Failure Analysis & Prevention

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Lecture – 39
General Procedure of Failure Analysis:
Examples of Failure Analysis

Hello I welcome you all in this presentation related with the subject Failure Analysis and Prevention. And now we have talked about almost all the aspects related with the failure analysis, like fundamental sources of the failure and the general procedure to be used for failure analysis of the metallic components.

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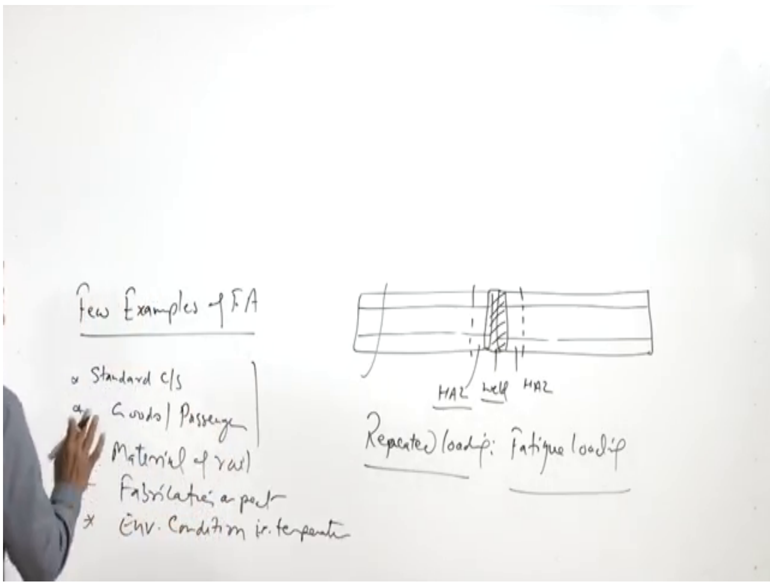

So, now here today we will take up the few examples which can be used just to have idea about how do we proceed for the failure analysis and how to make; how to investigate the different aspects related with the possible causes of the failure. So, few examples of the failure analysis, say I will take one typical example say there is a rail and the rail this is the I section of the joint and here it is joint using the thermite welding process and the joint is like this.

So, thermite welding process which uses the molten metal created through the exothermic reaction and this molten metal fed in between the gap of the rails gap between the rails and which after the solidification results in the joint. Around this some kind of the heat affected zone is also formed because the heat gets transferred. So, there is a heat affected zone and there is a weld and heat affected zone is found basically both the sides. So, it is common that the many railway accidents take place due to the fracture of the joints or fracture of the rails. So, there can be both the possibilities fracture can occur from the rails or fracture can occur from the heat affected zone or the weld area.

So, if we have to investigate anything then since the rails are of the standard cross section. And you know the load is also identified the kind of the goods trains their loading capacity or the passenger trains which will be passing over the rails. So, the loading condition is also almost fixed end for which the rails are designed, only thing is that the failure of the rails of which can occur on under the certain conditions of the certain conditions of the material of the rail 1, second is the fabrication aspect of the fabrication aspect related with the rail and third one is the environmental conditions like the temperature like the temperature, the conditions under which the failure is taking place.

Since we know that the trains will be passing at a certain intervals, so which the joints will be subjected to the repeated loading. So, this is means the rails are subjected to basically the fatigue loading. So, even if there is no discontinuity, no defect even in that case under the fatigue load conditions, the cracks can nucleate and they can grow gradually to cause the fracture eventually.

But a particular fracture has been caused by a specific reason if that is to be identified for that purpose we need to carry out the analysis systematically. So, what we will be doing first? We will be doing the like say the preliminary examination of the failed rail.

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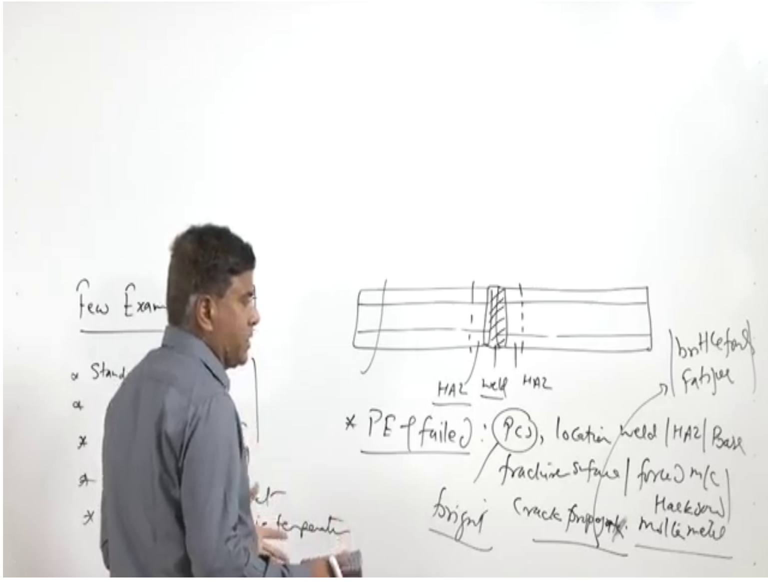

So, in the in case of the failed rail what we have to basically observe the pieces of the broken rail and then we have to see the location where from it has the failure has occurred, whether it is from the weld from the HAZ or from the base metal of the rail; then there is a possibility of the tempering of the these rails.

So, we have to see that the fracture surfaces, if they have any special kind of the marks which are reflecting in form of the forced machining like use of the hacksaw; kind of the blade for cutting purpose or some kind of the flame has been used for cutting. So, there will be molten metal on the fracture surface, so all these things can be easily checked and if it has happened we can easily establish that.

So, if but if the fracture pieces which are there if they are bright, then it will be reflecting that fracture surface is freshly created and if it was cut; it will have it is own marks on the fracture surface. And if it is melted forcefully then it will have the molten metal or the cast layer over the fracture surface. So, each will have it is own morphology and AHG is visual up and it will have it is own appearance.

So, that can be easily identified the way by which the suppressant has taken place, whether there was any tampering or it has happened it due to the crack and crack propagation. This crack propagation whether it has been sudden whether this the crack propagation which has caused the failure was in form of the brittle fracture or it was a fatigue fracture.

So, that also that we need to establish as per the case, so the the location where from failure has taken place will certainly will provide the greater directions and the possibilities for which we for the failure analysis. So, this is what we will be having idea from the preliminary examination of the failed component, thereafter we will be doing the NDT.

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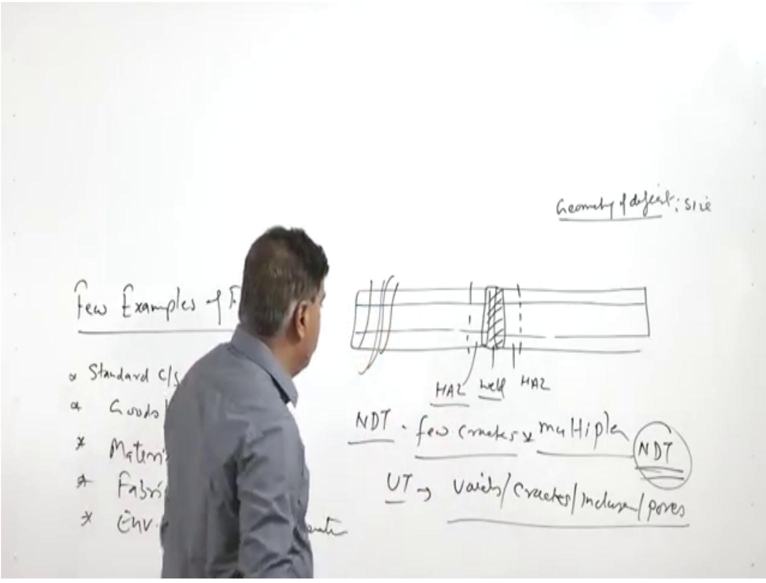

In NDT we will try to see if near the fracture areas few cracks were present, some times in the fatigue conditions especially the multiple cracks are observed near the fracture surface. So, but so if that is the case then it will be revealed under the NDT test or there is also possibility of there is this is.

So, multiple cracks will be revealed through the NDT or NDT like ultrasonic testing will indicate near the fracture surfaces, if there were some voides which have create have been created below the surface or some cracks were present inside cracks, inclusions or pores are present in the rail. So, these things can be identified say if the this is the failure location then UT and DPT etc, can be carried out to see near the fracture regions to investigate if there is really presence of this discontinuities or not.

So, if these are there the geometry of the defects or discontinuity is identified in terms of the size and the location where it is present whether it is at the surface or below the surface. After the NDT of the failed component we would like to see about the mechanical properties or the load carrying capability of the rails.

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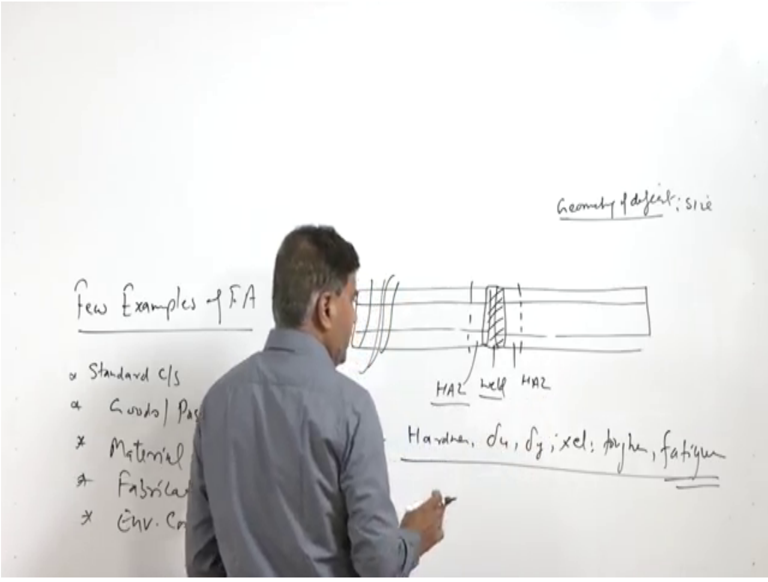

So, destructive tests are conducted for that purpose and we will be trying to identify the hardness, hardness test ultimate strength yield strength percentage elongation toughness and if possible if you sufficient it means for that purpose since the rails will be subjected to the fatigue loading.

So, it will be good idea to perform the fatigue test also to in or in order to see the resistance to the fatigue loading. And the data for the mechanical properties will be generated on the rails, to see how about the mechanical performance of the rails. So, this these properties will be identified and will be determined and they will be subsequently related with the fracture possibilities.

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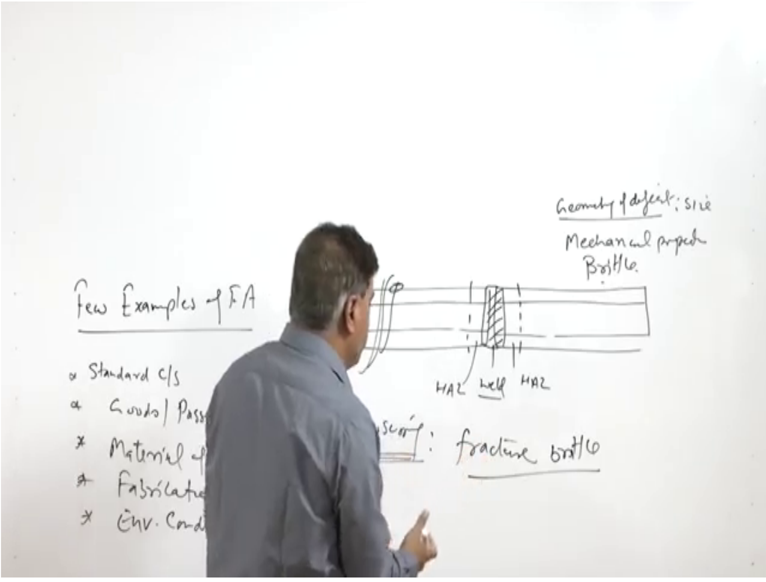

So, whether the material is the tough or the brittle, so mechanical properties will be established. So, they are after what we will be doing we will be doing the macroscopy of the fracture surface, which will indicate the fracture initiation site which may be at the surface or below the surface. So, if the fracture is initiating from the surface it will have it is own unique features present on the surface and it may not be, there may not be any unique feature present at the surface.

So, there is say there is no unique feature present or the on the fracture surface and the fracture fracture is the brittle and without any deformation. So, no deformation will indicate that the fracture is the brittle in nature. So, this is one of the possibility we can consider through the macroscopy; the bright signing fracture surface with no deformation indicating that it is a brittle fracture.

And there later on we can do the microscopy of the fracture surface microscopy of the fracture surface may indicate various types of the features since is it is the brittle fracture, so say if it is having the cleavage facets shown by the microscopy of the fracture surface or it may show the intergranular fracture also or since it is the catastrophic failure.

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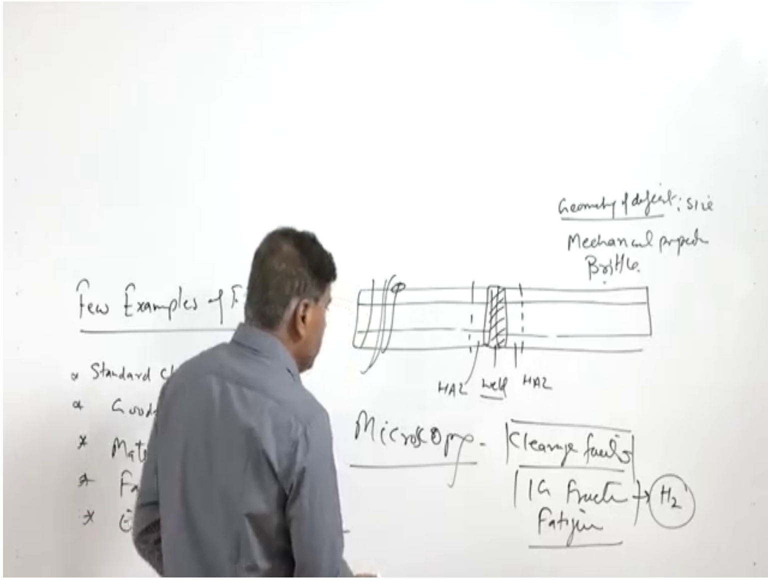

So, it may be the fatigue fracture also so if there are (Refer Time: 11:26) present that will indicate the possibility of the fracture by the fatigue, if there are intergranular fracture then it will present the possibility of the source of the cracking like the hydrogen embrittlement or the hydrogen induced cracking or if there is a just simply cleavage facets are there, then this is a overload fracture. So, microscopy will be revealing these microscopic fracture mechanisms and accordingly this will be used as a basis for the analysis subsequently.

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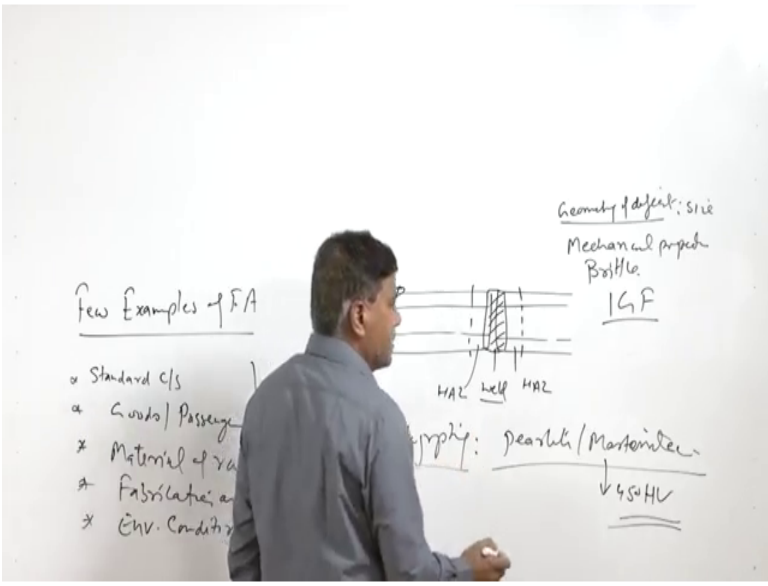

Say If it has revealed intergranular fracture then that also will be recorded, after that we will be seeing the metallographic aspects of the failed component, metallographic aspect of the failed component and it is a metallography suggest that no it is very perlitic and martensitic structure and martensitic structure and so and it is having the hardness of the like say 450 HV.

So, wickers hardness in of the 400 HV is the is on the little bit higher side, if that is the case either due to the presence of the fracture surface near the heat affected zone or in the weld metal or in the base metal due to the segregation of the certain elements if the hardness is on the higher side, so that will be that will also be recorded.

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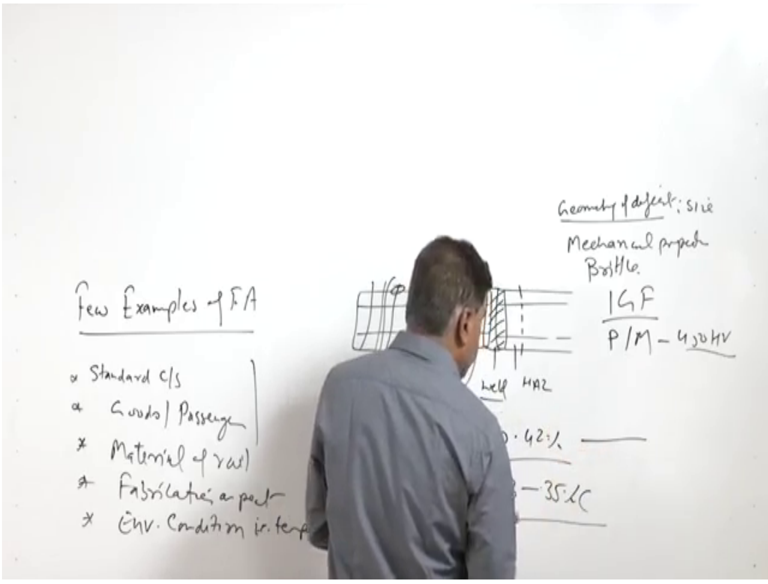

So, the perlitic martensitic structure with the hardness of the 450 hardness then that will be coming to the chemical aspect. So, the chemistry of the rails if that is investigated and chemistry if it may confirm or it may be on the higher side or the lower side. So, if the chemistry say coming out 0.42 percent carbon, so think that it is a medium carbon steel with the other residual elements while it may be the recommended range may be 0.32 0.5 also percentage carbon, so but if it 0.4. So, it may be say on the higher side which will be leading to the little bit higher hardness.

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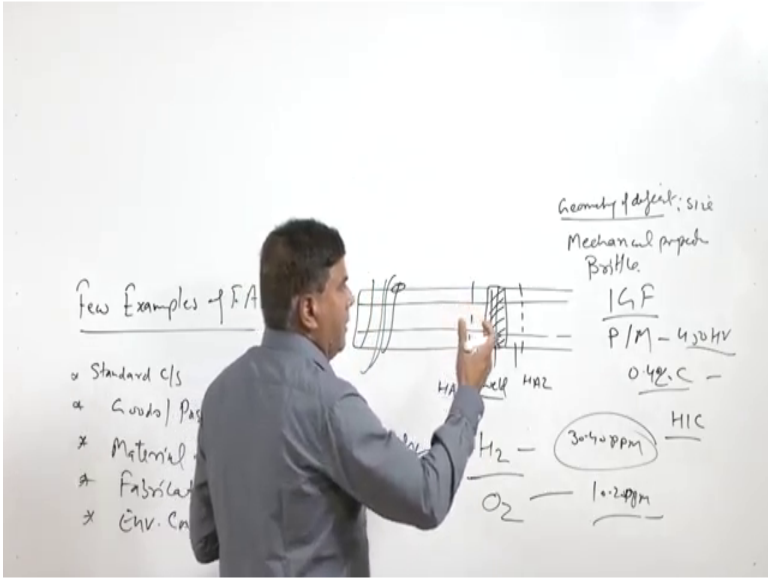

So, we will be recording that let us say the carbon content is 0.42 percent with the presence of other residual elements, which will be leading to the like say the higher hardness presence of the perlitic and the martensitic structure especially in the head affected zone and then apart from this we can do some gaseous analysis of the of the failed rail. So, the gaseous analysis may indicate the presence of say hydrogen or oxygen hydro oxygen, if it is like say 10 to 20 pm it may not be that harmful. But if it is like say 30 to 40 PPM for the hydrogen, this can create the trouble especially with regard to the hydrogen induced cracking, this can propagate the cracks through the intergranular fracture mechanism and cause the fracture.

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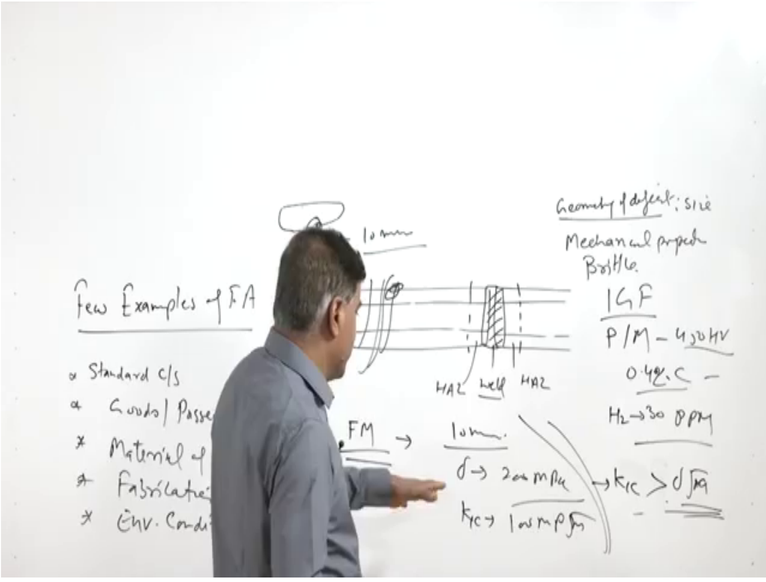

So, hydrogen gaseous the means I mean to say that the hydrogen or the gas analysis will indicate what are the gases which are present. So, say hydrogen is 30 PPM hydrogen is present and after that we can do the fracture mechanics analysis and fracture mechanic mechanics analysis, if suggest that there was a some kind of the crack which was present because the fracture surface; like the fracture surface showed that in the rail like this and there was a crack which was present and this was dull and this crack was especially present in this area of say 10 mm size.

So, what we can do using the fracture mechanics concept the open crack of the 10 mm size and the services stress conditions sigma say if it is 200 MPa, if that can be calculated through the loading conditions and then the fracture toughness of the material k 1 c can be easily obtained or characterized and say if it is coming 100 MPa raised to the power 1 by 2. So, using this we can simply correct establish if the this kind of the crack really can be critical or not. So, the cruciality of presence of discontinuity and it is role on the fracture can be easily established and thereafter we can say really if this can contribute towards the catastrophic fracture or not.

So, if the if the value of the k 1 c is less than the sigma pi a then it will indicate it has contributed significantly, in the fracture and if the k 1 c value is lower than the k 1 c value is k 1 c value is greater than the sigma pi a, in that case we will we will see that we will conclude that though. Now the role of the discontinuity means the crack and the applied load on the been causing the fracture was not that significant. So, this is how now we may now put our entire information in front of us and try to see what would have contributed towards the failure. So, the geometry size if you have determined say that is 10 mm.

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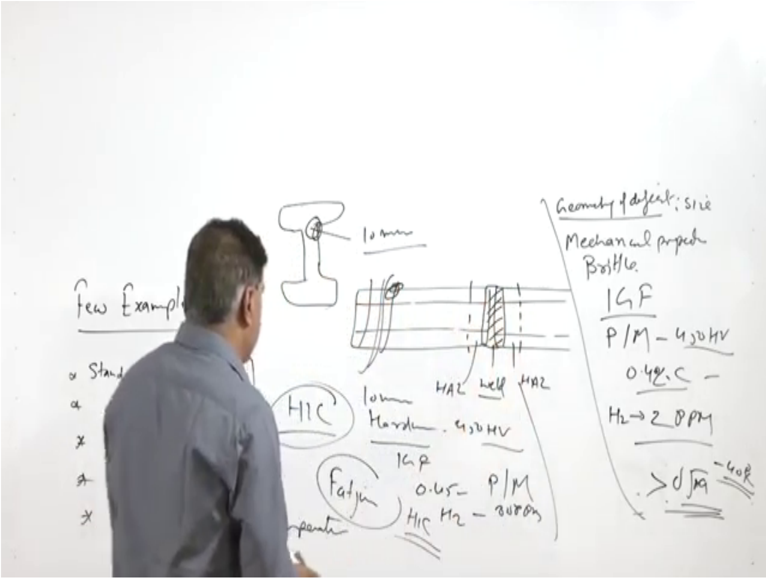

We have done the fracture analysis, hardness from mechanical properties hardness is coming out to say like 450 HV and it is the intergranular fracture and the carbon content is 0.45 leading to the perlitic and martensitic structure, hydrogen is also on the higher side 30 PPM.

So, all these factors are indicating that no the crack the fracture has not contributed significantly by the presence of crack, but the presence of the hydrogen has lead to the gradual growth of the crack, due to the presence of the hydrogen and the hydrogen induce the cracking or the delayed cracking subsequently under the repeated loading conditions lead to the growth of crack up to the certain fracture stage. So, it is it will be basically the fatigue fracture which will be facilitated by the hydrogen induced cracking. And if there is there is another possibility that that the temperature conditions were too low to and if the hydrogen is not say there may be another scenario when the hydrogen content is very low say it is 2 PPM.

But the temperature conditions are very low like say the temperature is minus 40 and degree centigrade, in that case we find that no actually it is not the hydrogen which is which has lead to the failure of the rail, but it is the loss of the toughness of the rail under the low temperature conditions have contributed towards the sudden fracture and for that what we need to do we need to then the direction of our study will be altogether different, if the conditions are established such that no the temperature at the time of failure was say minus 40 degree centigrade. And the hydrogen concentration was very low, the loading was also very lo is lower than the normal allowed stresses under at the time of the failure.

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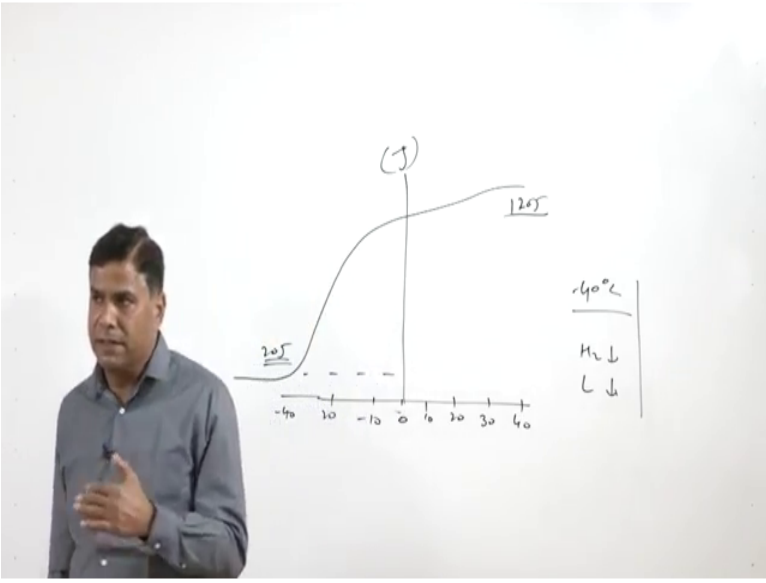

In that case we have to conduct one additional study, which we can say the study under the simulated temperature conditions and for that we need to study that the tile to brittle transition behavior of the rail steel.

And for that like say we will be testing the rail under the different temperature conditions 20, 10 minus 10, here 0 minus 10, 20, 40 like this. So, we can have it here for 0 and here the toughness in terms of the energy observed and rail steel if shows that there is a very sharp drop in the toughness at minus 40 degree centigrade. So, the steel which was having like say 120 joule of the impact toughness and it was reduced to only the 20 joule. So, this such a sharp drop in the toughness is indicating that rail had very low toughness under those conditions and because of that only the failure has taken place under the sudden load conditions.

So, sometimes the unfavorable service conditions also promote the fracture and it but to establish this kind of the behavior; it is it is required to start the behavior of the material under those temperature conditions. Now we will take another example related with the like say this is the hydrogen induced tracking.

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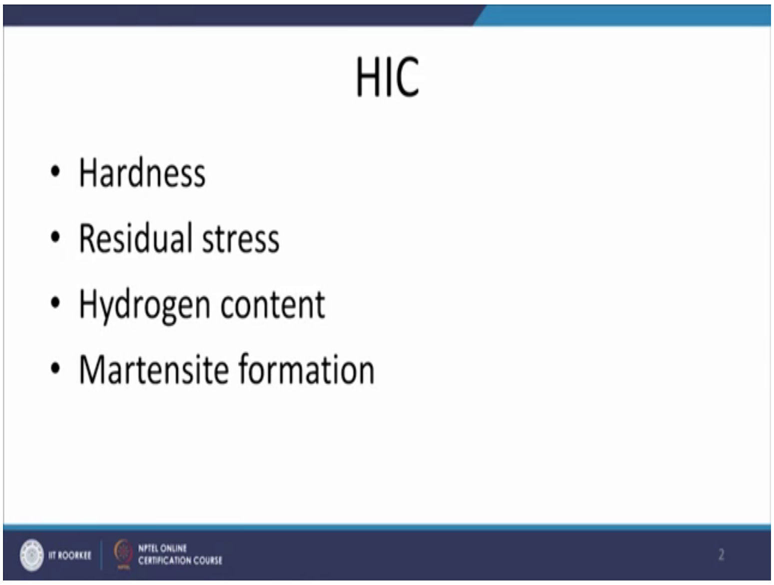

As I have already taken up these examples say this is the kind of this was the case of the rail steel, but we can take any other the weld joint like this and this is the t joint this is the weld and a wool fillet weld and here both sides this is a weld and if the cracking is taking place from this area during the service, then it will indicate that this is the toe of the weld leading to the high stress concentration

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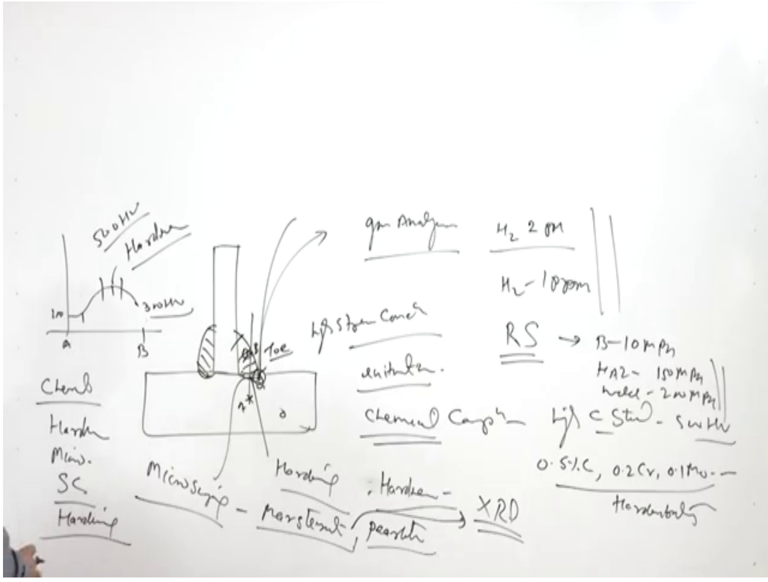

So, this is the obviously, the fracture initiation sight due to the high stress the fracture initiation sight due to the high stress concentration by, but why it has take place for establishing that we need to study all aspects like because, from the macroscopy we can easily say that this is the region of the high stress concentration.

But to why it has not tolerated the crack nucleation to establish that we have to carry out the extensive study on the various aspects, which we include like chemical composition if it is coming out to be of the high carbon steel; leading to the high hardness of the 500 HV. And then chemical composition may have like say 0.5 percent carbon, 0.2 percent chromium, 0.1 percent molybdenum and other residual elements. So, all these will be increasing the harden ability of the steel. And this then thereafter we can do the hardness study hardness study of the weld area where failure has taken place.

So, we can measure the hardness across the weld which is starting from the weld to the base metal and what we will be finding in this case especially, if we measure from A to the B location and then the hardness is plotted A to B. So, as soon as hardness is low, but as soon as we reach to the heat affected zone and then in the weld we find that there is a drop in there is . So, this is the base this is the heat affected zone and this is the weld.

So, weld is softer, but heat affected zone is harder the base is softer. So, this is what is shown so heat affected zone is hardness of the heat affected zone is high in this case which say if it is coming out to be of the 500 HV and the base metal is of having say 200 and the fillet is around 300 HV. So, this is suggesting that you hardening of the heat affected zone has taken place. So, this is one aspect and why the hardening has taken place for that we have to do the microscopy of this location, where the hardening has taken place and the area which has facilitated the nucleation and growth of crack. So, this may indicate that there is a possible there is a martensite the presence of the martensite, apart from the sum the perlite.

So, the presence of martensite will be supporting the hardness results and still if this is a if you are not confident of enough about the phases being formed then we can conduct the XRD analysis to confirm, if the martensitic transformation is taking place in the heat affected zone. In addition to this what we can do this location we can further carry out the gaseous analysis of the weld joint as well as the of the base metal.

So, gas analysis may indicate now the hydrogen is just the 2 PPM is present in the weld and it in the base it is 1 PPM. So, they may not be contributing significantly under the due to the. So, the hydrogen may not be a beak factor towards the nucleation and with the growth of the crack, but certainly the we can also do the residual stress analysis aspect.

So, for that obviously we have to measure the hardness in the weld, in the heat affected zone and in the base metal. And if the residual stress in the base metal is showing of the of just a 10 MPa in the base metal and the HZ it is of the tensile stress of magnitude 100 MPa and in the weld it is 200 MPa. So, of course this is showing that the weld is having the higher residual stresses as compared by heat affected zone, but since this area is of the greater hardness 1 and since the and this area is also of the higher stress concentration, that is why it did not tolerate the nucleation and the growth of a crack.

Thereafter so this is the triggering point which is analyzed why the cracking track has triggered from this particular location. So, through the chemical analysis, hardness microscopy metallography macroscopy of the fracture surface or even microscopy of the fracture surface we can establish some of the things why which have lead to the in cracking of the particular component from the toe of the weld.

So, here if we see all the aspects will be supporting the same thing like the hardness is like chemical composition is supporting it is high carbon steel 1 hardness is supporting because, hardness is high microscopy is supporting this observations because, of the martensitic transformation and the cracking and the toe of the weld is due to the stress concentration that is what is supported and the hardening has taken place in the heat affected zone due to the metallurgy martensitic transformation this is what can be confirmed through the XRD analysis also. So, means various aspects will be converging towards the one point at this is the area of the problem.

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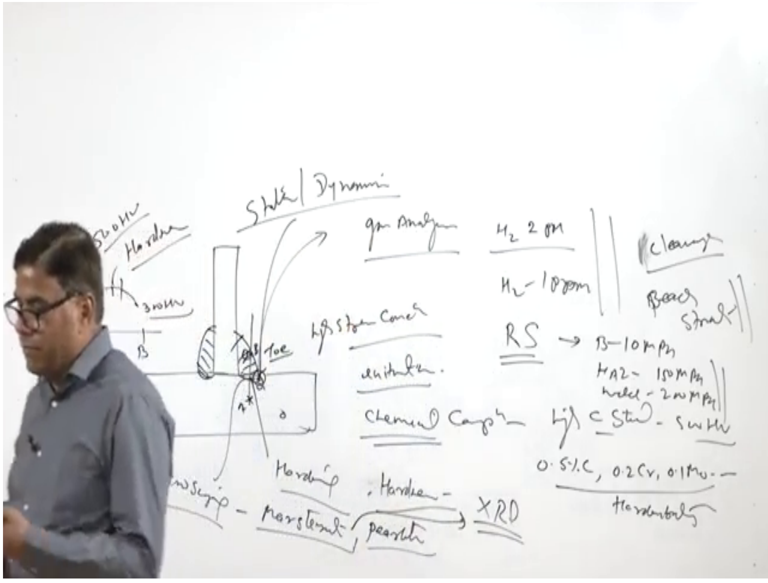

Now, whether it has been take this cracking has taken place under the static load condition or the dynamic load condition, that is what we can further establish through the macroscopy as well as the microscopy of the fracture surface. So, if it is a simply overload fracture then it will be indicating the cleavage facets on the fracture surface; the brittle brack the flat sign in fracture surface why and the macroscopy will be showing the cleavage facets, but if it is and if the failure has taken place under the cyclic load conditions; then it will be showing the beach marks striations on the fractures the fracture surface.

So, depending upon the kind of the features which are present on the fracture surface; we can suggest that if the fracture has taken and the cracking has taken place under the static load conditions or under the cyclic load conditions. Now here I will summarize this presentation in this presentation, I have talked about some general examples for and the way by which the failure analysis can be taken up to identify the potential causes of the failure.

Thank you for your attention.