Failure Analysis and Prevention
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Lecture – 23
General Procedure of Failure Analysis: DT, Selection, Preservation, Cleaning & Sectioning of Samples

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention. And you know we are talking about the different steps related with the general procedure for analysis. In the last presentation I have talked about the destructive test and some of the aspects of the destructive test will be taken up. in this presentation also, thereafter we will be talking about how to preserve the samples of the failed component, how to perform the cleaning, and how to perform the sectioning so that the samples can be made for further analysis.

So, under the destructive test remaining portion of the destructive test, we have talked about the; what kind of information which can be gathered from the destructive tests related to the failure analysis, but they are certain issues related with the data which is obtained from the tensile tests.

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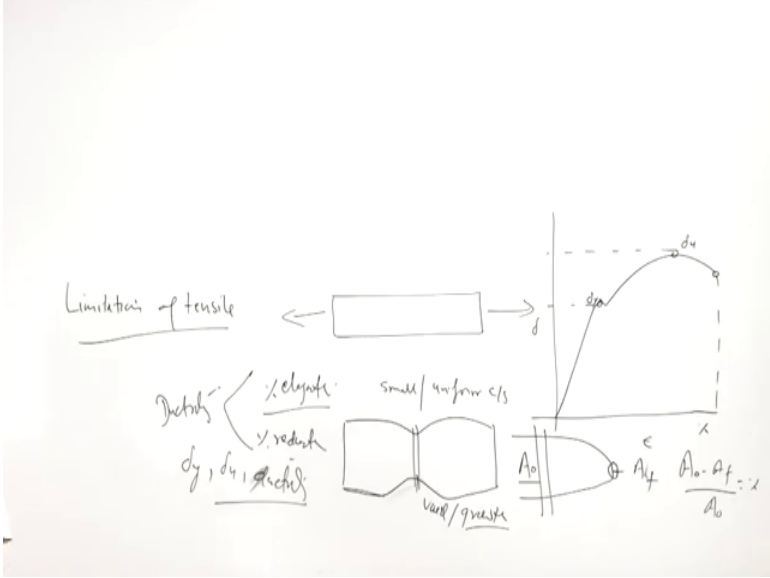

Like, limitations of tensile test. We know that the tensile test gives us for the tensile test what we do this is the sample, and the load magnitude is increased gradually until the

fracture where in the stress and a strain curve is obtained. And this curve gives us typically of this kind for like say a simple low carbon steel or mildly steel, this is the fracture point, this is the ultimate stress point, this is the upper and a lower yield points. And the area under the curve shows the and this one is the percentage elongation till a fracture and. So, that is the basically this is the strain, which shows the percentage elongation.

And so, these are the important things which can be obtained from the tensile test. But in this tensile test basically the sample is very smooth and uniform cross section. So, the ductility actually shows that the extent up to which first tilted long it is uniformly across the gauge length, and then localized yielding starts after the like say the yield point. So, this localized yielding will be causing the a localized reduction in the section of the component like this. So, this localized yielding sub subsequently triggers the nucleation of the void somewhere. Especially, near the notches or the interfaces or the defects, and then these voids eventually grow to cause the fracture or the separation.

So, if we consider these samples, the extent up to which this during the test the extent up to which this reduction in, the cross section of the component is taking place that is what is measured and compared with the original cross-sectional area. So, the extent of reduction like say this is the original, and this is the final cross-sectional area. So, a final reduction in cross sectional area; so, A o minus A f divided by A naught. This gives us the percentage reduction while there is a increase in length due to the elongation during the test. So, it that gives us the percentage elongation.

So, these are the basically 2 measures the percentage reduction in cross sectional area, or reduction in area, these are the 2 measures of the ductility of the material. So, from the tensile test basically we get the yield strength ultimate strength and the ductility in these 2, terms mostly the ductility is reported in terms of the percentage reduction. So, but this is the behavior under the very low rate of the loading, where load magnitude is increased very gradually. While in actual service conditions failure rarely occur due to the deficient tensile properties of the material.

Mostly failure occurs due to the some other circumstantial conditions imposed by the service, or the service conditions. So, wherein not just that tensile properties play a big

role towards the failure of the component. Many times, a like say the despite of having the good ductility a material shows the brittle behavior during this service.

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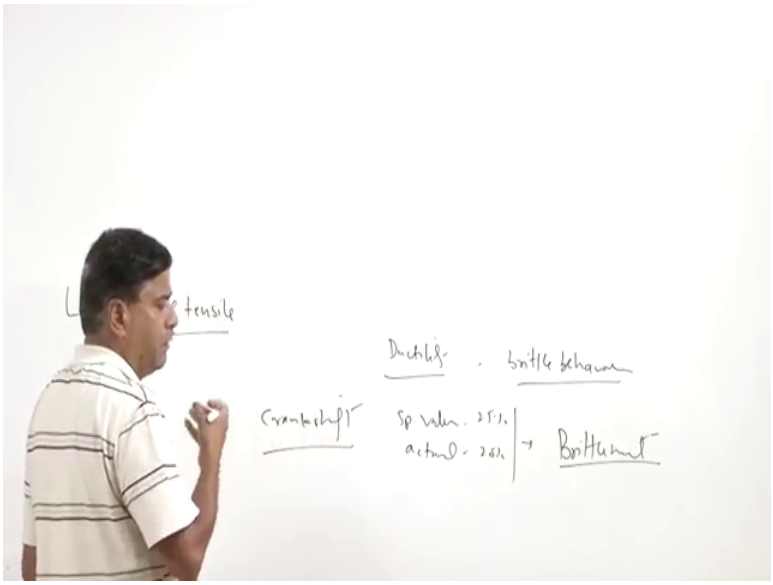

So, this kind of a why this kind of the behavior happens and, what is the reason behind this, what are the more useful parameter for that we need to consider. One simple example like, a crakshaft which had a specified value of the ductility was 25 percent.

While the actual value of the material was just 20 percent. So, this is all there is no major difference in the terms of in terms of the ductility, percentage despite of this crankshaft failed in very brittle manner. So, when it was investigated, it was found that really there was some kind of this stress raiser, and which resulted in the nucleation of the voids and subsequent growth during the service. So, what is the in inference or interpretation here despite having a of having the good ductility still material is failing in a brittle manner.

So, what is suggested that instead of the ductility it is better to probably assume that t he percentage reduction in cross sectional area can be the better indicator.

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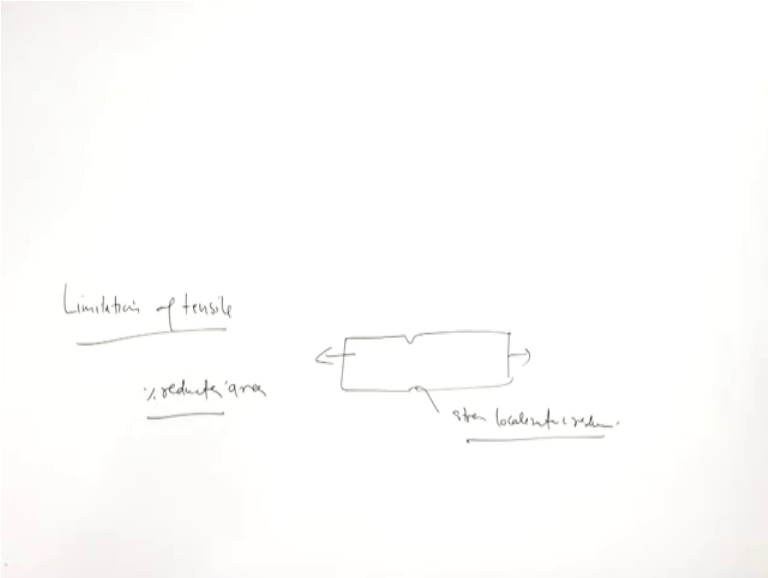

A percentage reduction in area can be a better indicator of the ductility, where like say even if there is a notch of the small size. So, under the external load conditions, the what extent of the reduction in area is taking place so that your the stress localization is reduced and chances for the failure are reduced.

So, the percentage reduction in a area which especially in the areas where there are a stress raiser or where localization of the stress is taking place can be a better indicator of the ductility as compared to the simple percentage elongation. Similarly, there is another one like the bend test.

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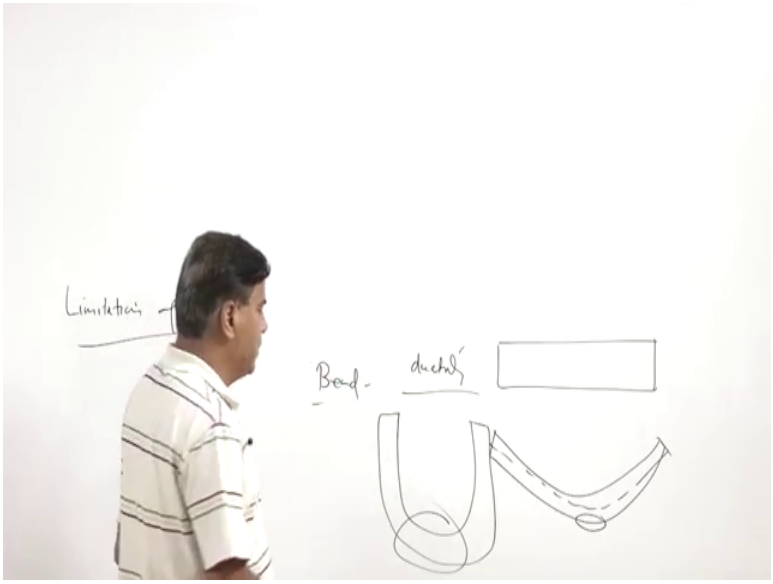

Bend test also shows the ductility behavior of the material, it does not quantify the ductility of the material, but it indicates the extent up to which a simple sample can be bend during the test. So, that the bending of the tests can be done like this, or the extent up to which it can be bent during the test like this.

So, if this is the extent up to which bending can be done. Without crack and thereafter cracks start appearing or the this is the extent up to which it can be bend before which crack starts appearing. So, this difference indicates the extent up to which the material outer layer of the material will be a elongating prior to the nucleation and the growth of crack on the outer surface. So, maybe the ductility can indicate the better resistance for a nucleation of the cracks and their subsequent growth.

So, maybe it will be more useful to conduct the bend test on the field components so that we can see really the extent up to which material can be deformed, plastically prior to the nucleation of the cracks or appearance of the crack on the surface which is being elongated. Apart from this the adequacy or inadequacy of the ductility in terms of the percentage elongation, or the suitability of the bend test, there is another aspect like a plate which has been like say the plate like this which has been produced by the rolling.

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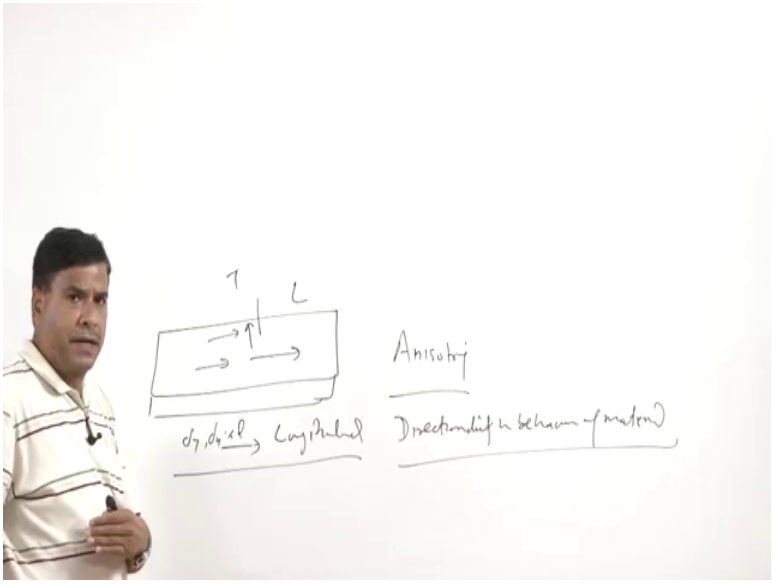

Ah so, the material when material is rolled in particular direction so that direction is called longitudinal one, and the direction perpendicular to the rolling one is called transverse direction. And the material in the 2 directions behave in different ways that is what is called anisotropy, or directionality in behavior of the material, directionality in behavior of the material. And this must be investigated if like say if the component due is experiencing the stresses in the transverse direction, which may be more crucial as compared to their stresses which are acting in the longitudinal directions.

Since the material behave in much better way material offers the much better yield strength ultimate strength and percentage elongation in the longitudinal direction as compared to the as compared to the transverse direction. So, it is important also to consider the behavior of the material in the transverse direction. We have also observed that not just the tensile properties where the toughness of the material in transverse direction is found to be lower as compared to that of the longitudinal direction.

So, the directionality related aspects should also be considered in failure analysis to see the possibility of the failures due to the poor mechanical properties in the transverse direction as compared to that of the a longitudinal direction. Some kind sometimes the variation in properties or the likes the directionality in properties variation in mechanical properties also occur due to the various other regions. Like, if the component is really very large in size so, the surfaces will be experiencing the more stresses more

deformation more thermal load, and the core will be getting the different kind of the thermal and mechanical history.

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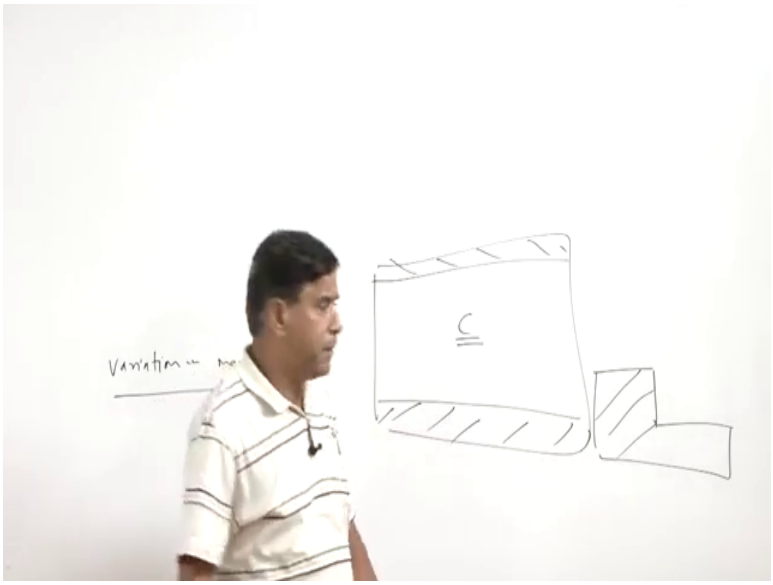

So, the surface layers will be offering the different kind of the behavior as compared to that of the core. similarly, if the section sizes are different like here one size is this and other size is this.

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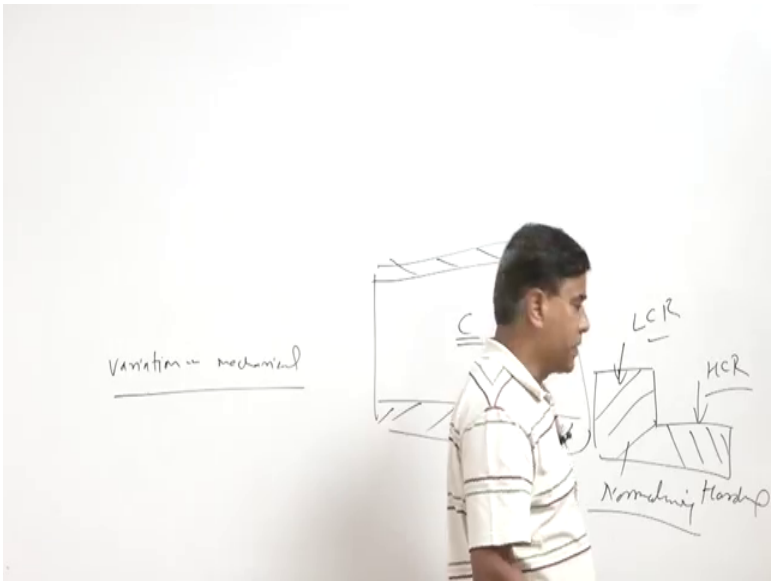

So, the one which is bulky will be experiencing the different cooling rate as compared to the other one, and that is why the cooling conditions may vary here it may get any like

during the heat treatment, and here it like say if like this steel is austenitized, and then it is kept in air.

So, in the air cooling this will this section will be experiencing the lower cooling rate as compared to the this section. So, here this will be experiencing the higher cooling rate. So, it may be experiencing the hardening, while this portion may be experiencing simple normalizing. So, there can be lot of a difference or a difference in behavior of or mechanical properties in a structure of the material. if the section sizes are different than during the heat treatment during the manufacturing then will they may be experiencing the different thermal and a mechanical histories or mechanical stresses; and because of that they may be experiencing they may offer the different mechanical properties.

So, these aspects should also be kept in mind while conducting the destructive test and thereafter efforts are being made to interpret the data for their relevance towards the failure of the component. Next step of the failure analysis which basically involves the selection of sample; thereafter once the sample is taken out, the preservation of the sample, and then we have the cleaning related aspect and then sectioning of the sample.

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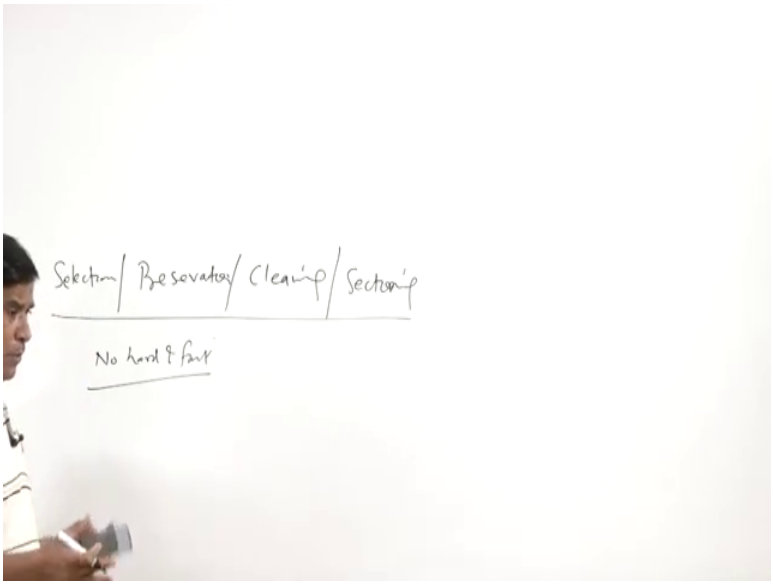

So, as far as the selection is concerned, there is no hard and fast rule for the location where from sample is to be taken.

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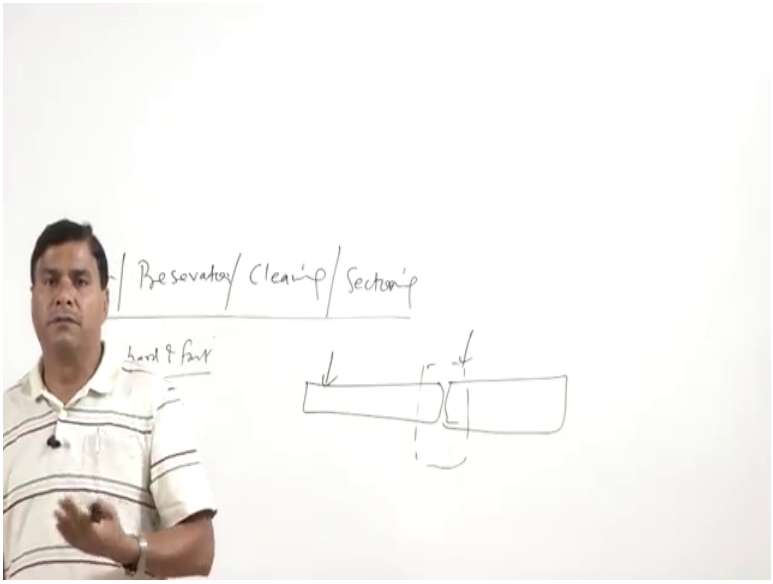

But of course, like this is the failed component; so, of course, if the failure has taken place from a particular zone, then that must be of a some importance. So, we need to take any in any case the samples needs to be taken from the location where failure has taken place. So, this is of course, in any case the sample is to be taken, but sometimes samples are also taken from other locations where failure has not taken place for the sake of the companies and if this zone has experienced the effect of the service conditions more badly as compared to the other locations.

So, as per the case as per the need the kind of the data which is to be established kind of things which will be important for establishing the cause of the failure a suitable sample need to be selected means a sample need to be selected. From the suitable location, but in any case, these are the 2 general locations, which are normally selected it can be newer sample also and it can be compared with the sample which has failed one to see if it has experienced the effect of service conditions for failure.

So, there is no general rule on the way by which failure sample is to be collected. But of course, the location waveform failure has taken place, the sample must be collected from that zone. And thereafter, another location where from sample is to be collected will depend upon it can be other an another new sample. Or it can be other location waveform failure has not taken place. thereafter know the next aspect is the preservation. So, preservation from what? like all the samples after the failure or a accident need to be

preserved for any kind of damage any kind of alteration due to the chemicals, due to the water, due to the loading due to the heat.

So, so, we need to we need to preserve the samples from any kind of the damage.

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So, there should not be any damage to the field component. Because any kind of the mechanical thermal chemical aspects or interaction can lead to the a mechanical chemical, or thermal aspects can lead to the change in the chemistry of the service, mechanical behavior of the material metallurgical behavior of the material, or the mechanical properties of the material. So, component must be prevented from any kind of the damage.

There are 2 types of the damages which can the. So, these are the 3 types of damages which can occur chemical mechanical and a thermal. So, what how the mechanical damages take place, for that we can see there are 3 pass, they are there are few possibilities, like the failed components may hit each other and so, they may get damaged further. So, one possibility is that in the fracture surfaces are hitting to the other surfaces. So, this may happen during the fracture itself, or fracture surfaces being hit to the other component during the transport or when it is being handled.

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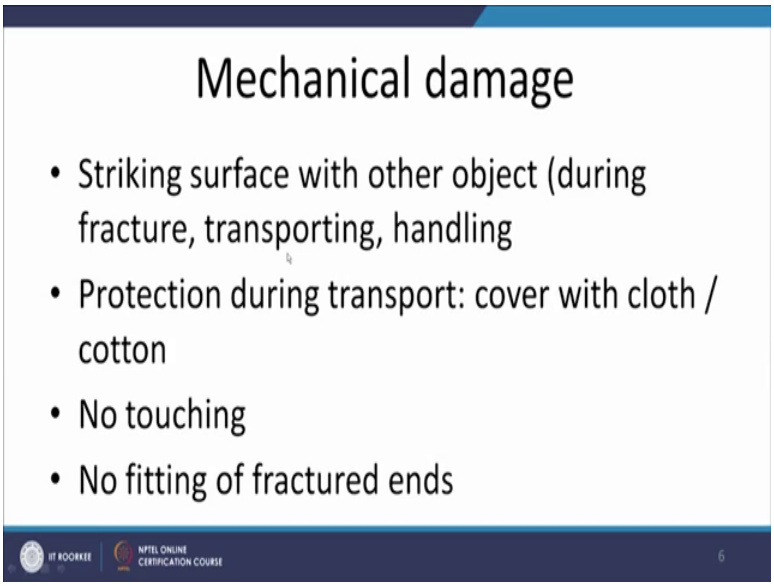

So, this kind of the hitting or a striking the fracture surfaces with the other surfaces, should be other objects should be avoided. Because this will be damaging the surface the fracture surface condition the fracture surface morphology fracture surface properties. So, all that will make the job of the failure (Refer Time: 16:34) less difficult because the fracture, surface morphology and the conditions will be modified due to the such kind of impact or a striking of the fracture surface with the other things.

The next thing is that when our the failed sample is being transported. So, the fracture surface must be covered properly so that if there is anything that is retained on to the fracture surface whether it is chemical or there is some debris or soil or paint. So, that should be retained and for this purpose, especially, during the transport the sample must be protected. And so, it can be covered with a cloth or cotton.

But you know if there are some loosely held foreign particle sitting on to the fracture surface. So, they can be taken away by the cotton or the cloth. So, that kind of precautionary also to be taken that whatever the foreign matter or particle material or particles are present on the fracture surface they are retained. And we need not to touch the sample, because it can leave some of the fingerprints or the things which were not there immediately of the fracture.

So, the touching of the fracture surfaces should be avoided. And we should not try to fit the ends of the fractured components because in any case this will be kind this will lead

further damaging the fracture surfaces, and will be modifying the mechanical morphology of the fracture surfaces. And this will make the job of a the failure and list further difficult. So, no fitting of the fracture ends no touching and proper protection of the fracture surfaces during the transport or the striking of the surface with the other objects results to be avoided.

Ah thereafter there can be chemical damage chemical damage may happen in number of ways like. The sample if capped in open for a long time. So, moist air may cause the rusting of the rusting of the fracture surfaces, or the failed component then foreign particles may also be present on the surface they may accelerate the chemical damage or chemical reactions with the fracture surfaces. So, there is also possibility that if there is a presence of the sea water or fire extinguishing fluid is present, then this must be removed if required, and then for that purpose it is cleaned by acetone or alcohol. And thereafter the fracture surfaces or the failed components should be washed, and then kept in the dry place.

So, the best is to dry the fracture surface with the compressed air jet, and then place in desiccator, but if it is required then we need to wash it the like if the fractional surface is having, the sea water or a fire extinguishing fluid then this can cause further chemical damage.

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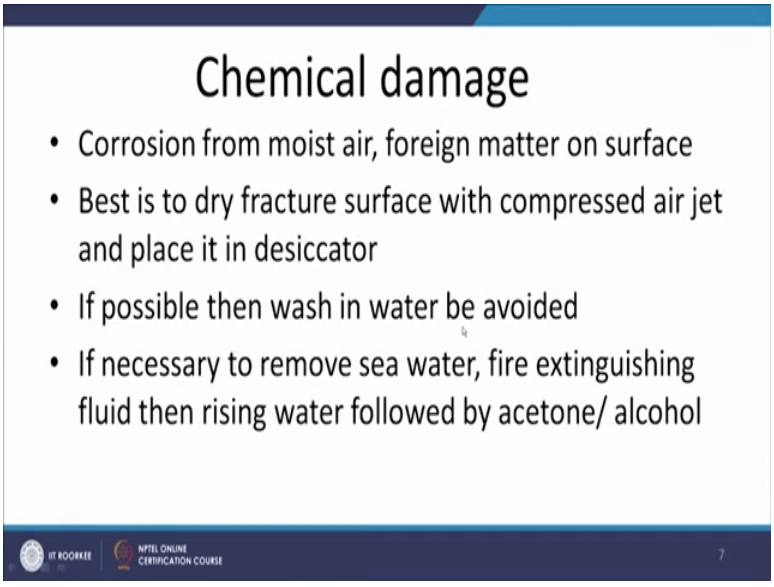

So to avoid that we need to do the cleaning under the water and thereafter like cleaning using the acetone and alcohol and thereafter after drying it can be kept in the dry place like desiccators; so, that no further damage of the surface takes place.

Ah the cleaning of the sample like the because the fracture surface if this is the fracture surface.

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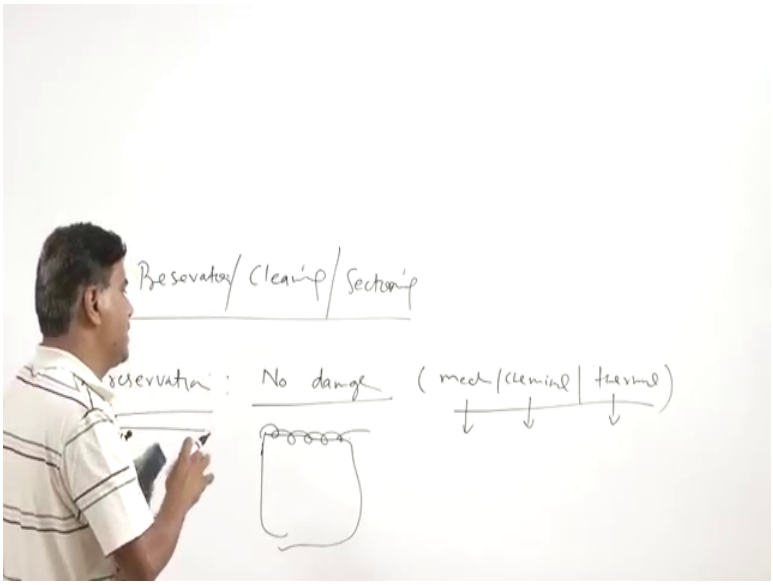

So, fracture surface will have a number of a the things which will be indicating the possible the regions the causes for the failure. So, like there may be present a presence of the debris, soil paint, and maybe oil, or anything else which is present as an evidence on the fracture surface.

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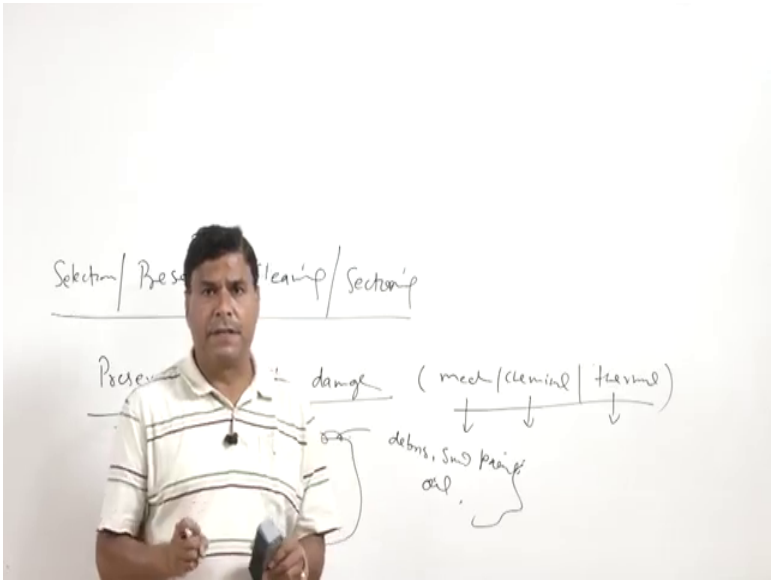

This must be preserved, and therefore, what we say that as far as possible then cleaning should be avoided.

But sometimes for a scanning the fracture surfaces scanning the failed surfaces, like for the sam it is necessary to clean the surface, and then if it is necessary like for the investigation purpose using electron microscopy if it is required to clean the surface, then we can use the number of options, which includes like we can use a dry compressed air. So, that if there is anything present that can be removed from the surface.

Then there is also possibility of use of inorganic solution, in such a way that the only impurities present on the surface can be removed, and the base metal or the failed component remains inert to the solution which is being used, and the same is true for the a minor mild acidic and basic solutions are also used for cleaning purpose.

So, as per the kind of the fluid or the material present on the fracture surface, and if it is important to remove and clean that for the analysis purpose then we can use a mild acids and the bases. And these are selected in such a way that our underlying base metal remains unaffected. There is another method of the ultrasonic cleaning where either acetone or the clean water, in the clean water the sample is placed and then that is ultrasonically treated. So, that all impurities are taken off from the fracture surface and the surface is cleaned. Then there is a plastic replica method wherein this method is

extremely good because it helps to not just to clean the sample surfaces. But also helps to maintain the record of the things which were present on the fracture surface.

So, I will explain little bit this plastic replica method for a cleaning purpose, in this case, in this case, basically the cellulose acetate sheet is used.

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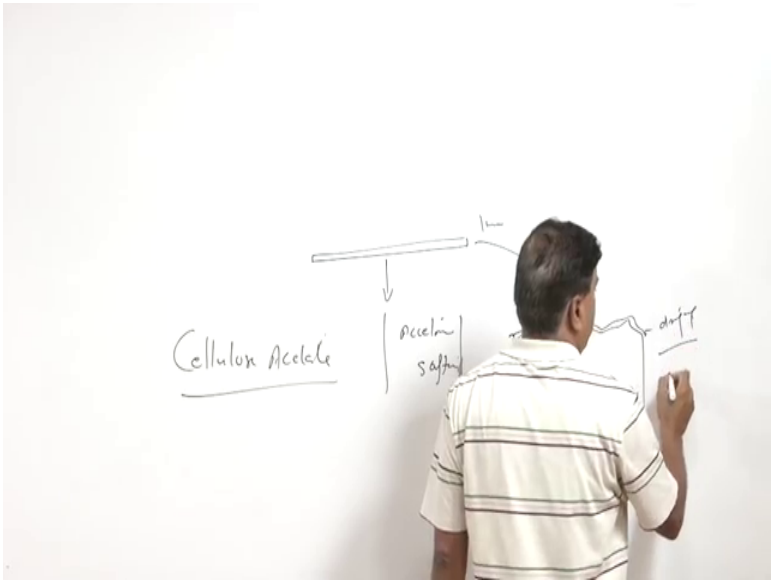

So, like say this is the sample having the a regular surface. And this is cellulose acetate, sheet a very thin sheet of a one mm this is a dipped in the acetone. So, that it is softened. And this softened the sheet is now pressed on to the fracture surface. So, it follows the path of fracture surface. And then this softened seat is pressed, and then it is kept or it is allowed to dry it out. So, normally like say 4 to 10 hours time may be given for the drying purpose or just like overnight exposure is given.

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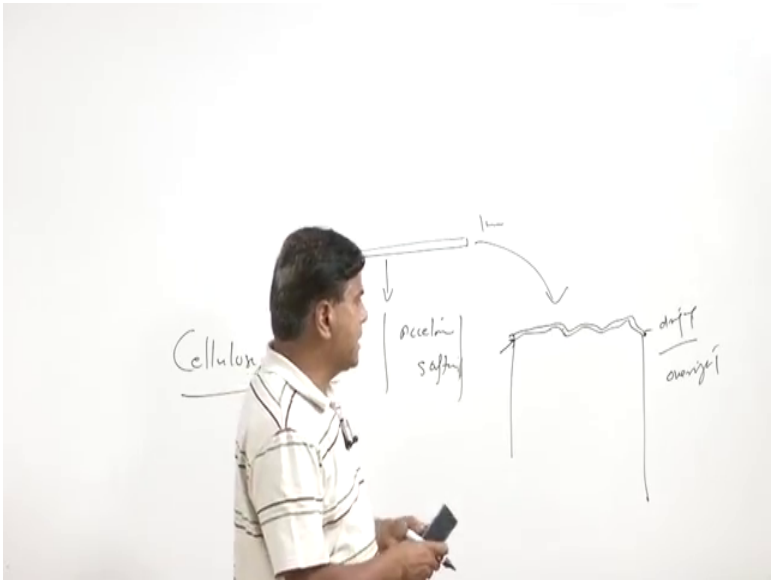

So, that it dries out, and then a at when it dries out all the impurities if they are present on the surface, they will get cling they will attached, they will it adhered with the with this seat. And once they adhered this the sheet is stripped off the failed samples. So, all the impurities some of the impurities will remain attached with the seat. And similar process is repeated, until we find that settle a sheet which is coming out after the stripping is clean; which will suggest that now the surface has been cleaned, and all those seats are preserved having the impurities and debris present which were which was present on the surface of the fractures.

So, this sheet morphology indicates the shape which is achieved by the a cellulosic acetate sheet, follows the path of the fracture surface. So, it maintains the record of the surface morphology of the fracture surface which can be used for interpreting for the failure analysis subsequently. So, in this method we not just create the morphology a record of the morphology of the fracture surface, but we are also in position to maintain the a record of the debris which was present or impurities which were present on the surface; which can be used subsequently for the analysis purpose.

Now, the next aspect is the sectioning, sectioning basically we know that normally failed components are large in size.

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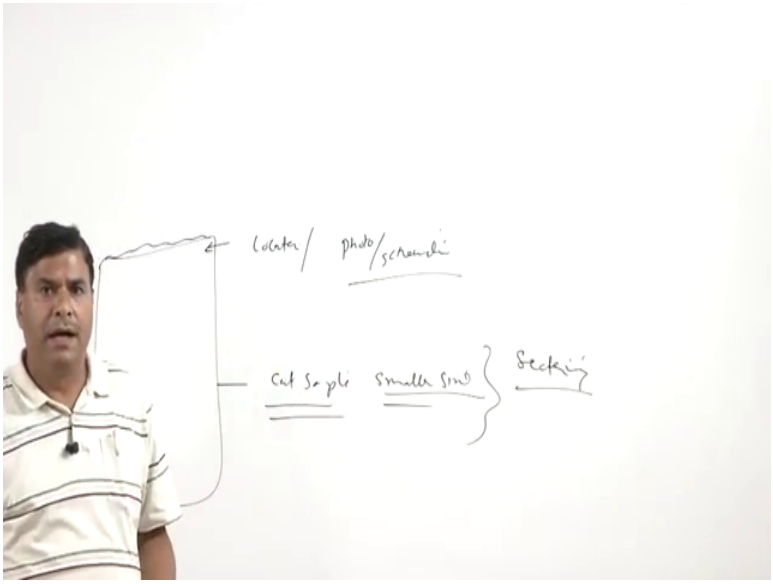

So, large sized components cannot be handled easily for a variety for conducting variety of tests. Like, we have to carry out microscopy we have to carry out my hardness tests. Or other similar kind of the tests if you have to carry out, then we need to cut the samples. The samples of smaller size for conducting the variety of tests; so, if this is the failed component, then the location waveform sample is being cut. If this is the fracture surface that location waveform sample is being cut is recorded.

So, the location for waveform sample is being taken is recorded with the help of the photograph or we can make a schematic of the location waveform sample is being taken. So, that we can tell subsequently the region of region which was used means the region waveform sample was taken for analysis purpose and. So, the this is the reason why we need sectioning, sectioning is needed for cutting the small sized samples they can be used for further analysis.

But how the sample and a once the sectioning is done? and the location waveform samples have been taken is recorded, the next job is to do how to perform the sectioning. So, there are basically the 2 methods of the sectioning. One is thermal method and another is mechanical method. So, in mechanical method is basically involves like cutting sign, or like, the cutting wheels are used for this purpose.

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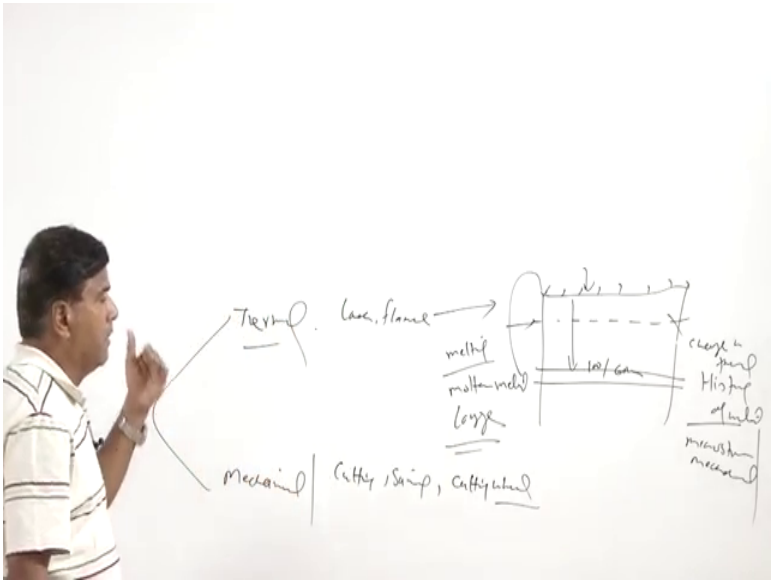

A diamond cutters are there, and in thermal method we can use laser or we can use a flame or similar category of the methods.

So, now there is a problem whenever like say this is the fracture surface, and cutting is to be done section is to be cut. So, we what we want that there is no damage to this surface, as well as there is no damage to the thermal and mechanical history of the component which has failed. And both these methods whether we apply thermal method or mechanical method, there will be possibility for damage to this region, due to the mechanical loading or due to the use of the cutting fluids during the machining you due to the heat being generated during the cutting or whenever the laser or a flame is being applied.

So, whenever this method is used, what we find? There is a possible because in thermal cutting method basically we will be applying the we will be doing the controlled melting so that sample can be removed. So, whenever melting is applied there will be molten metal. And this molten metal can fall on to the surface of this. So, such kind of the falling has to be avoided. This is one, and when thermal methods are applied there is always change in the change in the thermal history of the thermal history of the of metal. So, this change in thermal history will be leading to the change in microstructure which can lead to the change in mechanical properties.

So, this is more damaging, because we will be having the sample which has the whose properties in terms of the mechanical on microstructure have been modified. So, what is important? That if at all thermal methods are to be used especially when the large sized sections are to be cut, when the sectional size is large, and waveform samples are to be cut then only thermal methods are used. Because thermal methods are more damaging with regard to the change in mechanical properties change in microstructure and so, if at all thermal methods are to be used, then they will be applied at much larger distance from the region of our interest.

So, it may be like say a 100 mm or 60 mm distance so that the extent of damage to the component is less. So, depending upon the heat source this distance can vary and this distance must be sufficient in order to avoid any kind of thermal damage to the region which is to be investigated for the failure analysis purpose. In case of the mechanical method, it is basically in mechanical method we can use the like the cutter grinders or the diamond cutters, or a like hacksaw or a sign can be done, but in all these cases also some heat is generated.

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You know, in order to have the good tool life either of the blade or of the cutters we normally apply the cutting fluid.

So, if the cutting fluid is applied then also it can modify the chemical history of the component it may cause rusting, it may cause the presence of a additional cutting fluid

which might not have been there at the time of failure. So, and a heat is generated during the cutting during the sighing or the grinding, means, you when the cutter grinders are used. Then this heat may also lead to the change in structure and mechanical properties. So, we need to be very careful, if it is expected that the heat generated during the cutting by mechanical methods can also change the microstructure and mechanical properties then also cut should be made at a far away.

And all efforts should be made to avoid any kind of the cutting fluid falling on to the fracture surfaces, or alteration of the structure and properties due to the thermal due to the heat generation during the cutting. So now, here I will summarize this presentation. In this presentation basically, I have talked first about the limitation of the tensile test under the destructive testing.

And thereafter I have talked about the importance of the 3 aspects related with the samples sample preparation. The first one was the kind of a preservation, what kind of the damages which can happen and a how to preserve the sample, and a if at all cleaning is important then how to perform the cleaning and if the sample are to be cut from the failed component then how to do the sectioning.

Thank you for your attention.