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

Lecture - 06
Fundamental Sources of Failures: Imperfection in Base Metals

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. And in the previous presentation, I have talked about the role of the extra stages in failures and how it is important to consider the extra stages or take care of them, in such a way that the premature failure of the component can be avoided or today, we will be talking about one another fundamental source of the failure which is imperfection, in base metal itself, in base metal itself.

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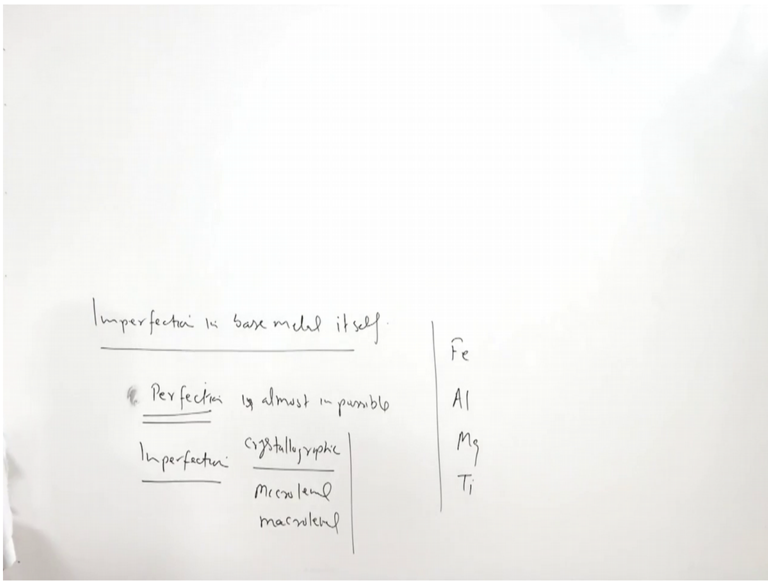

We know that, the components will be made of one or other metal for mechanical applications most like these may be in form of iron alloys or aluminium alloys, magnesium alloys, titanium alloys or there is a huge list of the metals and their alloys, which can be used for making the components for mechanical applications.

So, most of the metals generally possess, imperfections of one or other kind, it is very difficult to have the perfect metallic systems, it will have the discontinuity or imperfections of the different kind, whatever is used actually in practice. So, the perfection is almost impossible. So, we need to live with the imperfections and these imperfection, their variety of the imperfections which can be there in metal which range from the, crystallographic level crystallographic level to the micro level and macro level. So, these are imperfections according to their level or the form in which they are present, can have the different effects on the mechanical performance and their tendency to cause the failure.

For example, the crystallographic imperfections, no some of these imperfections are favourable and some of these are unfavourable, and sometimes these are intentionally induced to facilitate some of the mechanical properties.

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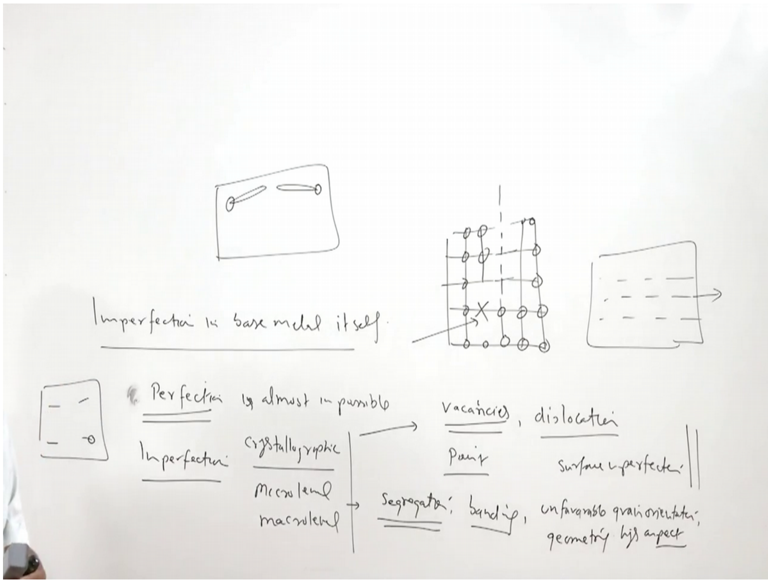

Say crystallographic imperfections may be, in form of the vacancies or vacancies in regular arrangement of the atom, say in a metal which is crystallographic in nature, say some of the atoms are missing, like atoms are here at these junctions and at one of the locations say, if it is missing, then that location will be termed as vacancies. So, this is the location where atom is missing. So, this will be a vacancies

Similarly, if one compete plane of the atom is missing. So, here you have this 1 plane, but here atoms are not present. So, one the plane where these atoms are missing that will be termed as dislocations. So, the vacancy is termed as point imperfection and the dislocation is termed as surface imperfections.

Similarly, we have the other volumetric imperfections, but these imperfections are useful also and sometimes and they do not diterate the mechanical properties significantly, as compared to that of the micro level imperfections. So, if we have to see in this diagram what we can see here. Here, the various the point defects or the vacancies are in form of like vacancy, where one atom is missing from the regular arrangement of the atom or some foreign particular or foreign atom, has been accommodated in between the regular arrangement of the atom.

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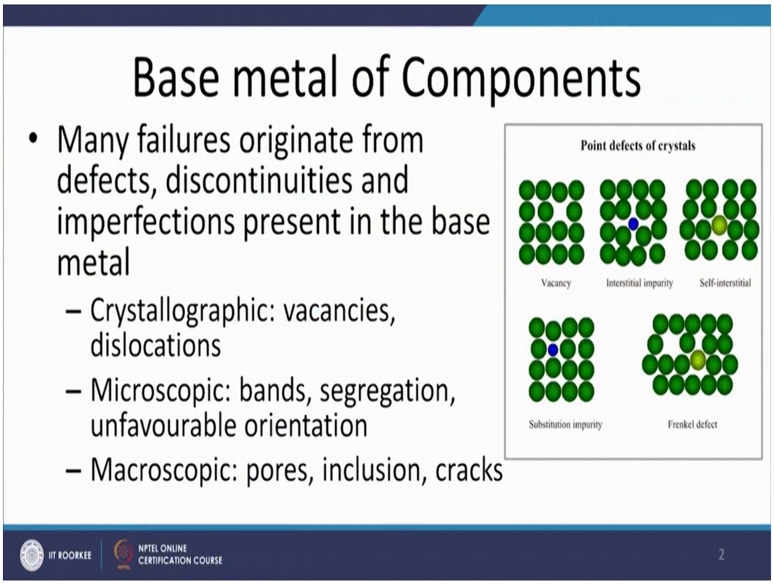

Which is like in interstitial impunity or then we can have like substitution impurity where, the atom is one foreign atom will be replacing the atom, which is which was present in the regular arrangement of the crystalline structures.

And here this is the freckle defect, where the disorder arrangement of the atoms exists. So, these are the crystallographic imperfections and at the level of them at the micro micro level imperfections. We have some of the defects like some of the elements have localise a presence or absence. So, which is termed as segregation either? So, when they are present in the large amount we call that things have segregated or they have depleted, if they are absent at other location.

So, this is one bending is another micro level defect, where certain faces are present in very localised way having a particular pattern. So, the bending is another defect or the issues may be in form of like say, unfavourable unfavourable the grain orientation, grain orientation. We know that the mechanical properties of the especially deformed components, are affected by the way by which grains are oriented in a given metal, and if they are oriented in the direction of the loading, like this then the mechanical performance seem proofs, but if the orientation is perpendicular to the direction of the loading, then it will adversely affect the mechanical property.

So, if the grains are unfavourably oriented or they have unfavourable geometry. Geometry is unfavourable, like high aspect ratio high aspect ratio constraints present in the metal matrix. If they are of the high aspect ratio like this in form of flakes needles or pit, like structures then they will be providing the easy source of the a stress concentration, at the particular matrix is interfaces especially near the tip of a such kind of the constituents like, in aluminium silicon alloy silicon is present in form of the needles in as cost condition. So, the tip of the needles act as a stress reserve that deteriorates the mechanical properties, in terms of the ductility and toughness and no sensitivity also improves.

So, these are some unfavourable or you can say the micro level imperfections, which can adversely affect the mechanical performance and the properties.

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So, now coming to the macro level imperfections may be in form of like say. The cracks are present maybe at the surface or below the surface. So, which will; obviously, be acting as a source of the stress concentration, these may be in form of the force, in form of the inclusions. So, these macro level imperfections actually act in 2 ways one is that like, if you either the crack is a internal or a inclusion is present of a particular at a particular location, or the big voids are present in form of like this say the pores.

So, such kind of the imperfections will actually be reducing the load carrying cross sectional area, if you consider tensile loading, if you consider this section. So, here entire cross section is sound. And so, it the stresses will be less, as compared to the case of this section, where we have a big void. So, the void will actually this region will not be carrying the load. So, the load resisting cross sectional area is actually reduced, when we have macro level imperfections.

So, even the nominal stresses are increase primarily due to the reduction in load carrying cross sectional area. This is one aspect, that for given load if the macro size discontinuity and imperfections are present, they will be increasing the even non the nominal of the stress, acting on the component, which we can say that actual. Load actual load resisting cross sectional area, and the load applied.

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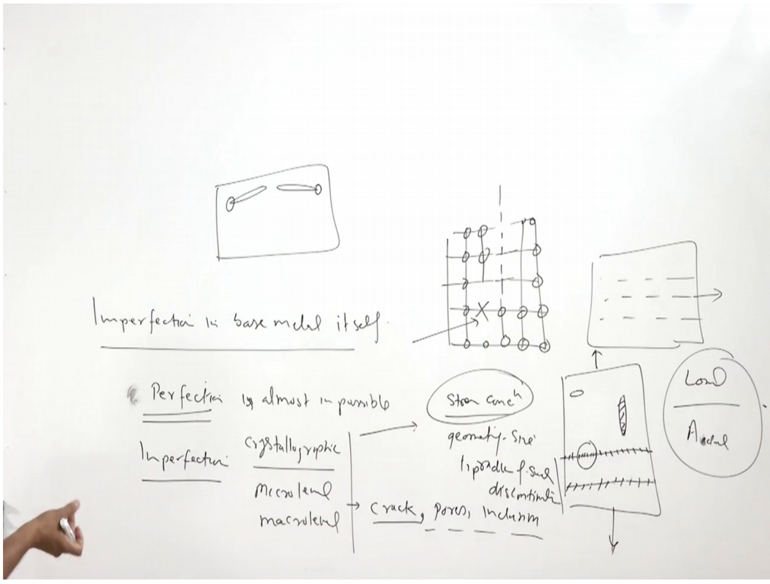

So, the load applied and the actual load resisting cross sectional area will be used, for calculating the actual stresses that will be acting. Apart from this actual load reduction in actual load resisting cross sectional area, due to the presence of these discontinuities these discontinuities also act as stress source of the stress concentration and we know, that the geometry geometry like size and the tip radius of the geome, such kind of the disk discontinuity radius tip radius basically, of of such discontinuities of such discontinuities it affects the stress concentration significantly. And lower the radius of the tip of the imperfection, in form of the crack inclusion or porosity or will be the stress concentration. So, such kind of macro level discontinuities, will be decreasing stress concentration and the load resisting cross sectional area, and both these are aspects will be increasing the tendency for the failure.

So, now we will be seeing the like say as I have explained if one complete plane of the atom is missing, then it will be leading to the dislocations like this. This is what has been shown as edge dislocation.

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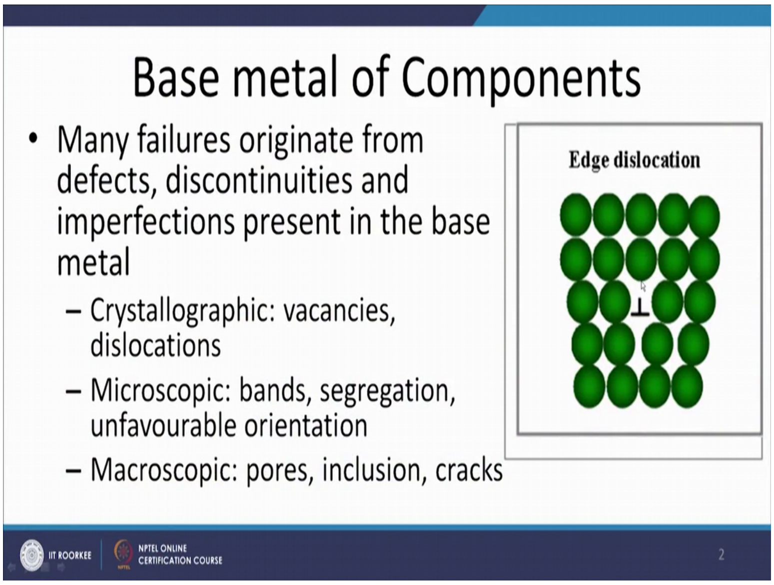

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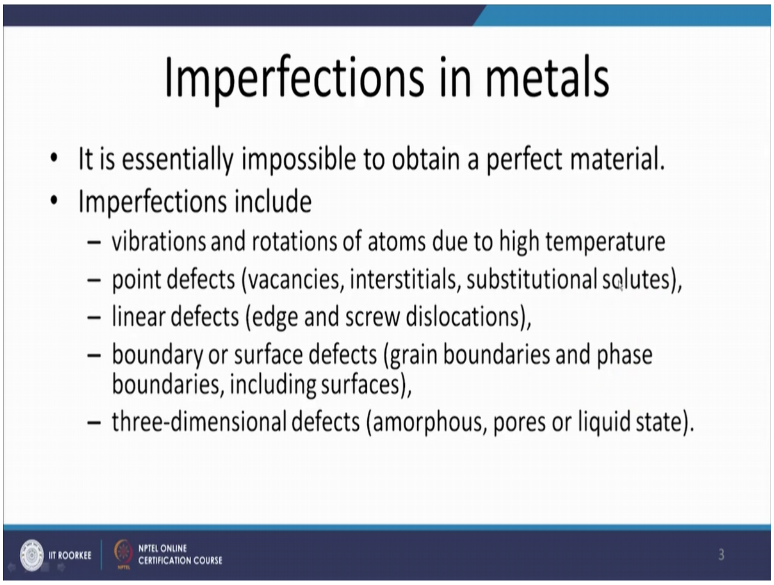

Now, this imperfections may be present in variety of forms like, when the metal system is heated the atoms start vibrating, or rotation at high temperature point, these imperfections may be in form of point defects like, at the vacancies interstitial is specious are failed in by for other foreign particles or substitution or solutes are present, these may be in form of linear defects like a edge and escudos locations and then boundary or surface defects in some of the grain boundaries. We know the grain boundaries are also are a form of the imperfections because, at the grain boundary arrangement of the atom is a highly disordered and a random.

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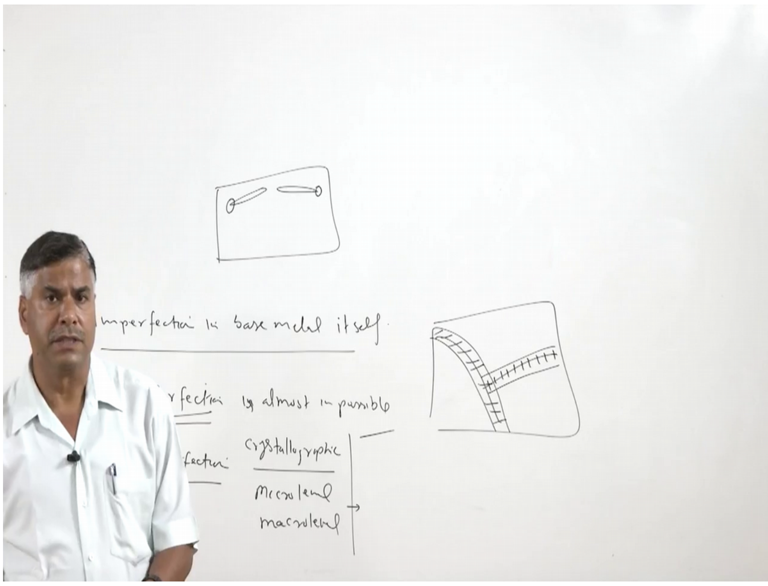

So, it is amorphous actually, it is not very order ordered arrangement. So, this grain boundary area also forms the forms a region of a lot of atomic imperfections, and the 3-dimensional defects may be in form of pores or of the amorphous constituents it is not always necessary that, these imperfections will be unfavourable sometimes these are helpful in realising some of the physical phenomena's, related with the manufacturing. For example, the vacancies and the atomic level imperfections help in the diffusion of the atoms and during the process.

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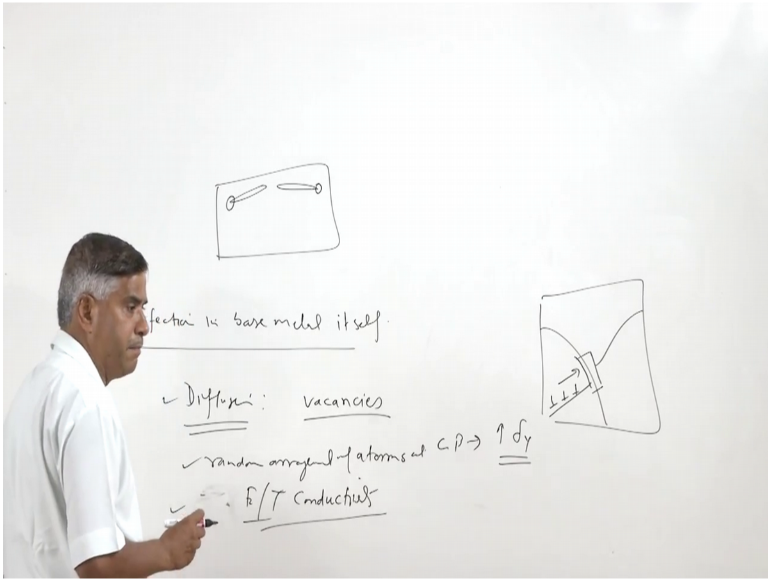

So, like lot of metallurgical transformation, under the diffusion bonding process all these involve the diffusion. So, the vacancies and atomic imperfections will be facilitated by such kind of the imperfections, then the presence of the random arrangement of atoms, at the grain boundaries this also helps in increasing the yield strength of the metal. Because, the wherever we have disordered arrangement of that term dislocations, can cannot cross that zone easily during the deformation and thereby the yield resistance, yield strength of the metal increases.

For example, if this is the metal this is the plane along which slip is taking place, on which there is a dislocations are moving. So, they will be stopped at the boundary, because this is the reason where disordered and random arrangement of the atoms exist and so the dislocations are not able to cross grain boundary area and thereby, the presence of the grain boundaries help in improving the strength of the metals.

In addition to the vac diffusion and the grain boundary formation favourably for increasing the strength the electrical resistivity electrical resistivity and the thermal conductivity, we can say that electrical and thermal conductivities, both are influenced by these vacancies and the crystallographic imperfections. Which will be facilitating the movement of the free electrons in the material and if such kind of the movement is restricted, then it will be leading to the reduction in the conductivity both in electrical as well as thermal form.

So, there are number of favourable things related with the imperfections, atomic level imperfections which will be helping to realise many physical phenomena, like the diffusion, the flow of current and heat the strengthening of the metal, by the grain boundary formation.

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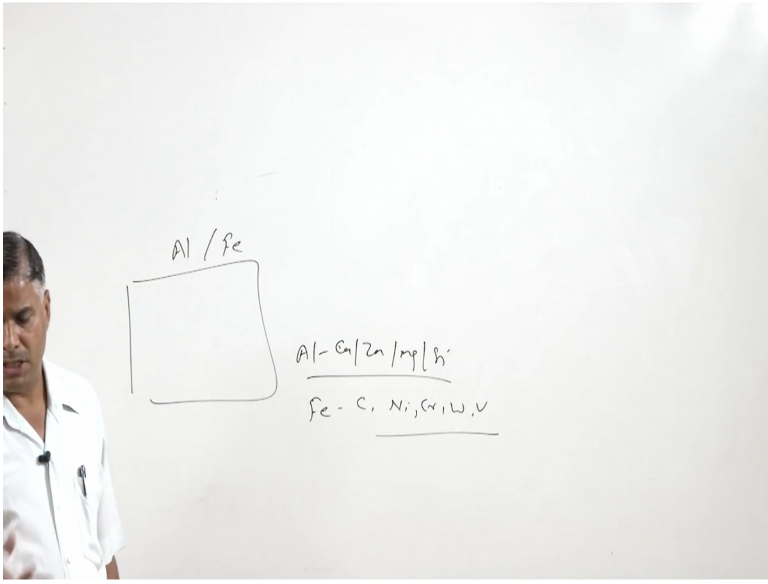

As we know that like if you take any metal system like aluminium or iron. So, for enhancing the strength of such kind of metal, we had alloying elements may be in form of copper, in aluminium may in from of copper or zinc or magnesium or silicon. Similarly in case of the steel, it is the carbon or nickel or chromium tungsten vanadium all these are added for enhancing the property and by controlling the concentration of the different elements, we try to enhance the performance of the iron or magnesium or aluminium based alloys.

But it is not just the composition, which solely governs the mechanical performance, it also it is also important that it is free from the imperfections, both micro and the macro level and in order to the micro level imperfections, which are like in form of the banded structures, segregation presence or absence of certain alloying element, at a particular location or the geometry of the micro constituents, which are governing the properties of the alloys.

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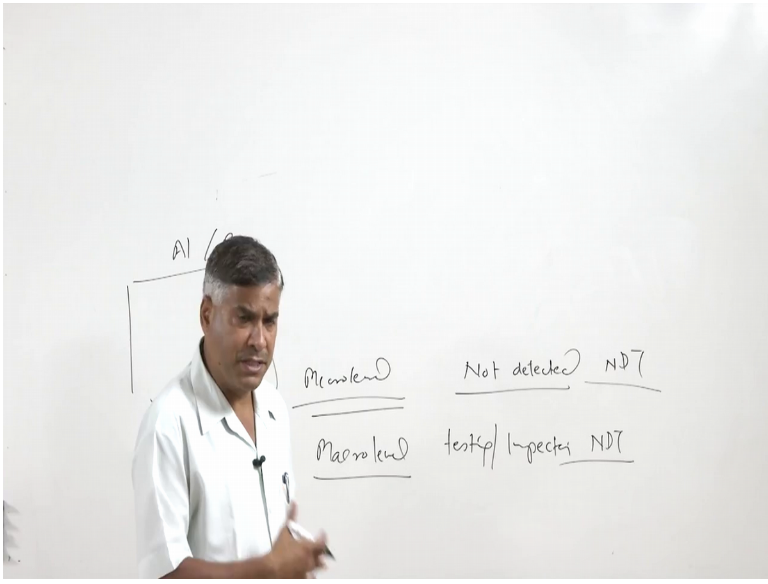

So, such kind of the imperfections, actually not detected using the conventional NDT techniques and therefore, such kind of the imperfections are most of the time overlooked, which can lead to the failure of the component during the service. Because, we have a setup for checking the commonly the macro level discontinuity is an imperfection, imperfections are detected using the simple the testing and the inspection procedures using dt NDT etc.

So, the macro level things are taken care of using NDT and the testing procedures. So, chances will be less for their presence and the therefore, most of the failures are caused by the technological regions, associated with the micro level imperfections which are present in form of unfavourable grain orientation, segregation, undesirable grain structure, undesirable phase which are present.

So, despite of having the same composition, we may have something else what is not really favourable for performance of the system under the given service conditions and that in turn can lead to the failure. So, the macro aspects as I have said, taken care of using the using suitable entity devices, but not the micro aspects we will be talking about certain micro discontinuities, which are frequently become the cause of the failure these may be in form of like, the dissolved gases, presence of the dissolved gases, in the base metal in form of hydrogen nitrogen and oxygen.

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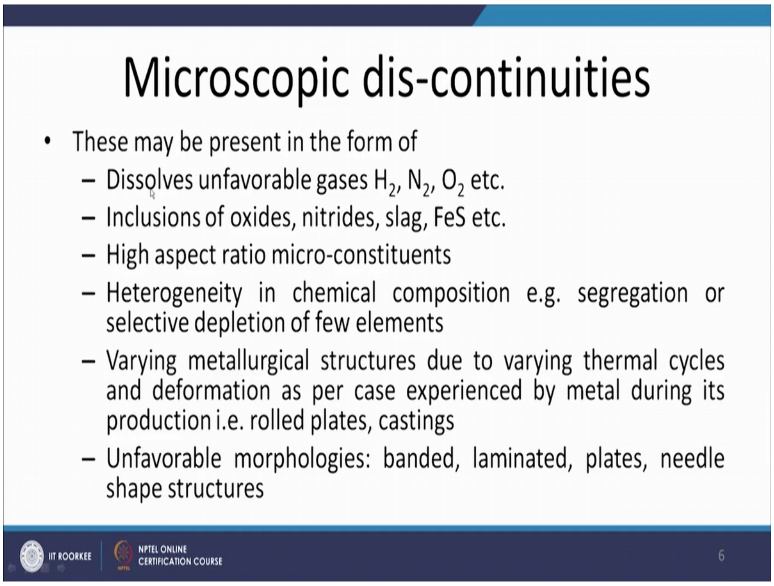

So, these gases will either be forming their oxides, nitrites or hydrides or these will be acting as a pores or these will be also acting as like hydrogen in steels act, as a source of the cold cracking or the delayed cracking.

Similarly, the formation of such oxides, nitrates, slags or sulphites will be present in form of the inclusions or metallic continuity and thereby becoming the source of the nucleation for the cracks under the cracks and void formation, under the influence of the external loading. Similarly, high aspect ratio constituents like plates, needles, etc, and the platelet us etce, act as a source of the stress concentration. Especially at the particle matrix interfaces and thereby they provide easy site for the nucleation of the voids and cracks chemical heterogeneity is about the presence or absence of certain things, at a one location and which will be leading to the heterogeneity, in mechanical properties as well as increased chances for the corrosion. Because, the varying compositions and at the difference in the phases which will you formed, due to the chemical heterogeneity that will be leading to the formation of the galvanic cell cells easily and that will promote the corrosion also.

So, chemical heterogeneity in form of segregation or selected depletion of the elements can adversely affect the mechanical properties as well as the corrosion resistance. Similarly, the varying metallurgical structures, due to the different thermal cycles and deformation experiencing during the metal processing, for manufacturing like the rolling or the casting that also, leads to the heterogeneity in terms of the mechanical properties, across the section and that under the unfavourable service conditions can become the source the fail failure. Then unfavourable morphologies like, morphologies about the size and shape of the micro constituents. So, if they are in form of like the banded structure or laminates plate needles etc, then these will provide the easy source for the failure.

Coming to the macroscopic features, which are normally present in the in the base metals, like the base metals are normally produced through the 2 routes, one is our as cast test things in form of the ingots or the billet us or these are further rolled down to the thinner sections like plates seats etc, so either as cast components or the posed or the rolled component. So, the deformed components we can say. So, when the things are produced base metal is produced by the casting only then, we may have the defects in the cast base metal in form of cold shut, inclusion pores shrinkage voids etc.

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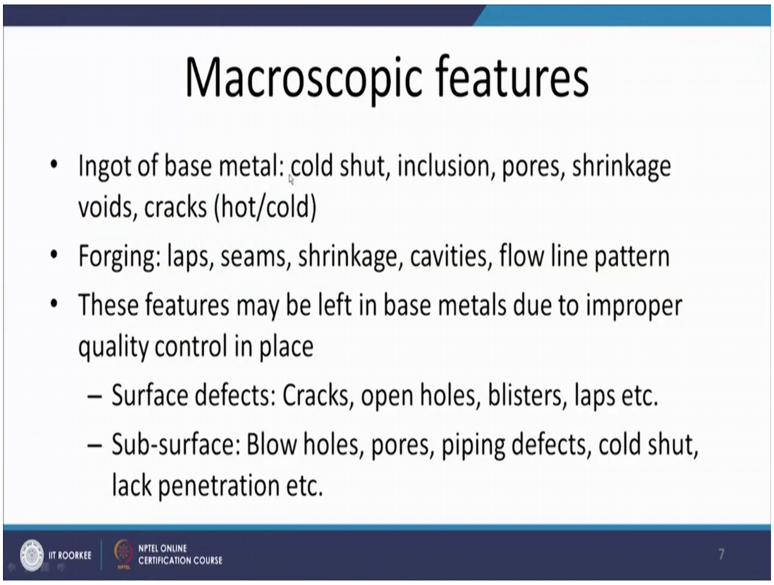

So, if the base metal is having these discontinuities, then in manufactured product these discontinuities can become the source of the fracture or the failure.

Similarly, in the post components the base metal produced by the deformation base processes like, forging or the rolling then, then we may have the defects like laps seams shrinkage, cavities and the flow line patterns, unfavourable flow line patterns and which may provide easy source for the nucleation of the voids and cracks, under the influence of the external loading. So, these features if they are left in the base metal, due to the improper quality control then, this will be leading to the presence of this defects in at either the surface, in form of cracks, open holes, blisters, laps etc, or the subsurface defects like blowholes, pores, piping, defects, cold shut lack of penetration in in the subsurface zone.

Whenever these are present, as I have explained just now whenever these discontinuities especially the macro level discontinuities are present, this will be affecting the performance of the component, under the external loading conditions in 2 ways, one either these will be acting as a source of stress concentration and second they will be reducing the load resistance cross sectional area, and both the cases the stress magnitude acting around these nearby these discontinuities, that they will be increasing. So, stress magnitude nearby the discontinuities will be increasing and which in turn, will be promoting the tendency for the failure and. So, most of the macro discontinuities increase the maximum stresses, much higher than the nominal stress are due to both of above factors.

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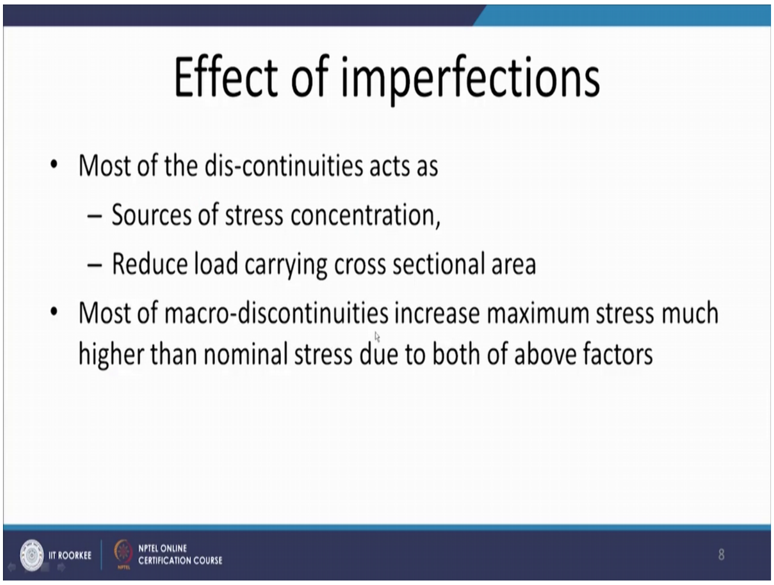

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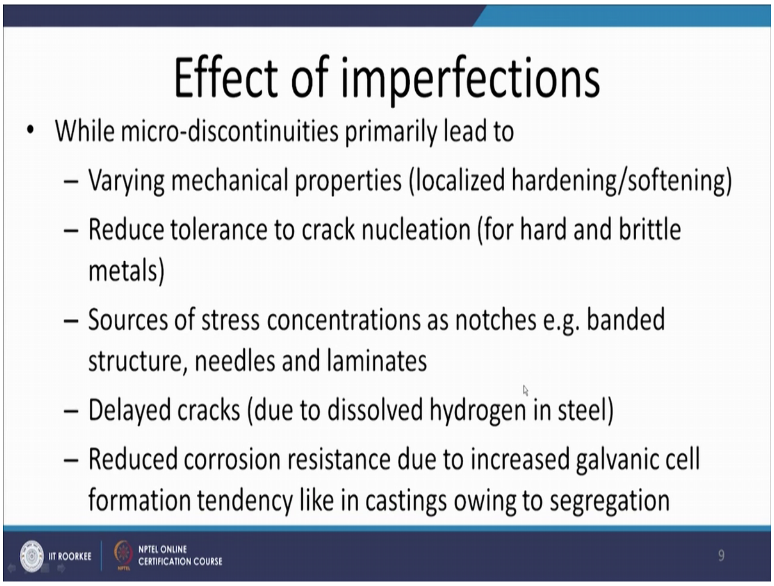

So, as I have explained, the while the micro discontinuities primarily lead to the varying mechanical properties, all reduced the tolerance to the crack nucleation sources of the stress concentration, delayed cracking in form if the hydrogen gases, present in the steel and reduce corrosion resistance. So, the implications of the micro level discontinuities, I have already explained either these connect as a variation in mechanical properties, due to the metallurgical homogeneity and chemical homogeneity metallurgical heterogeneity or the chemical heterogeneity. These can also which can lead to the either very soft formation of soft zone or hard zone of the hard zone is formed, then this will be reduce into this will be reducing the tolerance to the crack nucleation, this can also act as a stress results in form of, if they are present in form of the banded structures needles and the laminates and the delayed cracking is observed, the hydrogen is dissolved in steel and due to the chemical heterogeneity, there may be increased possibility for the galvanic cell formation, which in turn will be reducing the corrosion resistance.

Now, there is one case study. Now, there is one case study they related with metallurgical heterogeneity and how the failure is caused? In this particular case the failure of case study of failure of the forced connecting rod is presented say, the connecting rod was made of the medium carbon steel and the failed steel and the failed rod composition, when analysed using the spectroscopy was found within the limits. So, composition of the failed connecting rod was found, within the limits and microscopic studies showed that, there was no metallurgical imperfection in form of like segregation or like that, then it was found that the hardness of the connecting rod was, 140 BHN is in place of the recommended value of 160 to 205 BHN.

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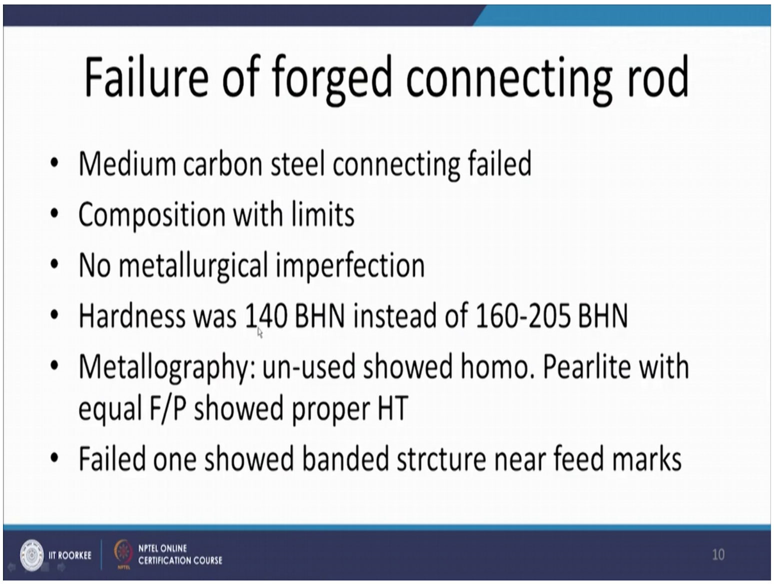

Metallographic of unused, showed the homogeneous pearlite with equal amount of the ferrite and pearlite, which shows that the proper heat treatment was carried out, but the failed one. So, this was the proper metallography showed that, of the unused means unfailed connecting rod showed that, the structure was pearlitic and pearlitic and ferritic with equal amount of the both pearlite and ferrite and which is suggesting that, proper heat heat treatment was carried out and the failed one showed the banded structure near the feed marks.

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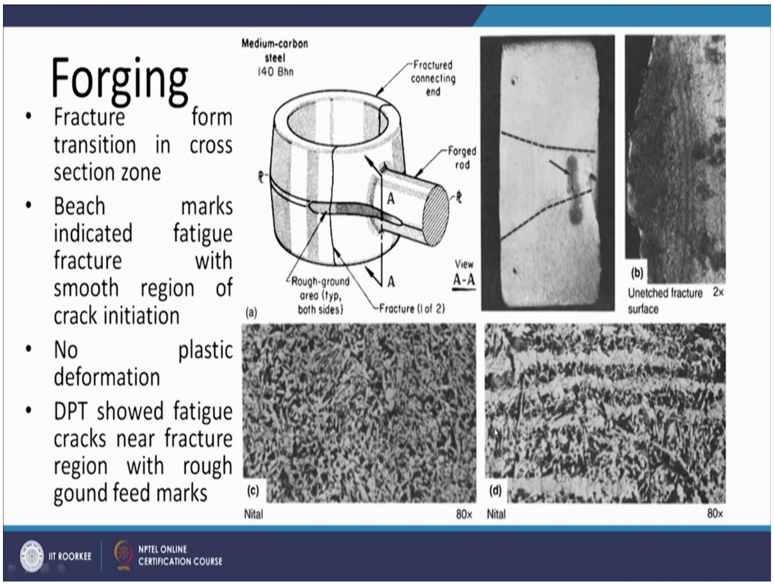

So, here this was basically the connecting rod, which failed from this particular location and in this it is cross section is shown here, which is suggesting that the crack nucleated somewhere here and the microscopy of the unused unfilled component showed that, it had the ferritic and pearlitic with approximately equal amount of the ferrite and the pearlite.

So, the fracture and while the failed one showed the banded structure, where the bands of the ferrite like this white or light zone, is showing the bands of the ferrite. So, since the ferrite is weaker than the pearlite. So, under the if these kind this kind of the banded structures fall in the zone of the high stress area, then these easily provide the source of the stress concentration source of weakness and where from cracks can easily nucleate.

So, in this particular case, this region where from fracture took place actually was subjected to the rough grinding and at the same time this also had the banded structure and this area was falling under the high stress zone conditions. So, these conditions let to the easy nucleation of the cracks in this areas and subsequently the growth and here, the beach marks in the fail component, is suggesting the fatigue the failure or the fracture of the connecting rod by the fatigue. So, the fracture from the transition in the cross section was absorbed, beach marks indicated that, fatigue fracture with the smooth region of the crack nucleation.

So, this region which is the smoother one indicating, the location where from it has initiated in in the direction in which it has grown subsequently and no plastic deformation also suggest the typical condition, corresponding to the fatigue fracture and dpt means dye penetrant test of the location, near the fracture surface showed that few fatigue cracks were present, and nearby those locations also the rough ground feed mask were also absorbed.

So, you see the presence of the rough ground feed marks and the bended structure and somewhat lower hardness, in high lower hardness especially in high stress areas lead to the nucleation and the growth of the fact and growth of nucleation and growth of the crack, which subsequently lead to the fracture by the fatigue.

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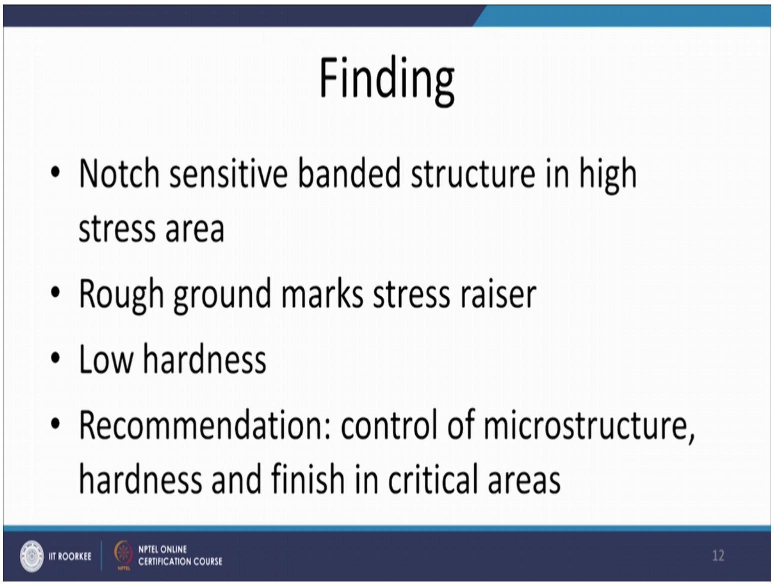

So, no sensitivity due to the banded structure and high stress areas, rough ground marks acted as a stress raiser low hardness resulted in the fatigue fracture of the connecting rod. So, recommendation was to control the microstructure properly. So, that the banded structures can be avoided and hardness can be maintained within the specified limit, of 1 6 160 to 205 BHN and the surface finish is also maintained properly, instead of forming the rough ground feed marks especially in high stress areas.

So these, over the recommendations in order to avoid the failure of the connecting rod due to the fatigue; so now, I will conclude this presentation. In this presentation basically, I have talked about the, importance of the imperfections, crystallographic imperfection sometimes favourable, but the micro and macro level imperfections are unfavourable, and most of the time these act as a source of the failure thank you for your attention.