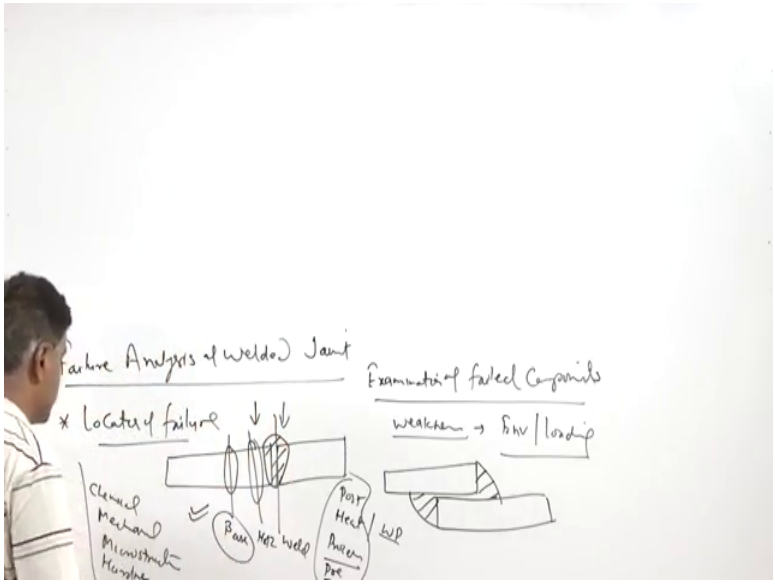
Failure Analysis & Prevention
Dr. Dheerendra Kumar Dwivedi
Department of Mechanical and Industrial Engineering
Indian Institute of Technology, Roorkee

Lecture – 38
General Procedure of Failure Analysis: Failure Analysis of Weld Joint

Hello, I welcome you all in this presentation related with the subject Failure Analysis and Prevention. So, far we have talked about the fundamental sources of the failure and also the different steps are related with the general procedure of the failure analysis for metallurgical failures and the last time we started the failure analysis of the weld joints.

(Refer Slide Time: 00:45)



Failure analysis of the weld joints and we have talked about a few general procedural steps related with the failure analysis of the weld joints. Now we will see how systematically we can proceed as far as the actual failure analysis is concerned. So, it involves the first one is the examination of the failed components which had the weld joint.

So, in this examination you see the weld joint can be the word joint or various other types of the joints also. So, like this is an example of the word joint similarly there can be a lap joint like this. So, a as per the kind of the weld joint which has failed we need to examine in the component which has failed and which has failed from the weld joint.

So, first of all what we need to see identify the location of the failure, where from the weld has failed. So, we know that each weld has 3 broader sections 1 is the weld second is the heat affected zone and third is the base metal which is unaffected by the heat used for preparing the weld joint. So, weld HAZ and the weld, so base HAZ and the weld.

So, we need to identify if what is the location of the failure. So, if the failure is occurring from the base metal, it suggests that the joint is stronger, but the weakness is there in the base metal So, accordingly our approach will be there to characterize the base metal properties in terms of the chemical composition or the mechanical properties or the micro structural aspects, if the segregation or a unique kind of the structural features which have nucleated the cracks and subsequently causes a fracture, the hardness toughness etcetera as for the requirement of the service condition, so that is what is done.

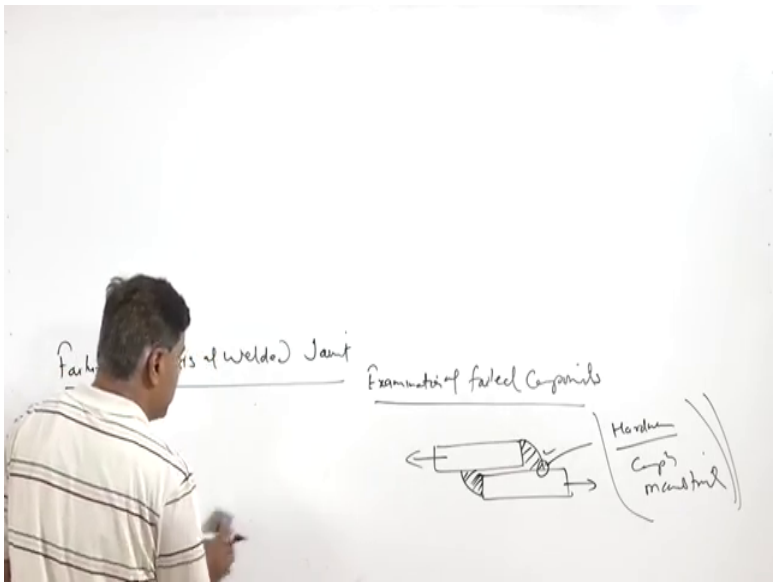
Ah some sometimes if it is observed that the weld the failure of the joint has occurred not from the weld metal or base metal, but it has occurred from the heat affected zone. So, basically the failure location always suggests that that location of the weakness, weakness from the environment point of view from the loading point of view or any other service condition which is expected from the that particular part of the weld joint and under which it could not sustain and that is why it has failed. So, there must be some reason behind the failure of the weld joint from a particular location and that needs to be investigated.

So, accordingly only we will be proceeding further what are the aspects to be investigated, like if the failure is occurring from the base then no need to investigate the kind of the welding process or the filler or preheat or post weld heat treatment of the weld joint has been carried out. But in the case of the heat affected zone as in if the failure is occurring from the heat affected zone or from the weld metal. Then of course we need to see the kind of the heat input which has been used using the welding parameters or the kind of the welding process which has been used and because of which heat affected zone has been formed or kind of the pre heating has been used or the post weld heat treatment has been carried out which has adversely affected the properties of the heat affected zone.

So, again each region of the interest whether the failure is occurring from the base or from the heat affected zone or from the weld, in any case we need to characterize it with

regard to the expectations from that weld and the kind of service conditions under which it was suppose to work. So, we need to do the chemical analysis mechanical micro structural hardness toughness etc which will be in line with the requirement of the service. If any other property is also expected from the joint then that also should be assessed. So, basically the location of the failure will help us to see; what are the different aspects that need to be investigated.

(Refer Slide Time: 05:46)



Apart from this one if the failure is occurring not exactly from the base metal or from the heat affected zone, but if it is occurring from the next through the weld metal or from a particular location like toe of the weld.

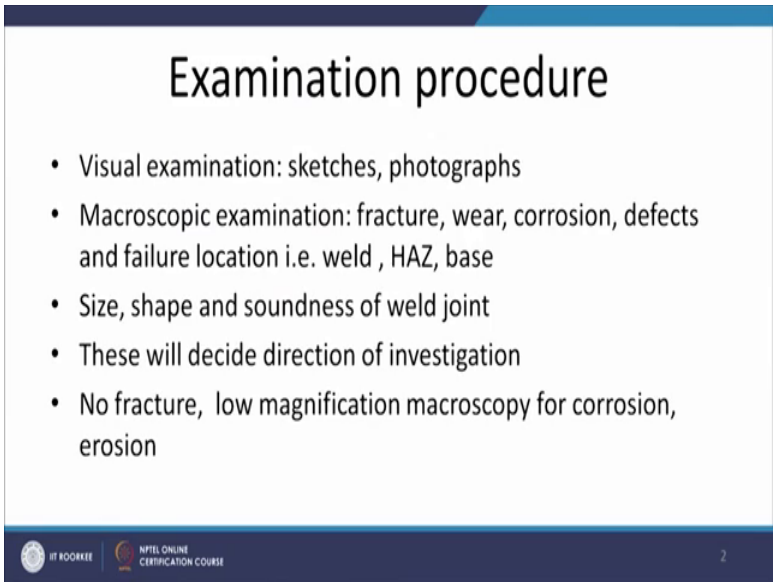
So, if the failure is occurring at the toe of the weld, then it will suggest that there is some stress concentration which was present by the toe of the weld and because, of which failure has taken place. So, in that case that the location where from the failure has been triggered needs to be investigated with regard to the kind of the hard mechanical properties, the composition, the microstructure, so all these things will support that why the crack was what are the different factors which have facilitated the nucleation and easy growth of the crack.

So, other factors also should support the conditions favorable conditions for nucleation and growth of crack from a particular location. So, this may be the triggering point the high stress concentration may be the triggering point, but other properties will also be

supporting the same aspect and because of which the crack is nucleating from the particular location. So, these are the general aspects like even simpler exam visual examination of the failed component will indicate the kind of things that should be looked into from the failure analysis point of view.

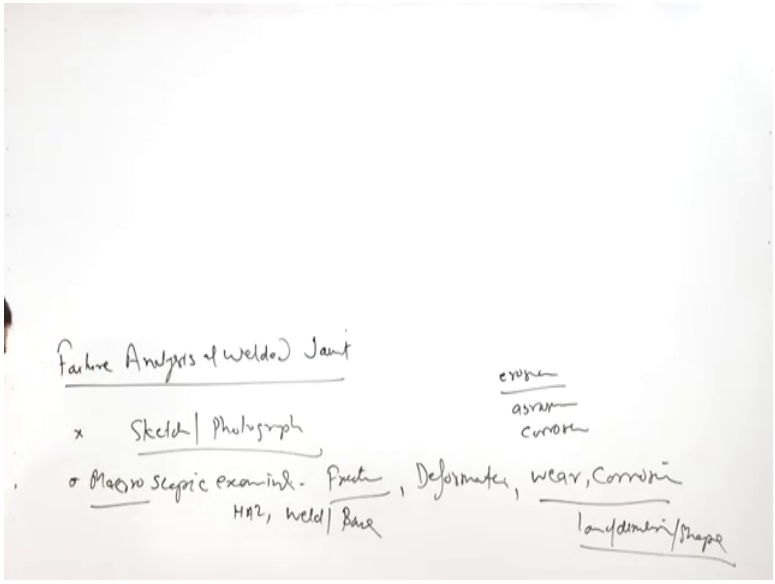
So, if we see so this is the general background related to the failure analysis of the weld joint, if you have to move six systematically as far as the examination procedure is concerned we need to make we need to do the visual examination of the failed component and for this purpose if the joint if the component which has failed and which was having the weld joint if it is really big.

(Refer Slide Time: 07:32)



Then we need to schematically make the; we need to make the schematic of the entire assembly and the showing the location of the weld joint where from failure has taken place.

(Refer Slide Time: 07:54)



So, we can use the sketches for this purpose, we can take the photographs to support the evidence regarding the location where from the failure has taken place where the weld joint was located. Then macro examination is the next aspect, macro examination basically in helps us to see the, what was the broader mechanism by which the failure of the weld joint has taken place.

Whether the failure has occurred due to the fracture or the separation of the component either from the base metal or from the heat affected zone or from the weld metal or there has been the deformation beyond the acceptable limits or the very joint has lost to the dimensions either due to the any specific wear mechanism which was operational under the service conditions, may be in form of like erosion or like in hydropower plants or abrasion like in cement industry and there may be like corrosion in petrochemical industry.

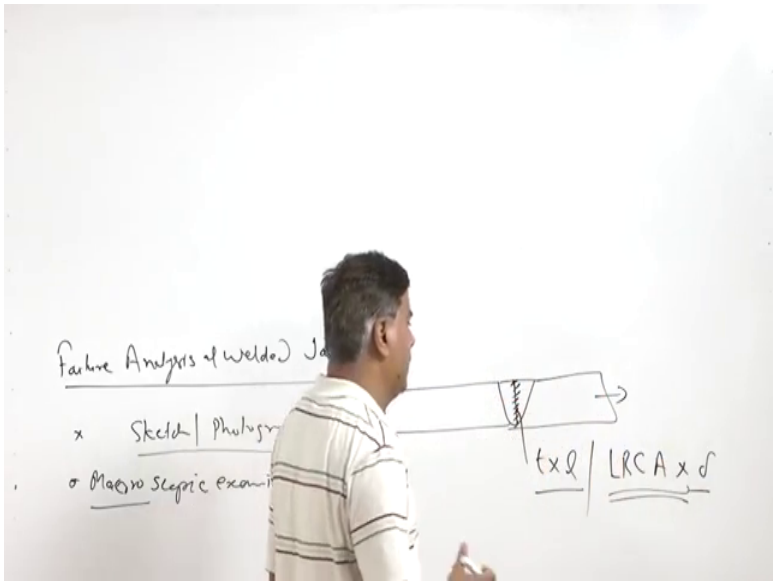
Where the weld joint may be locally attacked either in the heat affected zone or the weld metal as per the properties of the joint, so the wear and the corrosion. So, these will be causing the loss of the dimensions and the shape of the component, which may be leading to the improper functioning or reduce the efficiency of the component which is being considered.

So, the macro examination macroscopic examination will basically involve identification of the broader mechanism of the failure, whether it has occurred by the fracture or wear

corrosion or some kind of the discontinuities which were responsible for all these things and it will also help us to see the precisely the location of the failure weld (Refer Time: 9:58) or the base metal.

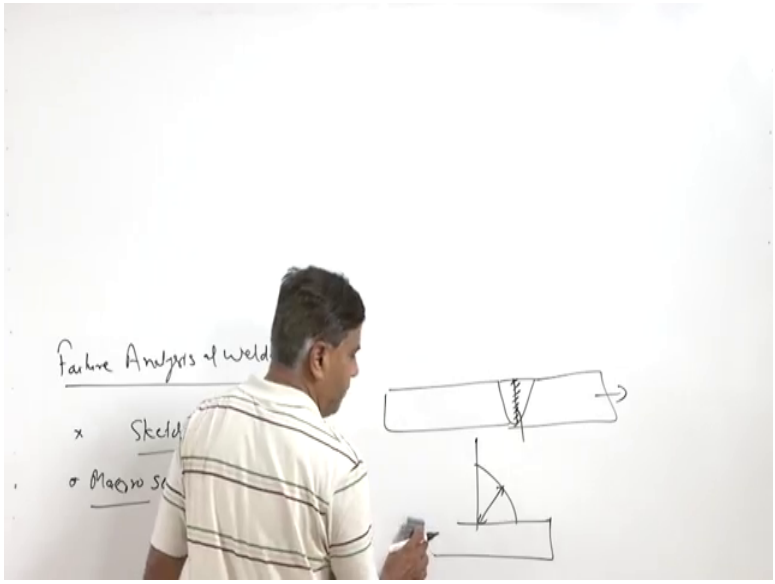
Another point is which will be able to help us to have the general assessment of the weld joint, that is about size shape and cross section of the weld; according to the standards like there are some few requirements like for fillet weld must we have this particular size or the butt joint should be of this much size.

(Refer Slide Time: 10:30)



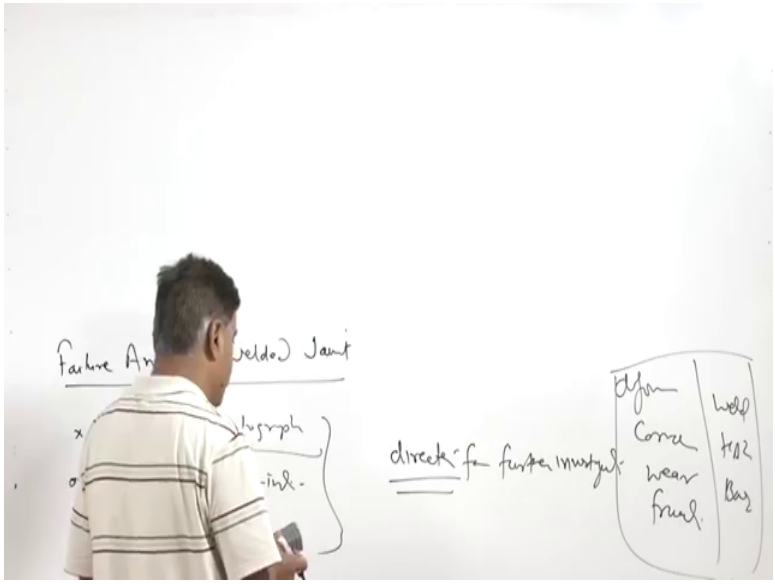
So, in case of the butt weld joints normally the thickness is the thickness of the plate is considered as a throat thickness that is the minimum, thick minimum thickness of the weld and that will be determining the load resisting cross sectional area. So, if you length multiplied by this thickness is divided then it will help us multiplied. So, the throat thickness multiplied by the length of the weld this helps us in determining the load resisting cross sectional area.

(Refer Slide Time: 11:20)



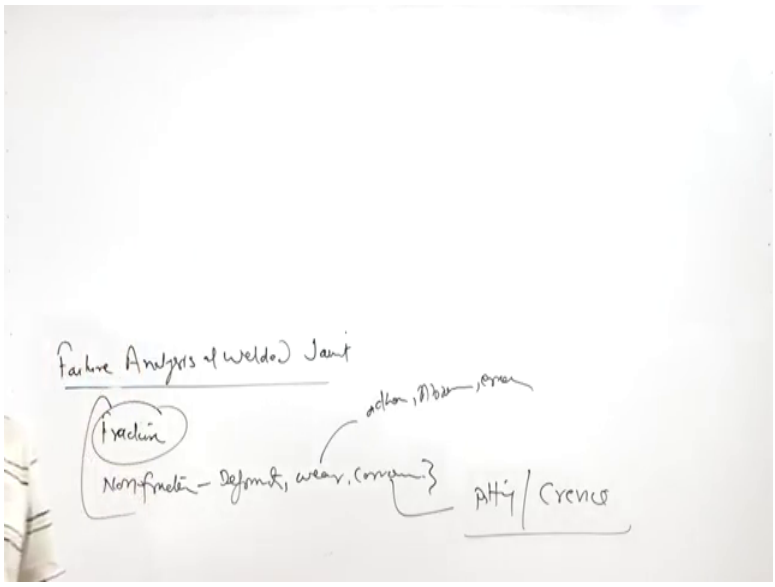
So, if the load resisting cross sectional area is available then considering the allowable stress we can determine the maximum load which it can take maximum service load it can take. So, this is the case of the butt weld, but in case of the fillet welds for a given thickness there is minimum throat thickness requirements, which must be fulfilled and that is what simply through the microscopic examinations can be measured, to have the general idea about the kind of the weld cross sectional area whether it was sufficient or not these.

(Refer Slide Time: 11:50)



So, based on these observations we will be able to have some idea about the kind of the directions need to be taken for the, for directions for further investigation. So, if whether it is the deformation, corrosion, wear, fracture and it is location from the weld HAZ and the base these aspects will determine what are the things need to be investigated and what are the different characterizations need to be carried out for the failure investigation.

(Refer Slide Time: 12:37)

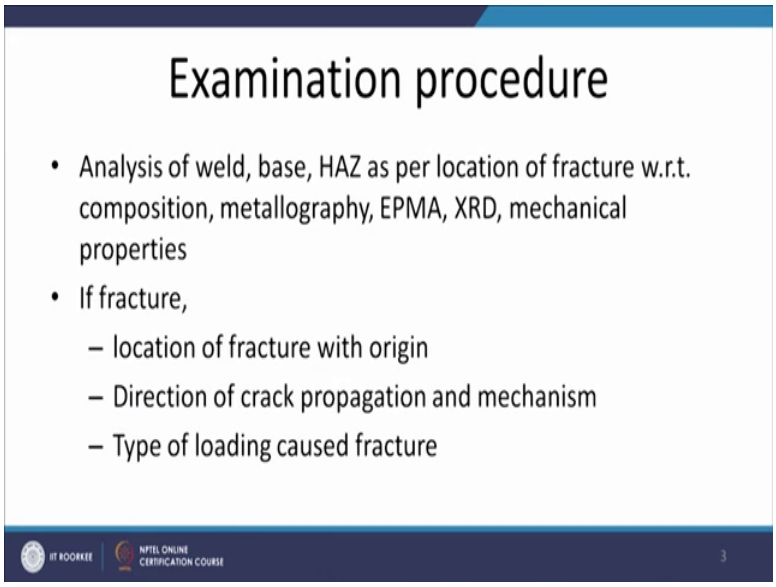


So, there can be as I have said there can be different broader mechanisms by which failure can take place. So, one is here like the fracture is one category and the non fracture failures are the is the another category, where it involves that deformation wear corrosion etc.

So, both needs to be the approach for both would be different as far as the further examination is concerned, normally the low magnification microscope is carried out for the for the for the failures where the either wear or the corrosion is involved to see the kind of the wear mechanism, which has been operational whether there was a adhesive wear abrasive or erosive wear. Similarly the kind of the corrosion which is involved like the pitting corrosion galvanic corrosion crevice corrosion so etcetera or it is the general corrosion. So, as per the case we need to basically carry out the magnification microscopy for microscopy for investigating the samples where the fracture is not involved.

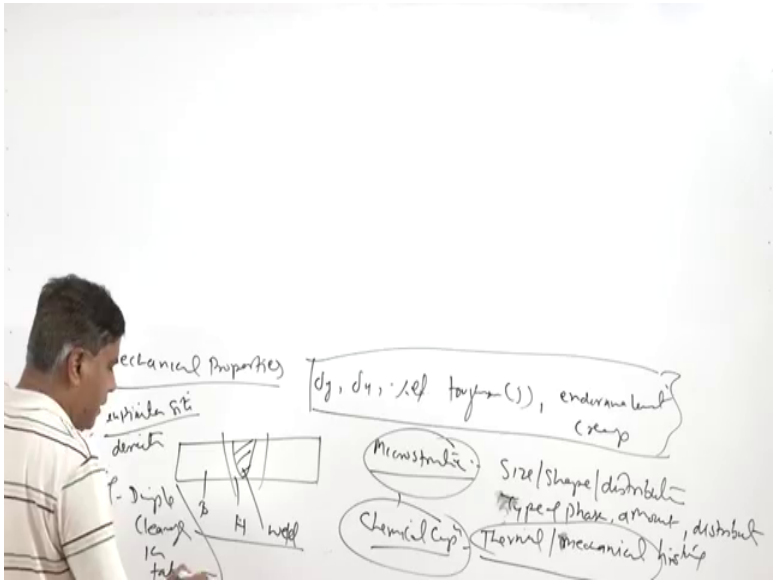
So, in case where fracture is involve our approach will be slightly different. So, so like this as far as the further examination is concerned the kind of things that we need to investigate, the analysis of the weld base metal or heat affected zone what are the aspects that should be investigated that will be decided by the location of the fracture and we can carry out the investigations in terms of the composition metallography EPMA XRD analysis mechanical properties.

(Refer Slide Time: 14:22)



And in the case when the fracture is involved then the location of the fracture with origin direction of the crack propagation and the type of loading that causes the fracture, these are the things which we can we can identify through the microscopic examination of the failed component. So, as far as the analysis of the weld metal base metal and heat affected zone is concerned. So, as per the location umm if the failure is occurring from a particular location then there would be some reason behind the failure to occur from that particular location. And under the given externals given load conditions or given service conditions, as per the broader mechanism of the failure there may be the deficiency of the mechanical properties especially with regard to the metallurgical failures.

(Refer Slide Time: 15:12)



So, if a particular zone is having the deficient mechanical properties in terms of this yield strength or ultimate strength, percentage elongation or the toughness that is the impact resistance toughness in terms of the energy absorbed or the fatigue life in terms of the endurance limit endurance limit or the kind you can say the fatigue strength or the creep resistance, these are the various properties mechanical properties. If they are deficient in the weld joint at a particular location this is the heat affected zone this is the weld and this is the base.

So, if any of these 3 is deficient with regard to these mechanical properties under the service conditions then, they will be leading to the failure of the component. So, what is important we need to see what are the factors that will be governing these mechanical properties and we know that the mechanical operators are governed by the microstructure of that particular location, which basically involves the grain size shape and the distribution of the various grains and another aspect is the phases structure which involves the type of the phases type of phases their relative amount of the various phases and their distribution.

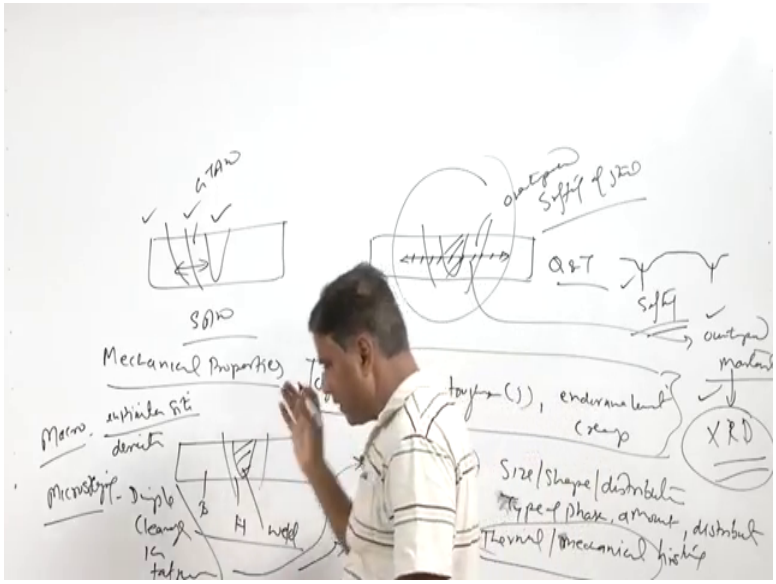
So, because these micro structural aspect will be governing the mechanical properties and this micro structure itself is influenced by the chemical composition of the material and the kind of the thermal and mechanical history it has experienced, which is a measured in terms of which is determined by the manufacturing process is used for

making the component thermal and mechanical history of the component. So the variation in thermal and mechanical history of the component either during the service or during the manufacturing which will be so apart from the com chemical composition thermal and mechanical history will be governing the microstructure and microstructure of variation will be affecting the these mechanical properties and which in turn will determine how effectively a weld joint will be performing the service. But if the failure has taken place from a particular location then it will be deficient from any of the mechanical properties point of view.

So, that needs to be investigated and for that definitely we need the chemic chemical means the characterization of the weld joint, especially of that particular location where from failure has taken place. So, we need to we need to first of all do the microscopy, so that the initiation site of the initiation site of the fracture can be identified, thereafter will have to we can also see the direction in which the fracture has propagated and thereafter we can do the microscopy of the fracture surface which will indicate the kind of mode of fracture, which was involved whether there were dimples or the cleavage facets or it is intergranular fracture or fatigue creations are involved

So, as per the case so these will be indicating the kind of loading conditions and the mode of fracture which has been involved and metallography will help us to find establish the micro structural aspects, chemical analysis will help to establish whether there whether the chemical composition of the base metal or of the heat effect base metal or of the weld metal were as per the specifications or not and if for the given composition everything is fine, but the thermal and mechanical history of the product was not as per expectation.

(Refer Slide Time: 19:26)



For example, in case of the weld joint If the given weld joint is expected to be made by the GTAW process and instead of the GTAW if it is made by the SAW process then it will have much wider heat affected zone and much degraded mechanical properties and the poor structure in the heat affected zone area.

Similarly, instead of giving a particular kind of the heat treatment, if another kind of heat treatment is given then there will be structural variation with regard to in the weld in the heat affected zone and also in the base metal. I will give 1 typical example like QNT is still used in automotive systems in form of very thin sheets.

So, these quenched and tempered steels when they are welded. So, the heat affected zone which experiences the heat being transferred heat from the weld metal this region gets over tempered, over tempering causes is the softening of the steel and such kind of the softening leads to the fracture of the weld joint from this location. So, the so for establishing this kind of softening what we need we need the measurement of the hardness across the weld at different locations

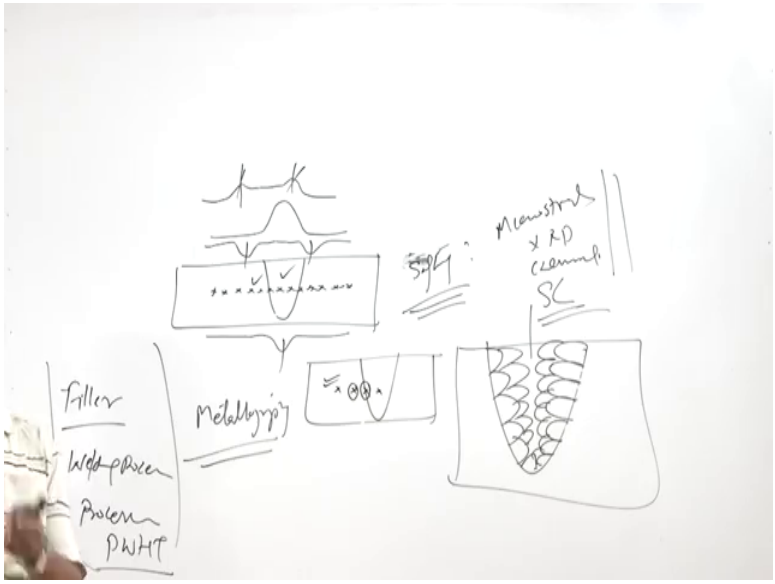
So, transfer section hardness distribution across the section of the weld joint can be measured and which may indicate us that near the heat affected zone hardness is lower while in the weld metal hardness is high. So, hardness reduction in hardness at both the sides in the heat affected zone will be indicating the occurrence of the softening and if it is due to the weld heat input, then not just the softening will be available, but we will

also be able to see at these locations wherever softening has taken place, there will be over tempered martensite over tempered martensite. So, over tempered martensite will further substantiate not just for the substantiate the reasons for the hardness value.

So, the regions for reduction in hardness values or thermal or for the softening of the steel in the heat affected zone, so this is how we can we can support our findings in order to not just the microscopy it will be sufficient for this we may do the XRD analysis. So, that the presence of the over tempered martensite can be identified which can also indicate the presence of the ferritic structure.

So, all these things will be supporting the will be supporting the regions for the softening and for the failure of the weld joint from the softened zone. So, now as I have just described that, we need to carry out the metallography also of the different zones and the metallography will help us in verifying whether the filler was of the correct type or not, whether the welding procedure parameters were proper or not. So, like the welding process and the procedural steps were appropriate or not.

(Refer Slide Time: 23:01)

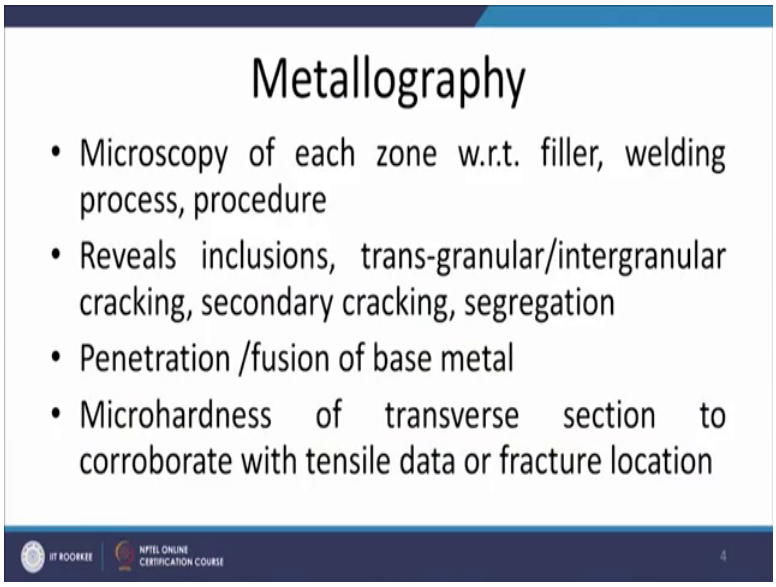


So, this is what can be identified to some extent through the metallography of the of the weld joint. So, like say this is the weld joint and if we do the metallography we can have the microstructure of the base, heat affected zone of the fusion boundary and also of the weld centre. So, these will help us to indicate whether the penetration has been proper or not at the fusion boundary or whether the kind of the phases which are being formed at

the heat affected zone and the base metal they are as per as expectation are there it is something else or if the in the procedural aspects if there is a PWHT.

So, micro structural is study itself will indicate if the PWHT of the correct kind has been performed or not whether the process parameters were appropriate or not all that can be int inferences regarding all that can be obtained through the metallography of the weld joints. But of course, we need to focus in the area where from the failure has taken place.

(Refer Slide Time: 24:01)



So, metallography can also help us in revealing the inclusions if they are present in the weld metal or in the heat affected zone due to the like say inclusions, if they are present it will be leading to the underbid cracking or the laminates of the inclusions can be there. So, which type of inclusions are present either in the weld or in the base metal that is what can be established through the metallography and metallography of the near fracture surface can also indicate, whether the fracture has grown in transgranular manner or in intergranular manner whether there were secondary cracks or there is any segregation or not.

Segregation invariably happens in the weld joints especially in this way like if this is the weld joint. So, the solidification will be proceeding from both the sites and then we will be seeing that the alloying elements are being rejected at the in the liquid metal and this will be leading to the presence of access concentration of the alloying element at the centerline of the weld and this sometimes leads to the solidification cracking. So,

certification cracking is attributed to the presence of access alloying elements especially at the centerline of the weld.

So, if this kind of segregation is taking place, then we need to change the way by which welding is being done maybe welding pattern can be changed, metallography can also help us to see if there is a proper penetration through the thickness or the penetration there is a lack of penetration or if the fusion of the base metal has taken place up to the appropriate depth or not all that can be observed. Another important thing is when the micro hardness measurement across the section of the weld like this, this is the weld. So, we will be measuring the hardness across the weld. So, at different points the micro hardness measurements can be read out this will indicate us the distribution of the hardness.

So, if the we may find that the different kind of the distributions where in 1 of the typical cases which is found like this, where in the hardening of the heat affected zone is taking place or we may have the distribution of hardness like this, where the weld is harder well there is no major change in the hardness of the heat affected zone and there may be also possibility where softening of the heat affected zone is taking place like in both sides in this manner and sometimes even the softening of the weld metal is also observed.

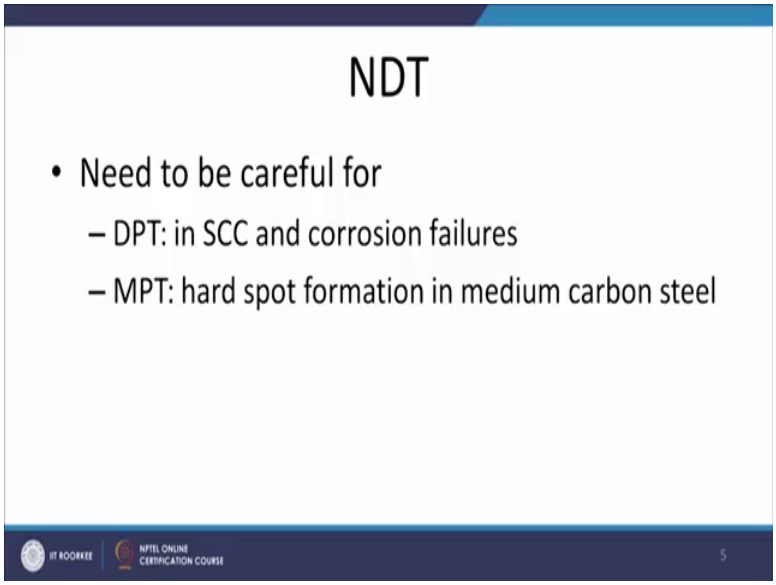
So, it will be showing little bit deep and wherever is the softening or the ha hardness is lower which will be the area indicating that these are the areas which has been adversely affected by the heat used for the welding purpose.

So, these locations so if it is a softening it means if there is a softening of the metal in a particular location whether it is the weld or heat affected zone, then that will be the potential location for the failure of the weld joint under the external loading conditions. So, such kind of the softening is to be established through the subsequent micro structure a study XRD analysis and the chemical analysis.

So, that we can support it suitably whether the chemical composition of the filler being used was appropriate or not or whether the micro structure being developed in the weld or in the heat affected zone is of the correct kind or not an XRD analysis will further substantiate. So, basically macro hardness distribution across the transverse section of the weld will indicate the possible tensile strength of the joint as a whole or the possible location where from fracture can take place. In case of the weld joints we need to carry

out the NDT with the care and it is primarily carry out to carried out to see the possibility of the discontinuities in the weld and if they have contributed towards the failure.

(Refer Slide Time: 28:09)

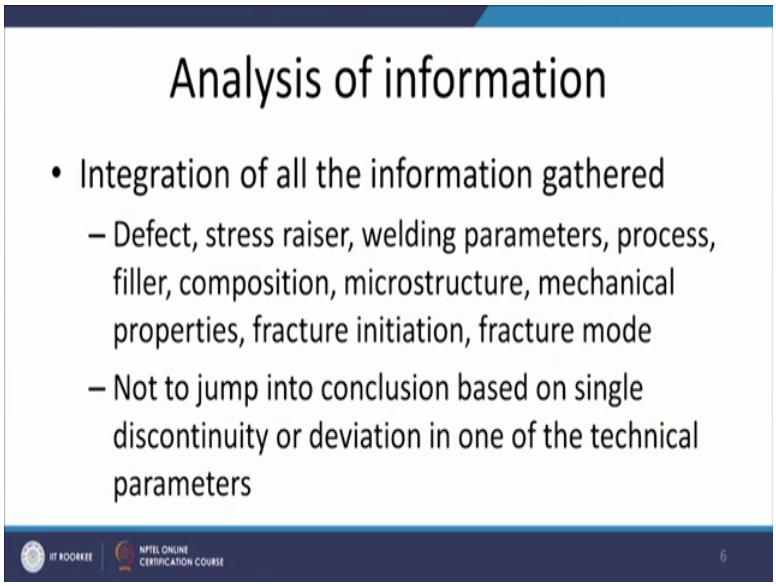


But in the 2 cases especially the DPT which indicates the surface discontinuities and if the failed component or the weld joint failure has taken place due to the stress corrosion cracking, wherein there is a possibility of the presence of the corrosive media in the in the fracture surfaces then DPT is to be avoided because, the liquid of the DPT test can get filled in and then it can create confusion with the corrosion media.

Similarly in magnetic particle test is also to be avoided especially in the medium and high carbon steels where electro magnets are used and for electro magnetism the high current is supplied and when current pass is passed through the work piece through the prods, it generates the heat at the contact areas where from current is being fed. And that, in turn leads to the formation of the hard spots; this such kind of hard spot subsequently can promote the cracking.

So, this can also be misleading situation whether the cracking has been there due to the NDT or cracks were present before the failure, at the end we need to do the analysis of the all data collected through the different characterization approaches and that is what we need to integrate. So, we have to integrate basically the information collected through the different characterizations and the study or the failure analysis which has been conducted.

(Refer Slide Time: 29:50)



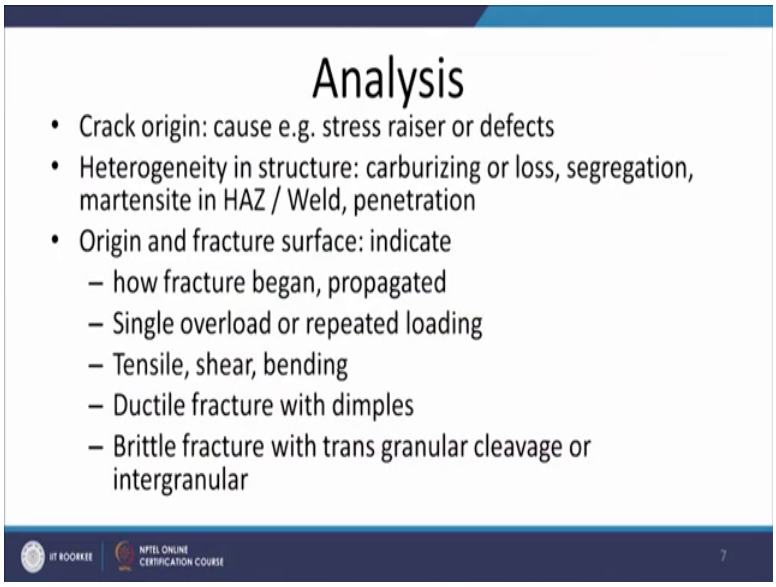
So, basically we have to see if there is any discontinuity is present and what is the possible role of the discontinuity that is, what we can analyze through the use of the fracture mechanics. If there are stress results then the fracture location near the fracture location near the fracture location near the fracture initiation site, if there are stress risers then they can be attributed to the triggering of the cracking and then their growth the use of the welding parameters will indicate the kind of heat input which would have been supplied and accordingly it would have developed the properties in the heat affected zone and in the weld metal.

The welding process will indicate the kind of the cleanliness of the weld and the kind of heat affected zone which will be formed based on the heat input, then the filler metal whether it was correct or not that is what can be easily identified through the chemical composition analysis. Then microscopy or if there is in presence of the martensitic structure which will make the joint brittle or if there is any presence of unfavorable phases or like formation of some undesirable kind of precipitates in the weld or in the heat affected zone, that will be degrading the performance of the weld joint which may not be fit for a given service conditions.

So, mechanical properties study fracture initiation site and fracture mode all these will be in 1 line basically we have to integrate all this information to see the kind of sequence of events which would have been there what led to the initiation of the crack and how did

the crack propagated during the propagate during the fracture and what and then we can make an informed conclusion about the failure of the weld joint. In these situations it is not good to jump into the conclusions based on the single discontinuity or deviation in the one of the technical aspects for which the analysis has been carried out. It is always good to look for the various aspects related with the information collected and definitely number of points will be indicating the possible cause of the failure.

(Refer Slide Time: 32:09)



So, in this regard what we need to see where from the crack has originated, whether there was any discontinuity or a stress raiser whether there was any role of the het role of the micro structural aspects with regard to the heterogeneity in structure due to the carburizing decarburizing loss of alloying elements or segregation presence of the martensitic structure in weld or a heat affected zone or lack of penetration. And then, how the crack has initiated propagated whether the load was repeated or the single loading was the tensile shear or the bending type, and in which we fracture has facilitated all these information need to be analyzed so that we can make well informed and well informed conclusion about the potential causes of the failure of the weld joint.

Now, I will summarize this presentation in this presentation broadly I have talked about, the what are the things we have to keep in mind while carrying out the failure analysis of the weld joint, we need to focus on the locations where from failure has taken place and look for the mechanical metallurgical and the presence of discontinuities mechanical

properties chemical properties and metallurgical properties of that particular location, so that we can have a better idea about the things which would have led to the failure of the weld joint.

Thank you for your attention.