of the stresses or complexity of stresses, that different sizes and shapes may a play a crucial role. So, the complex stress conditions for the newer application may also lead to the failure.

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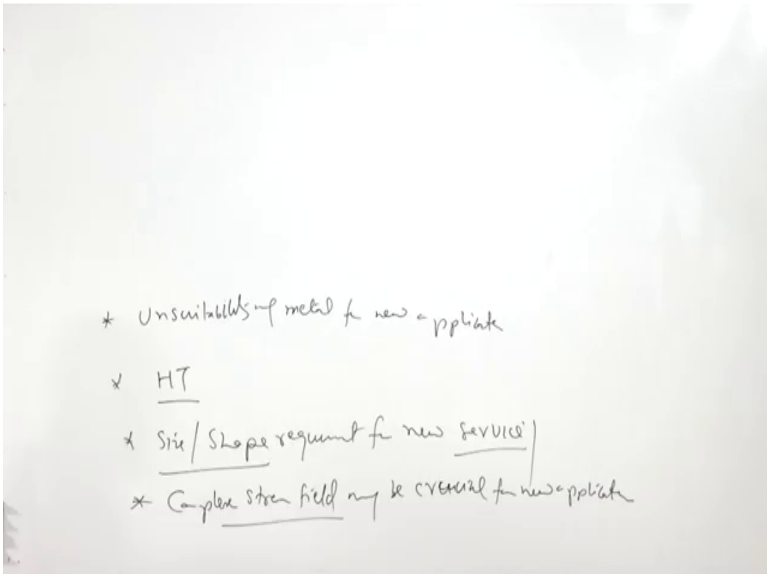

So, the point is about complex stress field may be crucial for the new application, for new application. Then there is another point like the presence of stress raisers which were not that important, but these may be very crucial under the newer conditions because of the complex stress field or the more sever loading conditions. So, they need to be considered differently. Say for example, if there was a notcher with the radius of like say 0.5 mm.

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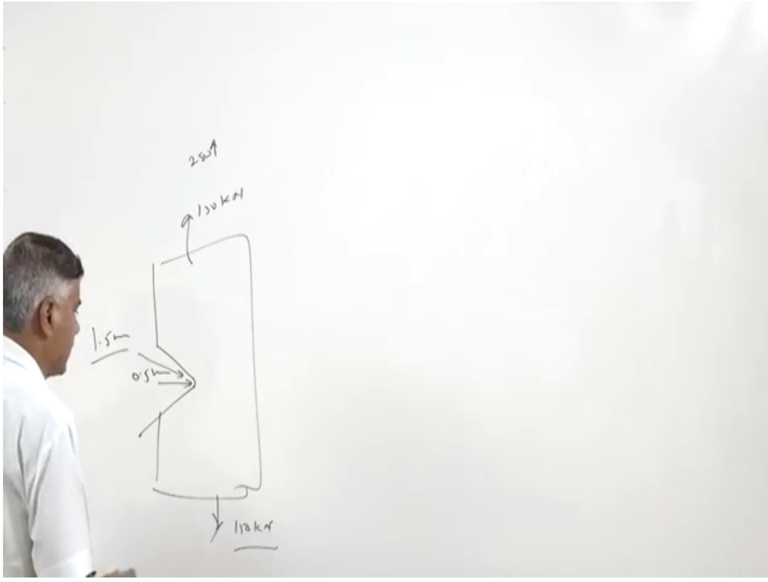

So, this will be causing the more severe stress conditions as compared to the case, when it had like say 1.5. So, under the low load conditions like 150-kilo Newton, it may be ok; But if the load magnitude is increased to the 250-kilo Newton then these stress raisers may become more crucial and that case it may require the different, radius at the cractive for avoiding the necessity too high stress concentration; so that the premature failure of the component can be avoided.

So, presence of stress raisers can be critical, for more sever conditions as compared to the earlier service conditions. Now in light of these points will be taking of one case is study where the engineers encouraged with the very long and successful performance of the spring inner cap for the automobile; which we can see here in this diagram.

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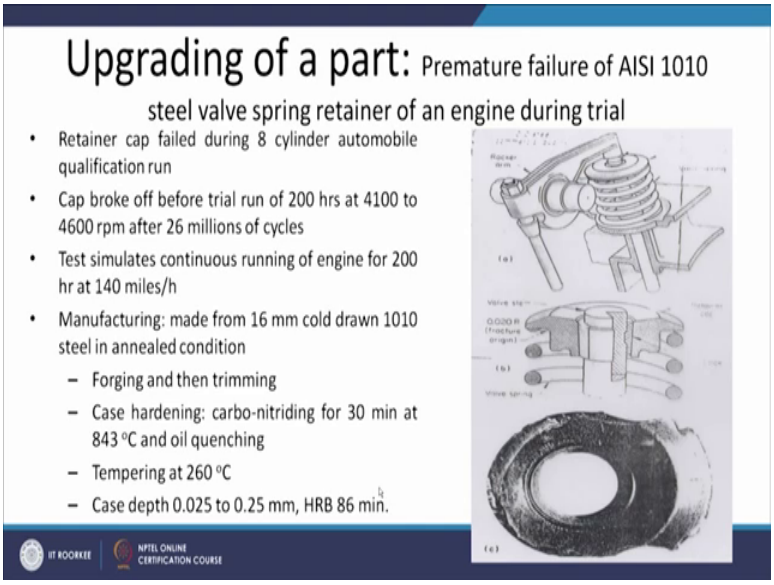

What this diagram shows? This is the spring which is used in case of opening and closing of the walls in IC engines. And this is spring is retained with the help of this cap. So, this is the stress string retainer cap and this cap with the cross section of this cap can be seen how this is the upper portion and these are the different levels in the cap which are used to accommodate this springs.

So, spring remains under the spring will keep on. The retainer will always be under the loading due to the spring. And in this case, we can see there are some junctions, warren cross sections and at the cross sections some the fillets are there. So, these fillets will be used for having the gradual change in the loading and gradual change in the stress distribution. So, ah, but in this particular case, the retainer cap for the retainer cap was which was which had a very good record of the performance.

Retainer cap which had a very good record of the performance for the low capacity engine like say 4-cylinder engine, but when it was a used with a 8-cylinder automobile, during the qualification run itself the retainer cap failed. So, retainer cap failed during the field trails or the qualification run often a 8-cylinder automobile, and the cap broke before trail run of 1200 or 200 hours at 4000 rpm to the 4600 rpm after 26 million cycles. So, this test simulates continues running of the engine for 200 hours at one 40 miles per hour.

And so, these were the service conditions this the retainer cap field, and the cap was made of the made from the 16 mm cold drawn 101, this is the plain carbon steel having the 0.1 percent. Carbon was made of the 101-carbon steel, this is AIS designation of the steel, and it was in an yield condition. So, the processes watch which were used for making the retainer cap over the forging and then trimming followed by case hardening using the carbo nitriding for 30 minutes at 843 and the oil quenching for the hardening purpose. And in order to induce the desired toughness and to avoid unnecessary development of the residual stresses tampering was done at 260 degree centigrade.

So, are through this case hardening heat treatment the case depth was a it was desired to harden the case up to the depth of 0.0 up to the depth of in a range of 0.05 to 0.25 mm so, as to achieve the hardness of 86 HRB. So, the macro is copy of the broken cap showed that showed that the fracture actually originated from the section where, changing cross section was taking place.

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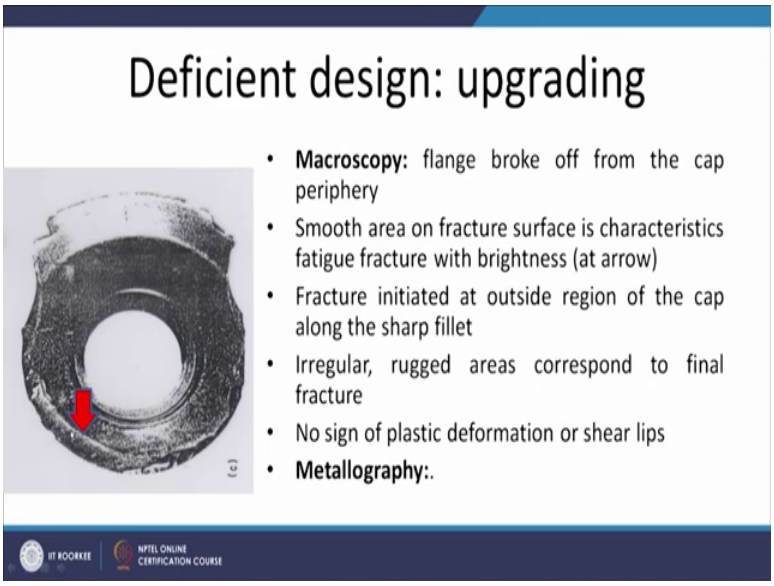

And which we can see here, this is the periphery along which the cross section, change in cross section was taken taking place. And this and this arrowed zone showed arrowed, this arrow shows the location where from it was triggered, a smooth region at in this area shows the nucleation of the crack by the fatigue. And there after it has grown in this direction. And then sudden fracture zone is rugged rough and irregular. So, all this area is corresponding to the sudden fracture zone, and a smooth zone shows the location where the crack propagated in fatigue manner.

So, a smooth area on fracture surface is characteristic of the fatigue fracture with the brightness at the arrow zone shows the location where from crack initiated regular rugged areas correspond to correspond to the final fracture. And there was no sign of the plastic deformation; which suggests that material had a good in strength, but the crack nucleated in the high stress areas, and then it grown under it grew under the influence of the fatigue loading, and then it failed catastrophically. Metallography also suggested the normal the ferritic and paralytic structure with the dominance of the ferrite. So, the microscopy also did not show any issue related with the microstructure.

So, to confirm whether the cap had required properties or not, chemical analysis was performed. And chemical analysis of the cap showed that it is the composition of the cap is corresponding to the AISI 101 with the percentage of the carbon 0.11.

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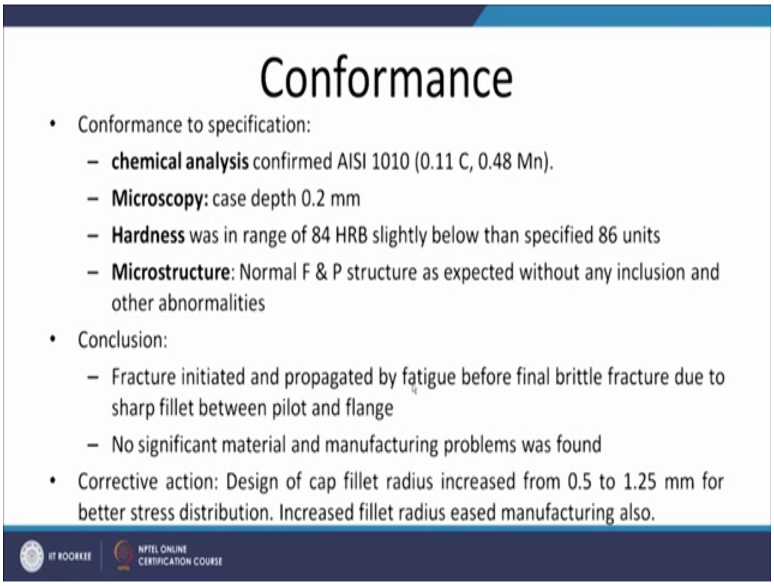

And the manganese percentage 0.48, and the microscopy of the case-hardened depth showed that it was have 0.2 mm, and the mic and the hardness was found in the range of 84, which is slightly below than the specified value of the 86 HRB. And the microstructure because the; because it was of the low carbon steel. So, it had a normal paralytic structure as expected without any inclusion and the other abnormalities. So, this analysis showed that the fracture initiated and propagated by the fatigue. And before final fracture, the crack growled at the crack grew at the junction where cross change in cross section was taking place.

So, the crack nucleated at the fillet between the pilot and the flange and now significant material and manufacturing problem was found. So, in order to overcome this issue because the location suggested; that the crack nucleated and it grew from the fillet zone. So, obviously, it was indicating that high stress concentration due to the some (Refer Time: 18:59) fillet led to the nuclear nucleation and growth of the crack under the fatigue conditions easily.

And that is why design of the cap fillet radius was increased from 0.5 to 1.5 mm. For better stress distribution, which in turn increases the fillet and this increased fillet radius also helped in the manufacturing. Because it is more difficult to read to realize or to achieve the find radius as compared to the bigger radius. And this correction led to the successful performance of the retainer cap subsequently. Now we will be talking about the other aspects related with the deficiency in design.

So, this one about which we have talked like upgrading of part upgrading of parts of a part to new application for which, in this particular case in appropriate fillet radius led to the failure.

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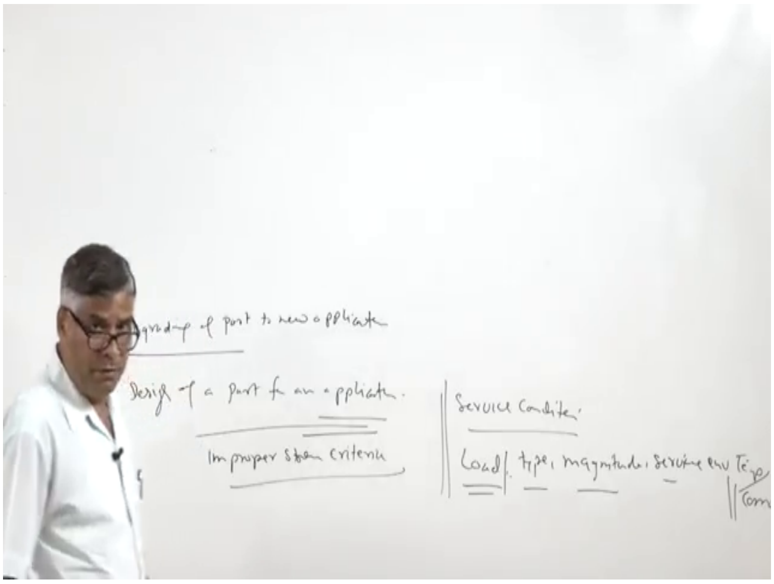

There can be number of reasons for the failure when a part is upgraded to the new application because the part is not designed for that application. Now the second aspect is that the design criteria, you see whenever the opponent is designed, the design of a part or component for an application. So, whenever the design is made what we consider we consider the service conditions, which for the mechanical design are primarily in terms of the load. Like that type of the load magnitude of the load and service environment like in form of the temperature or corrosion.

So, all these need to be considered when we are talking about the a design to be developed for a given applications, but many times due to the improper calculation of the improper stresses for the design purpose, means the if the design is based on the if the design is based on the improper stress criteria. Then it can lead to the failure and we now we try to find out the service conditions effectively.

So, that we are aware of the type of the load the type load in terms of the type of load magnitude and the service conditions. But sometimes we find it really difficult to have the kind of a stresses which are to be used properly. And this is can arise due to the two types of situations; in that improper is stresses are being used for the design purpose, this can arise from the two causes. One is incorrect estimation of the load.

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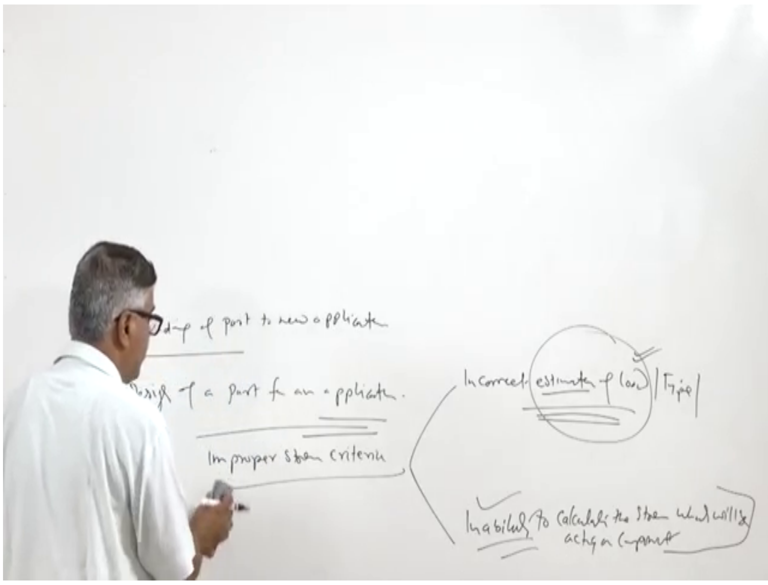

So, basically component parts machine systems we used as an earth moving must seems or that excavate or, the mining equipments which are which can be subject to the varying load conditions. So, in those conditions becomes really very difficult to correctly estimate the kind of load which will be acting during the service. So, incorrect estimation of the load during the service, and it is that type and magnitude. All these can be leading to the improper stress criteria or the improper stresses during used for the design purpose. And sometimes it becomes difficult to calculate inability to calculate the stresses which will be acting on the component.

So, sometimes the geometries of few components are so complex, that they make it difficult to properly determine the, calculate the kind of a stresses, which will be acting on to the component. So, improper estimation of the load and inability to calculate the stresses accurately for a given service conditions due the complexity of the geometry of the component.

So, these are these two situations will be leading to the use of improper a stress. And if the design is based on the incorrect stresses, then of course, it will provide the easy source for the failure of the component. Because the section size and the shape of the component all those will not be proper. So, under a continuing with this one, if we really do not know what kind of the service conditions are there we are not able to estimate the load properly, and we are not able to calculate the stresses properly, then this can lead to the improper design of the component. So, apart from the improper design of the component, there can be another issue like, whatever the metal is being selected, metal selection for a given application.

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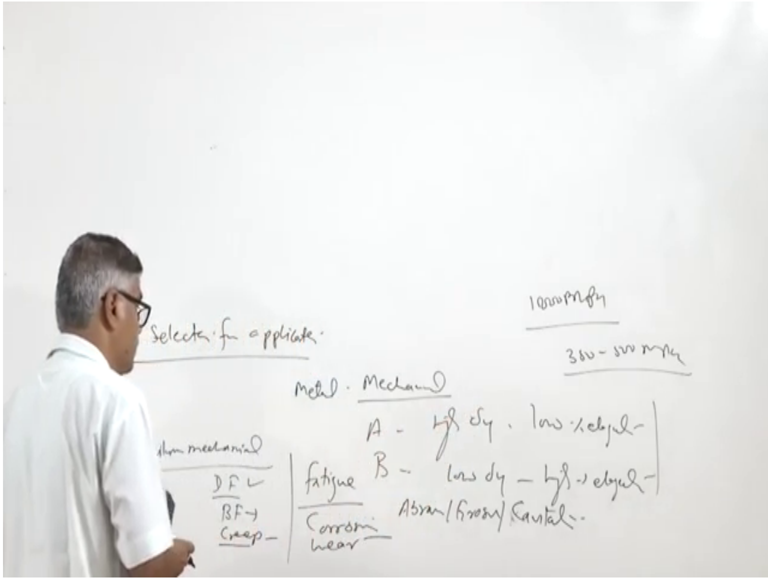

So, in on what basis the material should be selected? For the given application we know that, each metal will have certain mechanical physical properties. Like say, the metal A maybe of the high sigma y value and the low percentage elongation. And the metal B maybe a very low sigma y value, but the high percentage elongation.

So, and likewise there can be very wide ranges. Like, the titanium alloys may have the strength of 1800 ampere; on the other hand, our simple mild steel may have like say 350 to 500 ampere. So, there can be lot of variation in terms of the extent that they offer in terms of the toughness and ductility that they offer. So, what we should consider for the designs purpose? On what bases are given material should be selected? And for that purpose, basically, we need to consider the expected failure mechanism. You know the, whatever component will be made that will put into the use.

So, during the application according to the service conditions, we need to estimate we need to predict we need to identify in which way the component can fail. The failure of components say can occur due to the ductile fracture brittle fracture ductile fracture, where lot of elongation and deformation will be taking place brittle fracture where without any change in cross section or change in the size, and shape of the components suddenly the fracture will be taking place, or the component will be subjected to the high temperature.

So, the change in dimensions will be taking place due to the creep or the component will subject to the fluctuating loads. So, here it will subjected to the fatigue or the component will be put into subject the use this component will subjected to the corrosion. So, likewise there can be different situations, there can be v r variety of firms like abrasion, erosion, capitation etcetera. So, there can be variety of ways by which the failure of metal can take place during the service.

So, that failure mechanism expected failure mechanism is to be identified. And accordingly, we need to see how material should be selected in which kind of material should be selected for successful performance in a given application. Design and design actually helps to find out the suitable size and shape, but what parameters to be used for determining that size, and shape that will depend upon the expected failure or expected failure mechanism, whether it will fail by tile brittle creep ductile brittle fracture creep fracture creep fatigue corrosion or v r. So, coming to this one unlike if the component say if the component is expected to fail by the plastic deformation, at room temperature, then will be considering the yield strength.

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If the component is expected to fill the deformation, by at high temperature then we need to consider the creep rate or the creep behavior of the material.

Similarly, if the failure of the component is expected to cover expected to occur under the over load fracture fluctuating load facture or impact load conditions, then we have to consider the impact sorry ultimate strength or endurance limit or and endurance strength the impact strength of the material. So, these are so, as per the case we have to consider the suitable kind of the parameters which should be used for selection of the suitable material. Now coming to the few failure mechanisms and the parameters which is to be considered, for and these this table basically shows the parameters that needs to be that should be considered for a selection of the suitable material and suitable design.

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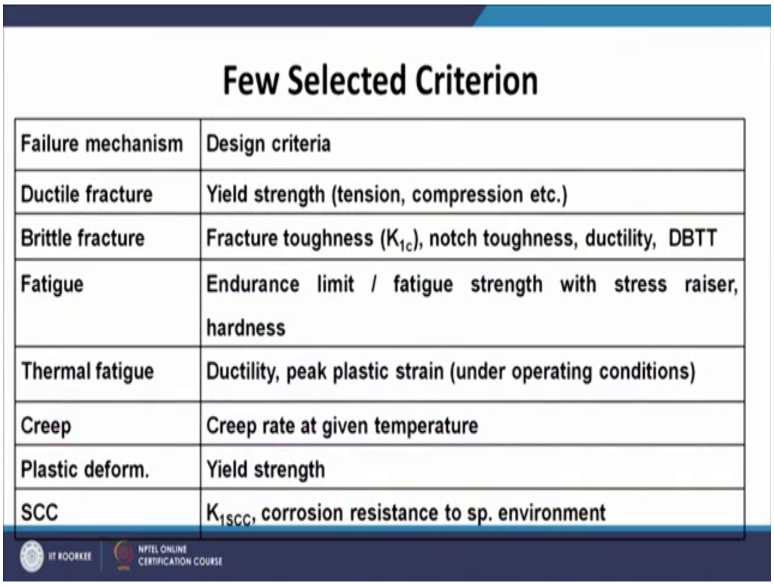

Few Selected Criterion

Failure mechanism	Design criteria
Ductile fracture	Yield strength (tension, compression etc.)
Brittle fracture	Fracture toughness (K_{1c}), notch toughness, ductility, DBTT
Fatigue	Endurance limit / fatigue strength with stress raiser, hardness
Thermal fatigue	Ductility, peak plastic strain (under operating conditions)
Creep	Creep rate at given temperature
Plastic deform.	Yield strength
SCC	K_{1SCC}, corrosion resistance to sp. environment

So, if the if the ductile fracture is taking place, if the if the estimated failure mechanism is the ductile fracture, and the yield strength as per the type of load it may be tension compression, then if the expected failure mechanism failure mechanism is the brittle fracture, then we need to consider the fracture toughness notch toughness ductility ductile to brittle transition temperature so, that the material can perform on it is design can be based on these parameters.

And so, that it can perform the intended function successfully in order to avoid any premature failure. So, if the failure has taken place then we need to see what kind of force what would have been the mechanism of the failure and whether the material had these characteristics or not to register those service conditions. So, this list can also be used to see what kind of characteristics a metal should have to perform under given service conditions. So, after the failure, we can easily identify the kind of failure mechanism which would be there for a metal, and if the material is material which has failed is having those characteristics or not that can be used to identify if the design was proper or the design was deficient. So, the fatigue fracture like if the design is to be based on the fatigue.

If the expected failure mechanism is a fatigue then the endurance limit and the fatigue strength with this stress raiser, and the hardness should be considered thermal fatigue is the probable case for the failure, then the ductility and the peek plastic strain under the given temperature variation should be considered as a creep is the foreseeable mechanism, then the creep rate at a given temperature needs to be considered. And for the plastic deformation if that the change in dimension of the component under the given service conditions is a possible way by which the component can fail.

Then we need to consider the yield strength or at high temperature it is the creep condition creep. And if the component is subjected to the tensile stresses in crosier enrolment, then we need to consider the k one ssc which is the stress critical, stress concentration factor under the corrosive environmental conditions. And the corrosion resistance to the spes environment also needs to be considered.

So now, will I will conclude this presentation. In this presentation, I have talked about the how upgrading a part to the newer applications can lead to the failure. And also, I have talked about how the in appropriate design criteria, and the inappropriate, improper stresses can lead to the failure.

Thank you for your attention.