Failure Analysis & Prevention
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Lecture - 10
Fundamental Sources of Failures: Improper Manufacturing IV and Improper Service Conditions

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 failure. And under that we are also talking about the improper manufacturing conditions. So, although various aspects related with the improper manufacturing conditions; we have talked in the previous presentations.

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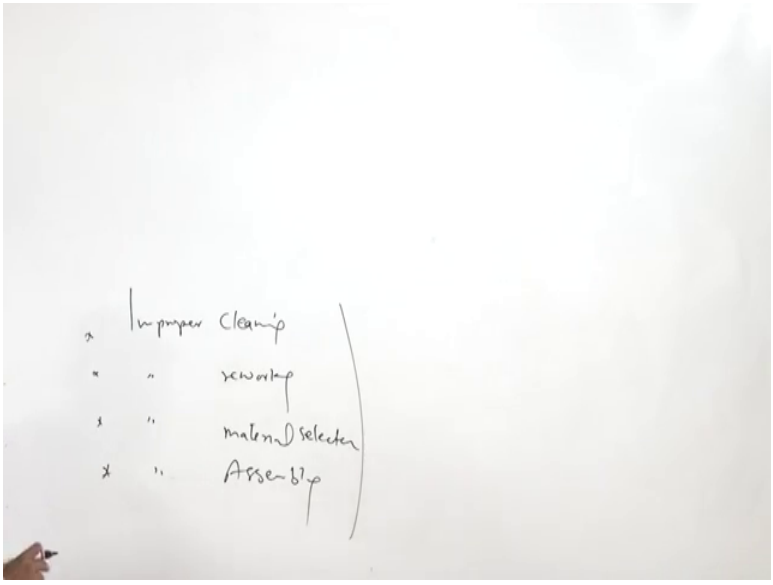

In this one will be taking of the improper cleaning procedures, if they have been applied improper reworking methods, if they have been applied, then improper material selection if it has been made then also the component can fail. And then improper assembly of the components

So, these are the 4 aspects about which we will try to talk let us see, that how much we can talk in this presentation related with the improper manufacturing. So, here we know that most of the metals interact with the environmental gases like, oxygen, nitrogen and hydrogen.

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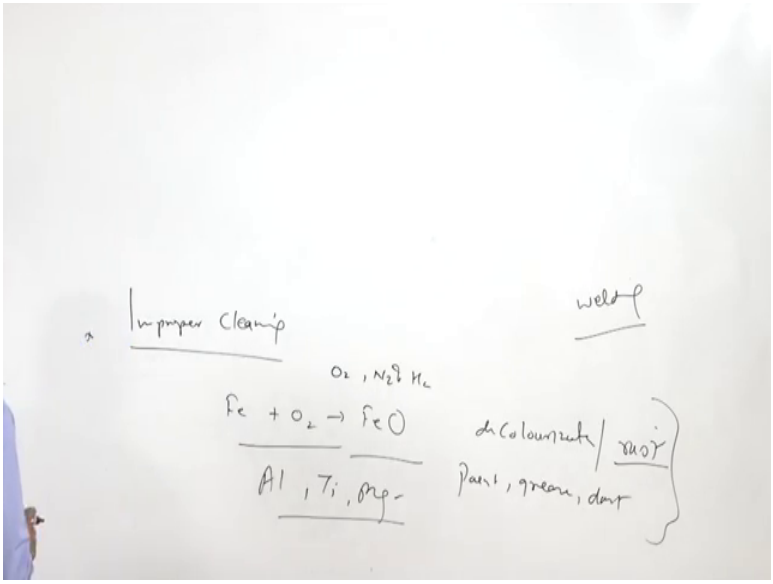

And this kind of interaction becomes very aggressive at very high rate especially in the high temperature conditions.

So, like iron when interacts with the oxygen, it forms the various types of the iron oxide like Fe 3 O 4; Fe 2 O 3 etcetera. So, such kind of the oxides they lead to the decolourization, or sometimes it appears in form of the rust also. So, similarly the aluminuim, titanium, magnesium all these also forms their oxides which will present at the surface. In addition to that some of the impurities in form of like paint, grease, dust, dirt etcetera; if it is present during the manufacturing under the during manufacturing by various processes the cleaning is required.

For example, before welding, we need to clean the edges of the plates to be welded or the edges of the plates which have been machined out needs to be prepared by cleaning so that during the welding all these impurities if they are present at the surface, they can be removed to produce the sound inclusion free weld joint.

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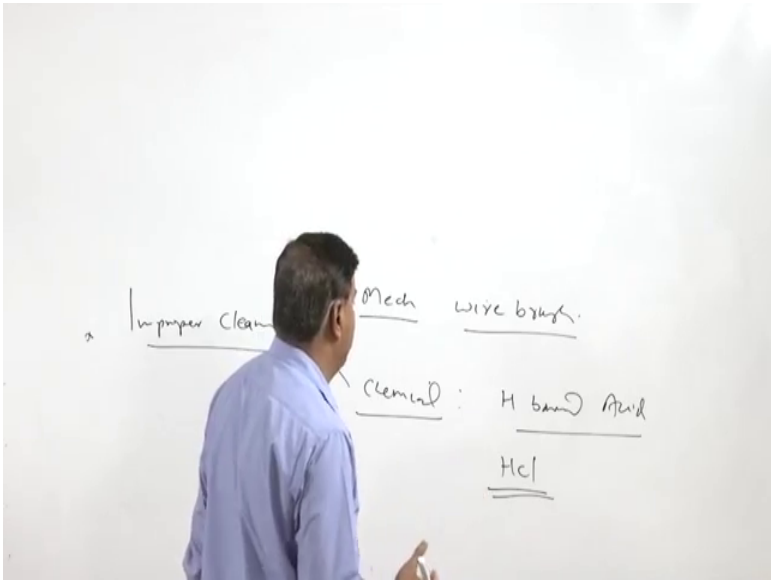

So, the cleaning is required, one typical example here is mostly for this kind of cleaning their various methods are of the cleaning; like, in the mechanical methods where wire brush metallic wire brush is commonly used. Apart from that, in chemical cleaning like scratching also we can consider that. But there is like chemical cleaning some of the oxides which are very adherent very nonporous, then chemical cleaning is applied. And mostly the hydrogen based acids are used for this purpose.

So, like say Hcl is commonly used for removing the rust or the oxide scale, from the surface of the steel. So, these hydrogen-based acids when are applied on the surface of the metal to remove these impurities, frequently this hydrogen gets introduced on the surface of the component.

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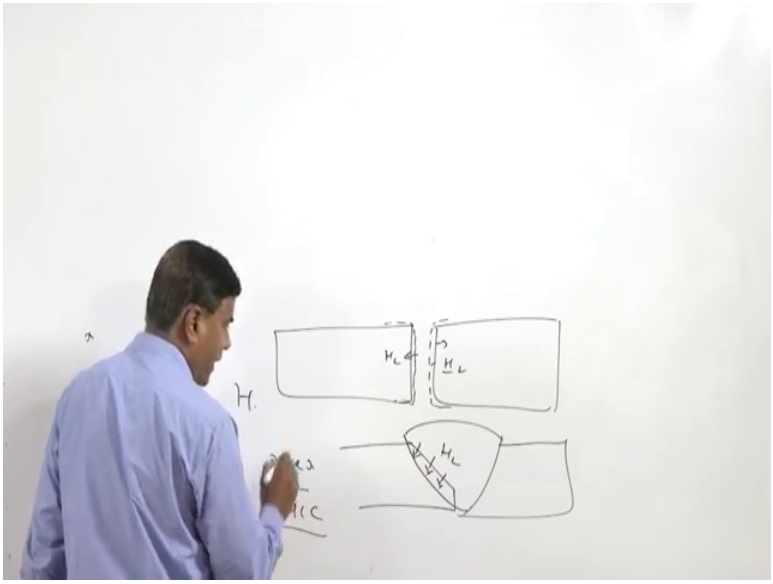

Like say the component clean by use of the hydrogen-based acids, and if hydrogen gets introduced into the surface of or; in the subsurface region of the base metal; so, this introduction of the hydrogen into the base metal has to be taken care of and if it is not done then like the edges of the plates prepared introduced with the hydrogen during the cleaning.

And subsequently, either welding or the development of the coating will be leading to the hydrogen related problems, which may be in form of like say fine pores or like hydrogen induced cracks in case of the hardenably steels, or like fine pores in case of the aluminium alloys. And this kind of phenomena is especially a problematic if immediately after the cleaning either welding is performed or some kind of coating is applied.

And therefore, such kind of the hydrogen if it has been introduced on account of the chemical cleaning must be removed and for this purpose.

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Normally heating of the components, components clean using the acids has to be applied so that through the diffusion all the hydrogen introduced can be diffused out into the atmosphere so, that the components can be made free from the hydrogen and the related adverse effects.

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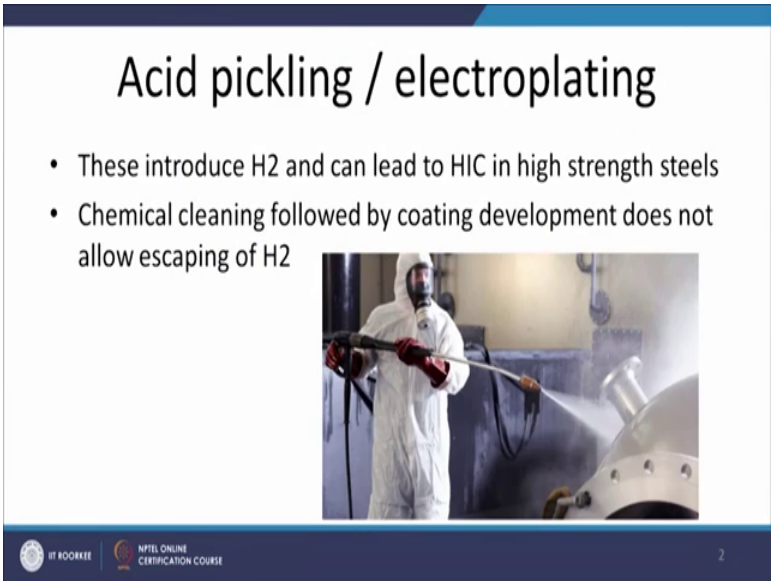

Another aspects; so, this is what we can see here during the acid pickling or followed by the coating, or the welding hydrogen introduced and this hydrogen can be problematic especially in case of the high strength steels in form of hydrogen induced cracking, and

the chemical cleaning followed by the coating becomes more problematic, because it does not allow the scrapping of the hydrogen from the metal which has been cleaned by the acids.

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This is one typical diagram show photo which is showing that how the chemical are used for the cleaning purpose reworking under the repairing is the another important aspects. We know that whether it is casting having the surface defects, which are open in form of like say the blowholes, cracks, or other defects which can be corrected using the by deposition of the metal.

So, such kind of the casting like say if there is a problem then this portion is gauzed out and then metal is deposited a fresh so that such kind of defect can be taken care of. So, this is called like in all these cases there will be partial processing of the metal, which may involve like partial melting, to correct the defects to rectify the defects if they have been introduced in course of the manufacturing processes.

this is one example where immediately after the casting we have recognised that there are defects and discontinuities, and which needs to be corrected. So, that unnecessary so that the component after the reworking can be can be used for the purpose for which they have been prepared. So, this is one aspect of the repairing and reworking.

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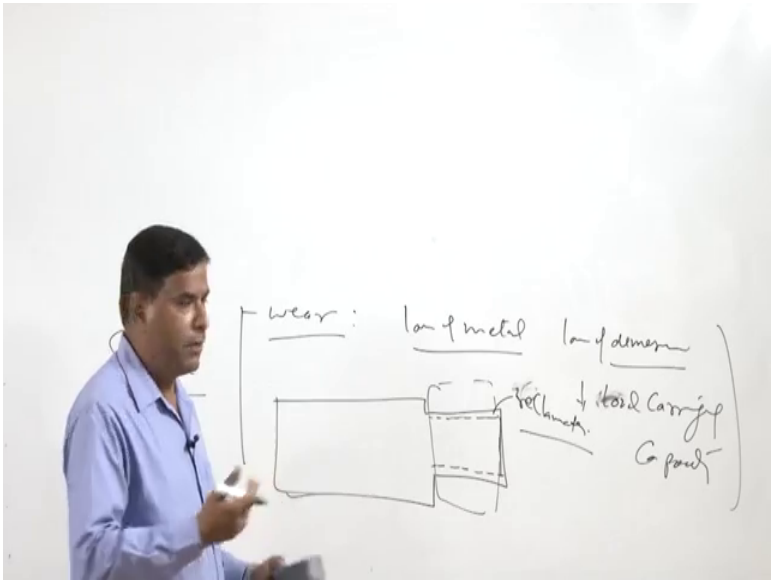

Another is like during the service also, we come across the variety of issues like the component if subjected to the wear over a course of over period of time, we will see that wear leading to the loss of metal from the surface, which is leading to the loss of dimensions. And loss of dimensions leads to the malfunctioning of the component or can lead to the reduction in even their load carrying capacity.

So, reduction in load carrying capacity due to the loss of dimensions and this needs to be taken care of and for this purpose. Normally, the metal like say the component is this and part of it has been worn out say this is the region which is subject to the saviour conditions, and the loss of metal has led to the reduction in dimensions like this and so, we need to rebuild the dimensions which is called reclamation.

And the reclamation is nothing it is just deposition of the matter from outsides by the welding or any other coating process so that the dimensions can be rebuild, and they can after the machining the same as the original one can be prepared. So, this also involves the reworking. But in all these reworking approaches, the partial melting and partial processing of the metal is involved. And if it has not been done properly, then it leads to the various issues which may be in form of; like say the development of the heat affected zone.

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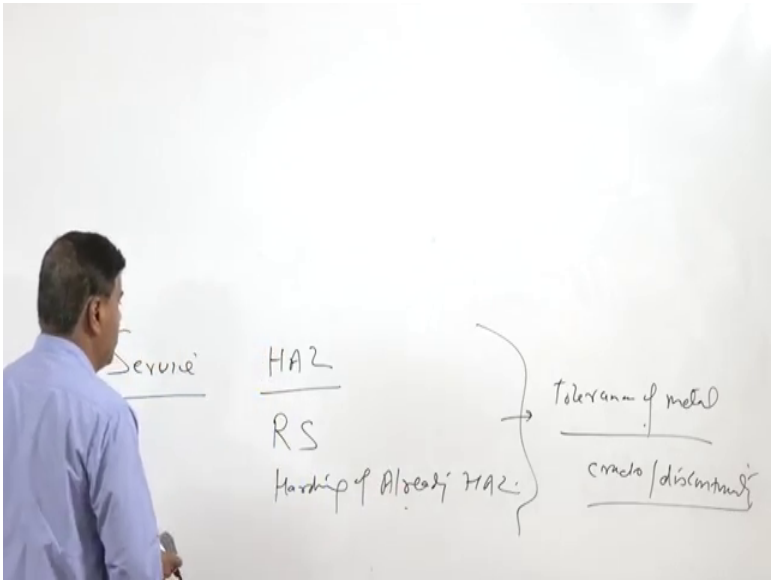

Or it can lead to the development of the residual tensile stresses, or it can lead to the excessive hardening of the already existing HAZ. So all these sensor will be increasing the sensitivity of the metal towards the tensile stresses, towards the shear stresses and towards the notches if they are present. So, basically these will be reducing the tolerance of the metal system or the component which has been reworked, for the cracks and discontinuities.

So, it is always preferred that if the reworking is to be done, then the issues related with the formation of heat affected zone due to the partial melting development of the residual stresses, and the development of the heat affected zone again over the already existing heat affected zone can be taken care of properly. So, that unnecessary increased sensitivity of the metal towards the discontinuities can be reduced.

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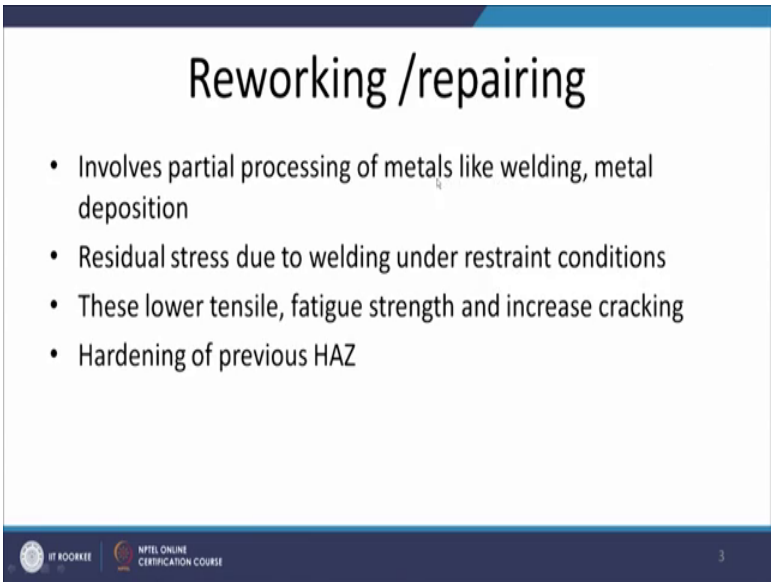

So, as I have said reworking and repairing involves partial processing of the metal, using processing like welding and metals deposition which may involve again the welding, or the thermally processes residual stresses due to the welding under restraint conditions can really adversely affect the in the fatigue strength, tensile strength increased cracking tendency.

So, a combination of the tensile residual stresses, and reduced ductility increased hardness actually lower the tensile strength fatigue strength and increased and these increase the cracking tendency. So, these are the different ways by which the failure can occur during the reworking. So, reworking has to be planned out procedures for reworking has to be developed properly so that these aspects can be taken care of. And it is not the difficult to establish that if they have contributed towards the failure.

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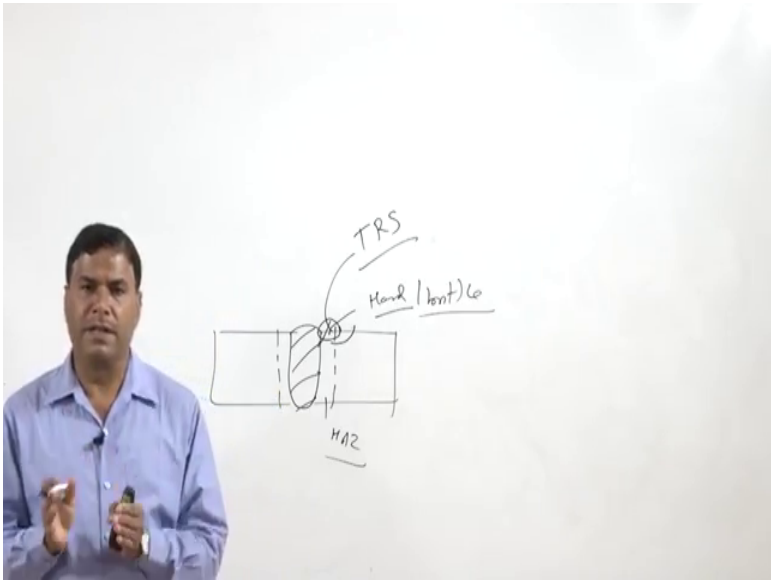

For example, like if we have one these are the plates, which were welded, and during the service if the crack was founded here like say in the heat affected zone. So, obviously, it will the due to the earlier welding there will be one heat effected zone. To take care of this crack again the metal is deposited since this is already hard, and this is brittle having the tensile residual stresses, and if again the welding is applied for reworking purpose repair purpose in this area, then this will be creating another heat affected zone one, and this will be introducing the tensile residual stresses.

So, this zone in any cases going to be a source of the weakness source of the problem if; all these adverse effects are related with reworking and repair are not taken care of. So, reworking is procedure for reworking has to be established properly and then accordingly should be established; else it can be the another source of the weakness and source for the failure.

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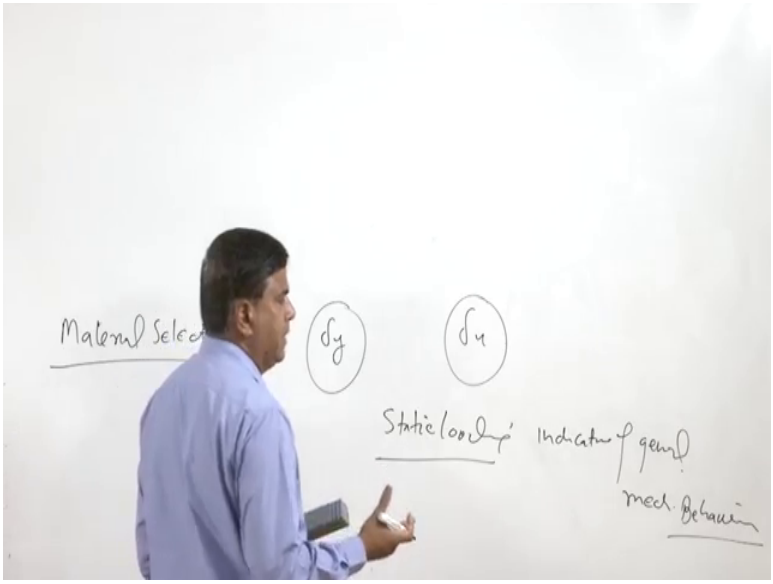

Another important aspect is about the material selection. we know that most of the designs are made are based on the yield strength of the metal like if the deformation is to be avoided then we take some factor of safety whether here to the yield strength to determine the allowable stresses. And similarly, if the fracture is the criteria then may be ultimate strength and some factor of safety to determine the tensile stress.

But these are the 2 properties which are good for the static load conditions. And these are indicative of the general mechanical behaviour, general mechanical behaviour, under the normal ambient conditions. The show the mechanical resistance of the metal means resistance of the metal towards the external loading in very general way. So, these are obtained through the tensile test.

So, the tensile test tensile properties are extensively used for the design purpose, but these may not be applicable for entire range of the applications. Because in some of the cases this be these becomes these become very irrelevant. So, the first thing is inadequacy of the tensile data, tensile inadequacy of the tensile data.

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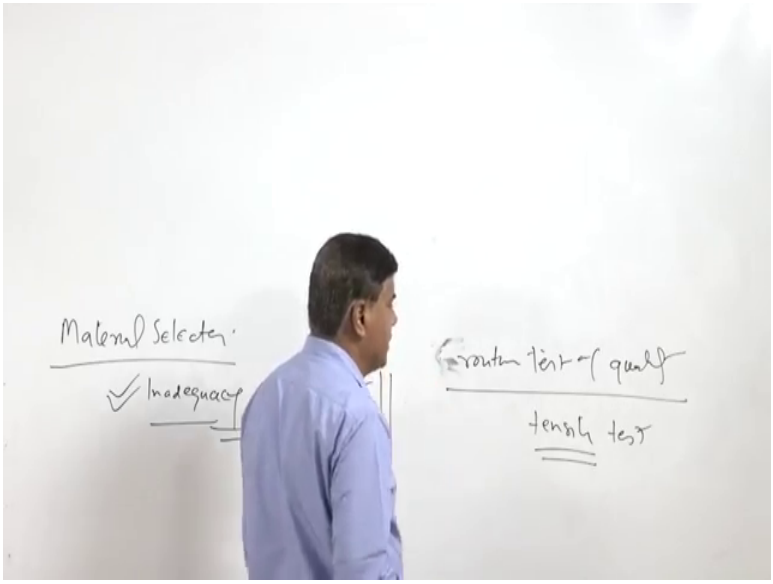

So, means the tensile data really does not represent to the suitability of the material for the entire range of the applications, which may be in form of like the fluctuating loads in the corrosive environment or the load carrying capacity at high temperature load carrying capacity under the room temperature means the low temperature or some 0 temperature conditions.

So, different approaches different parameters need to be considered apart from the tensile load tensile data for selection of the suitable material tensile data. So, only is not sufficient to for the design purpose if for entire range of the applications which we come across. So, this test is good for the routine, routine tests of the quality of the material. We know that the steel is made or the metals are made in different batches, like, the different heats and each heat will be producing a particular amount of the metal. So, what is the general quality of the metal that is checked using the routine tensile test, it is good for that.

So, routine general quality test is can be effectively performed using the tensile test, but if it is to be designed for the specific if the component is to be designed for the specific applications then it is required to consider specific set of the properties. So, this is one aspect the tensile data we should not rely much on the tensile data for the design purpose, but the criteria has to be selected appropriately.

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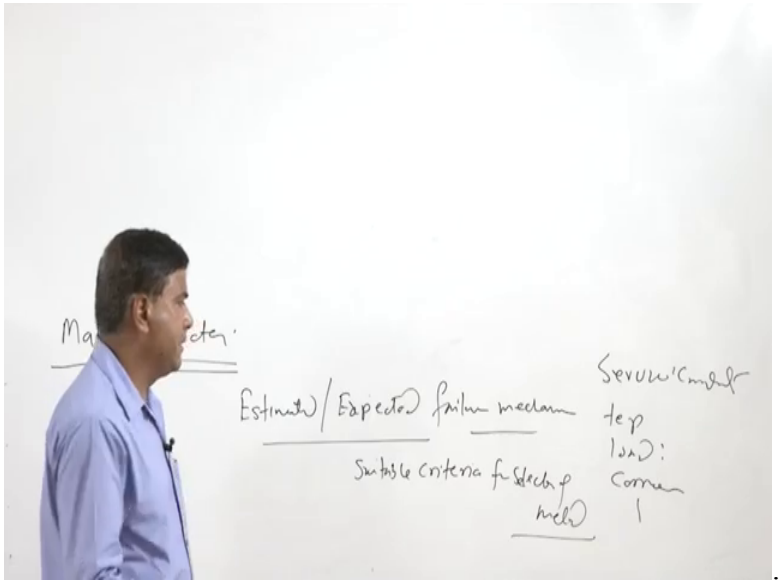

And for that purpose, one thing is to be considered the estimated or expected failure mechanism. As per the obviously, we need to consider the service conditions which may be in form of like say the temperature load, corrosion, load type of load rate of loading temperature high low etcetera.

So, all these conditions will be giving us idea about the potential mechanisms which can lead to the failure of the material and this expected failure mechanism should be the basis for the selection of the suitable criteria suitable criteria for selection of the metal. So, about various parameters and properties that we need to consider we have already talked earlier. it is just to reiterate that we need not to over rely on the tensile data, and as per the service conditions suitable means the expected failure mechanism need to be identified. And so, that the component designed can survive and can deliver the intended service for the design life of the component.

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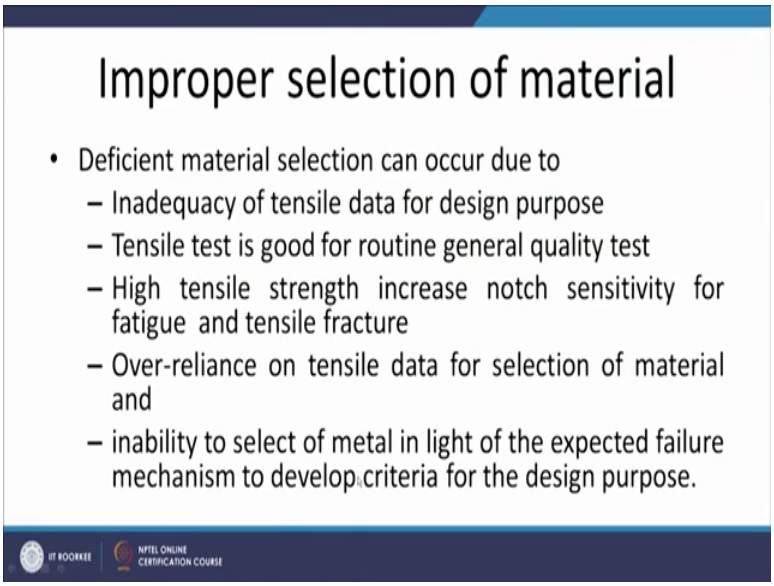

So, here and if that does not happen like if we do not select the material in light of the expected failure mechanism, then it can lead to the premature failure of the component.

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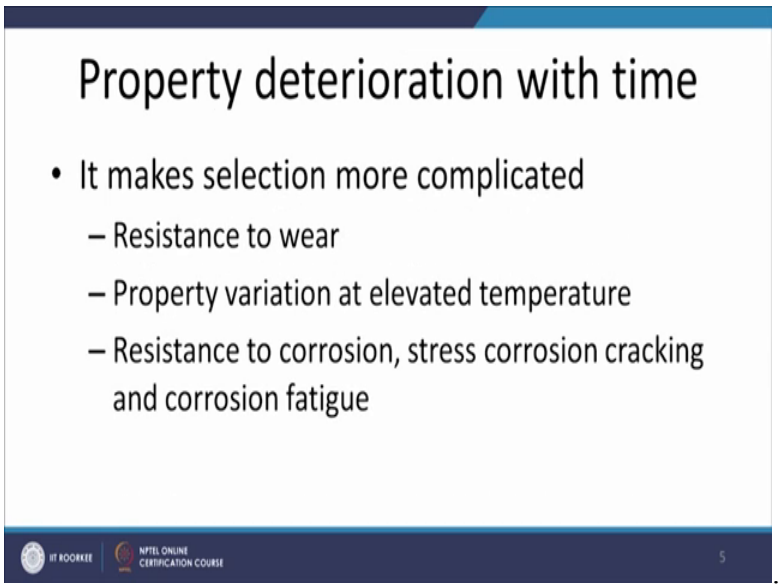

The selection of the material really becomes complicated and more difficult in certain situations.

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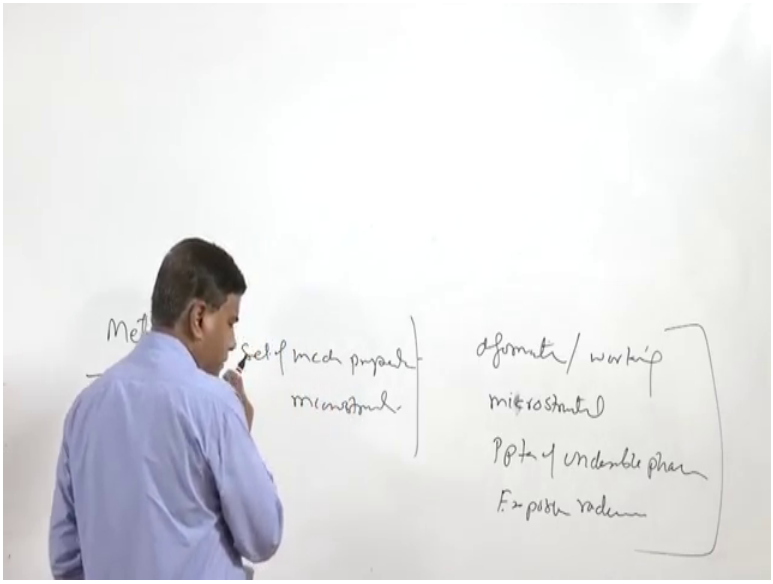

We know that if we take any metal. So, metal initially has and when it is produced it will have one set of the mechanical properties, as well as it will have one set of the microstructure.

But during the service so many things happen; like, it will be subject to the surface layer deformation it will be subject to the microstructural variation, microstructural variation it may be. So, deformation will be leading to the work hardening microstructural variation precipitation of undesirable phases or exposure do the radiations which are harmful for the structure and the properties of the components.

So, those things which will be altering the properties the properties microstructure and the deformation condition, means the plastic means the metals the metal condition in terms of the deformation. So, all these things will be adversely affecting their load carrying capability; so especially the properties which properties for which resistance of the metal changes as a function of time. for those application selection become difficult.

For example, here the wear; whenever wear happens like it may be like abrasive or adhesive or erosive or cavitation the surface is exposed.

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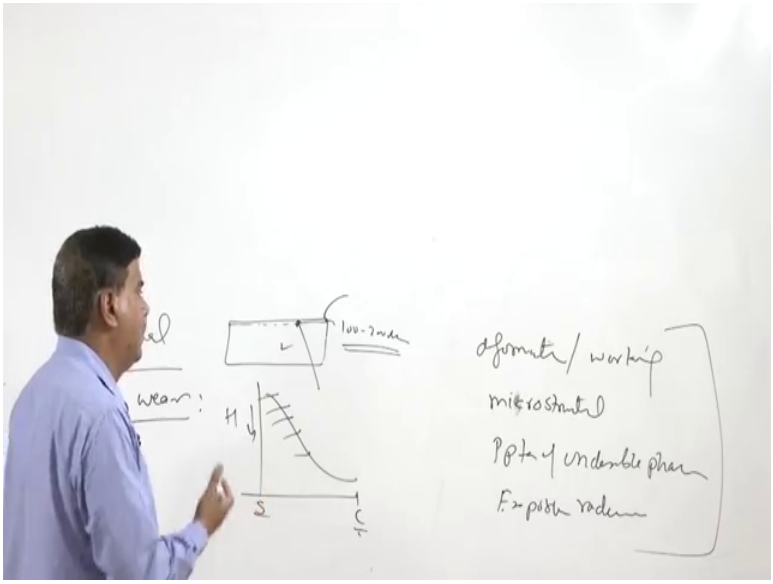

So, wear surface layers are exposed to the external conditions. So, in case of say adhesive here wear surface layers have to say 100 to 200 micrometre depth these are condition in terms of the chemical composition in terms of the deformation. And so, the properties found to be different at the surface and in the core region. And normally this trend becomes like this where surface, and wear surface layers are harder as compared to the subsurface zone.

So, here if this is surface and this is the core, then the hardness will be decreasing as we increase the distance from the surface. And go down into the core of the materials. So, this distance is; so, in all these cases as the materials material subject to the wear the surface layers get deformed chemically modified and forms various kind of the mechanical mixtures which will be altering the surface properties; so, this one case where the properties change as a function of time.

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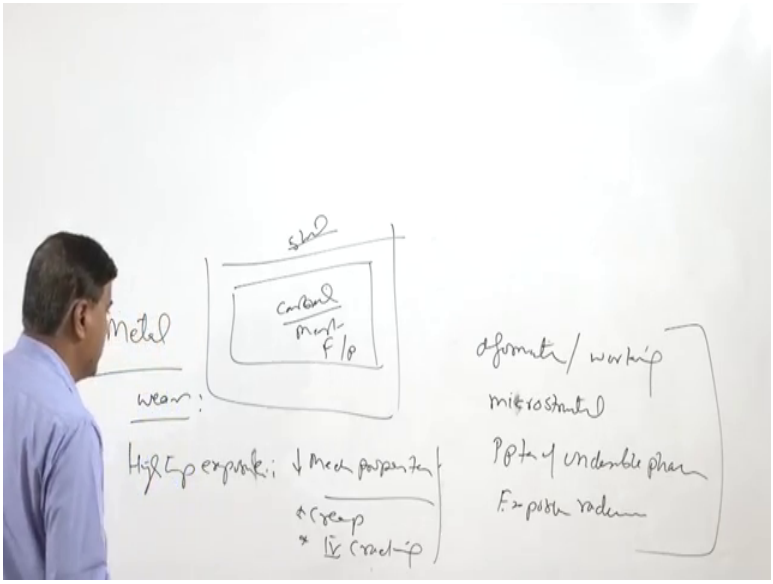

Another example is high temperature exposure high temperature exposure. So, here we know that as a function of time like there is metal system like steel having the different carbides design for high temperature stability, may be martensite ferrite pearlite etcetera, all these are there in initially in the desired form.

But when if the component is exposed at high temperature for longer period, all these tend to get destabilised carbide tend to get destabilised, and they will get coarse and fine carbides will be dissolved or they will be eliminated which; so, these things basically lead to the reduction in the mechanical properties, there mechanical load carrying capacity is reduced.

And therefore, high temperature exposure frequently leads to the creep this is one thing. And also, sometimes the cracking, it is called tie for cracking is also observed if the unfavourable metallurgical transformation, after a long time at high temperature takes place especially in the chromium molybdenum steels, then the type of cracking is also observed.

So, these are the changes which are which will be experienced if the steel is exposed at high temperature. So, there is a particular temperature limit up to which a particular steel can be used. Thereafter it will it is hardness will decrease there will be loss of the alloying elements in form of decarbonizing there will be instability of the structure etcetera.

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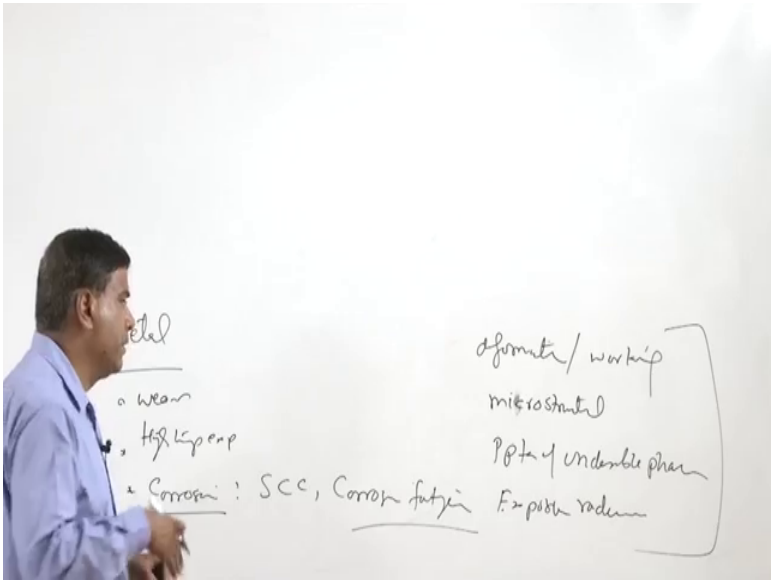

So many things happen and; so, apart from the wear and the high temperature exposure there is a third thing that is about corrosion. Resistance to the corrosion is also adversely affected especially stress corrosion cracking and the corrosion coupled with the fatigue. So, the resistance of the metal to these environments is gradually decreases as a function of time and which will be adversely affecting the performance of the component during the service.

So, for such kind of the applications there will be continuous change in the properties of the material, and therefore, and therefore, the selection of the material for such kind of the applications become more difficult more complicated and we need to see more seriously, and carefully; when the selecting when selecting material for such kind of applications, a special applications like wear high temperature conditions and the corrosion.

Then we have one typical example, where improper material selection leads to the failure of the components.

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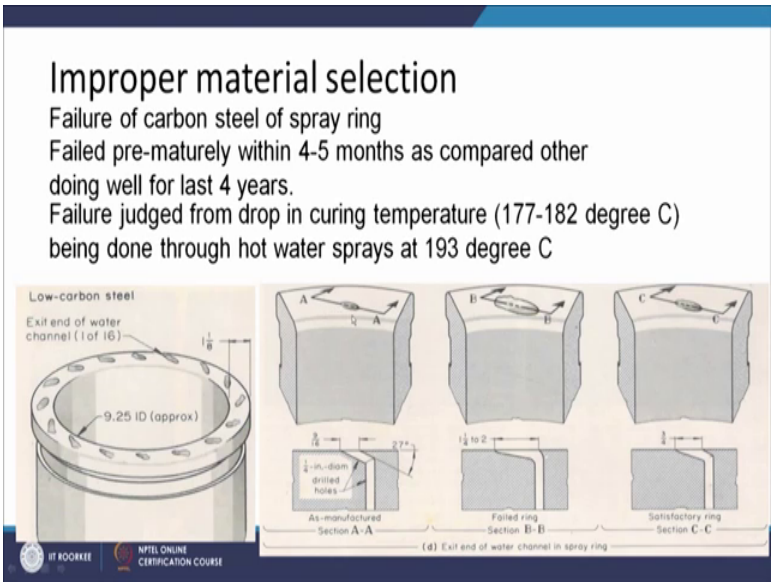

So, for example, here we can see this is one nozzle which was being used to a direct the jet of the hot water for curing of the rubber tyre. So, this jet actually failed prematurely under this failure was just through the reduction in temperature during the curing which was desired.

So, failure of the carbon is steel is spray ring is the case. So, this ring failed prematurely within 3 to 5 months as compared to the other rings which used to survive for more than 4 years. And the failure was just from the reduction in curing temperature because these nozzles were used to direct the hot water onto the rubber tyre. So, during the curing it was observed that this rings were not able to increase the curing temperature and temperature was drop to 177 to 182 degree centigrade and while it was expected that the curing will be done at 192 degree centigrade. So, such kind of the drop was the first indicator, that there is something wrong as far as the nozzle ring is concerned.

So, and what the cross section of the nozzle was like this where the a line is showing the direction of the section where from and the cut section was obtained. So, this is the a a section along this line. So, in the cross section of the nozzle; so, the nozzle here the cross section, we can say 0.25 inch in the diameter hole was drilled. So, this was 0.25 and this was also 0.25 and to have a particular angle like say 27 degree centigrade and this opening was little bit larger it was a 9 by 16.

And then after some time what was observed the some worn out openings of the nozzle the cross section was studied, and the failed ring cross section failed ring opening showed that the outlet was increased from 9 by 16 inch to one 0.25 inch to the 2 inch. So, there was significant increase in diameter of the opening in case of the failed ring. And similarly, another and the one which was showing the satisfactory result this also had the diameter of the opening of 3 by 4 inch without much increase in the diameter.

So though the ring opening which failed one was showing the larger diameter. So, increase in diameter led to the in reduction in velocity of the jet, and which in turn reduce the reduction in drop of the reduction in the curing temperature.

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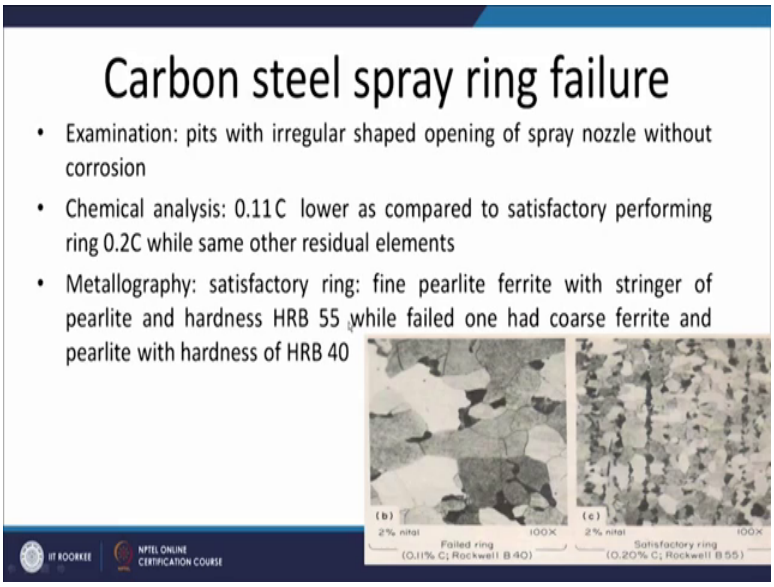

So, this case was investigated and it was found that the nozzles or nozzle openings in the nozzle had pits with the irregular shape without corrosion. So, there was no sin of the corrosion, but few pits were observed in the opening of the nozzle. So, the chemical analysis of the ring was performed. So, the chemical analysis showed the 0.11 percent carbon as compared to the required carbon content of 0.2 percent in the steel ring in the metal. And while other elements were the same as the required one.

Metallography showed that the fine pearlite ferrite with stringers of the pearlite, and the hardness of the 5 HRB in case of the ring which performed successfully. So, these were the stringers of the pearlite, and the structure as a whole is fine as compared to the one which had failed and one which performed well had fine structure stringers of the

pearlite. And the hardness of the HRB 55 while the ring which failed showed the coarse ferrite and pearlite with the hardness as of the 40 HRB.

So, the hardness was lower and the structure was coarse. So, this was the finding of the chemical composition and microstructure of the steel ring. And so, the conclusion was that the failure of the desired curing temperature was due to the enlargement of the opening of the spreading, which in turn increase the hesitation, and reduced the velocity that lead to the lower heat transfer, and which in turn reduce the accruing temperature. And erosion was caused in form of pitting due to the cavitation.

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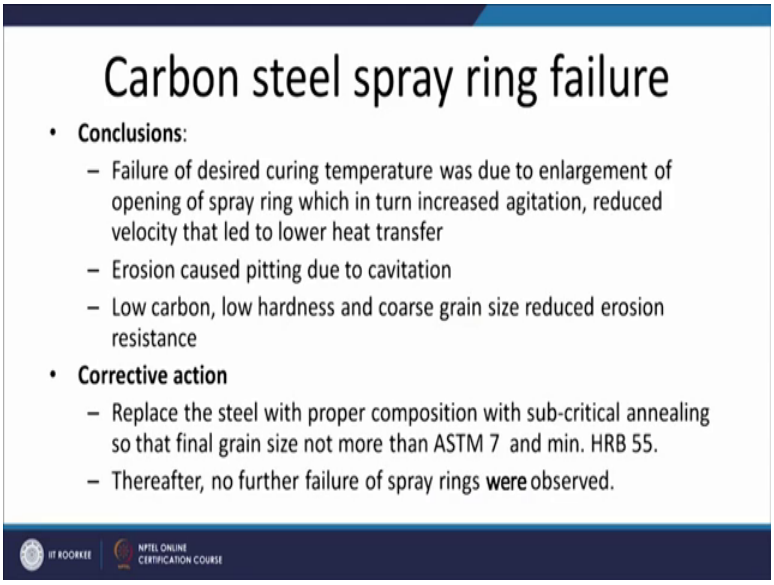

And cavitation occurred due to the lower carbon content lower hardness, and the coarse grain size of the ring which was subjected to the erosion. And so, all these factors in turn reduce the erosion resistance like low carbon low hardness and coarse grain size.

Therefore, corrective action which was taken was that the proper composition of the steel with the sub critical annealing. So, that the final fine grain size can be realized which is not more than 7 ASTM, and minimum 55 the HRB should be maintained. And once this recommendation was applied thereafter no further failure of the spreading were observed.

Now, here I will summarize this presentation in this presentation. I have talked about the 2 aspects one was about the improper, material selection and we should not rely too

much on the tensile properties of the material for the design purpose. And another aspect about which I have talked was that we should develop the proper procedure for reworking and repair purpose as it can lead to the premature failure of the component.

Thank you for your attention.