Machinery Fault Diagnosis and Signal Processing
Prof. A. R. Mohanty
Department of Mechanical Engineering
Indian Institute of Technology, Kharagpur

Lecture - 56
Introduction to Failure Analysis

Well this is the last week of your course, three month course. On the way us be bringing our twelfth week and I will talk on a topic which never should happen if you are doing condition based monitoring correctly and that is a failure analysis ok. We have been doctors so far, where we have diagnosed before sometimes given good remedies to cure default of the machine.

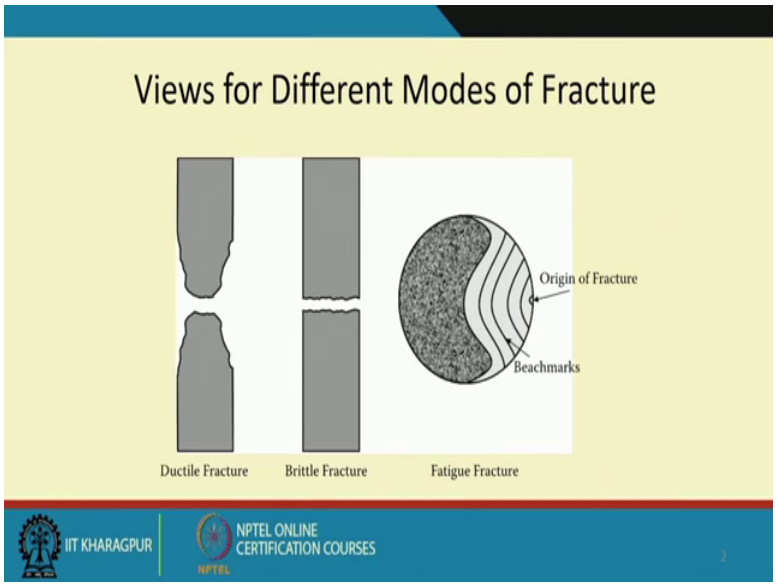
But despite our best maintenance efforts machines may fail machines will fail, because no system is perfect and if you believe in the thermodynamic second law and there are reasons why things will fail because no system is perfect. But question is do we learn from the failure and what does the failure what new information does the failure give us and that is very important. Can we learn from our mistakes in design in maintenance, in manufacturing, in material selection so that the component has failed ok.

So, as you see I tell the areas of material selection, design, manufacturing maintenance in that sequence. So, most important comes at the location of mutual selection. So, we leave it to the designers, who have done a good design selecting the optimum material, but sometimes I have seen in many instances we have imported machines, in steel plants where no rolling mills are failed.

Because the designers would have specified a particular material, but the manufacturer may be for some unknown reasons used a different material of an inferior quality, may be not did do a proper heat treatment process and in the process we have just what a new machine despite our best CBM technologies which we have implemented in it there are failures. So, we will go to the step by step reasons why failures occur and then if a failure is occurred, how to do a forensic examination or what is known as the postmortem of a dead human being.

So, we will become a forensic doctors towards the end of this class.

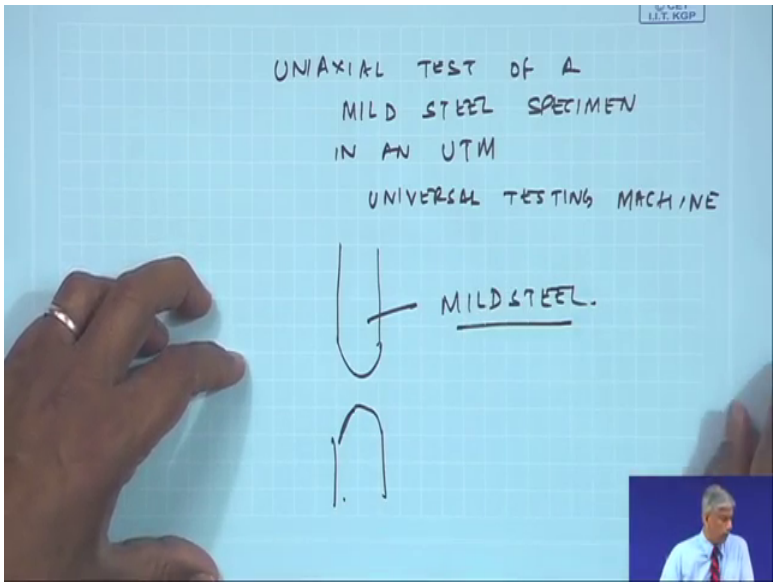
(Refer Slide Time: 02:55)



So, well materials will fail materials will fail because and looking at the failure we can know what is predominant the reason of filling a ductile material if you fail it would make a cup and cone like a form. So, looking at the failed component and those of you who are students you would have seen, when you do a uniaxial test of mild steel specimen in an UTM Universal Testing Machine.

You will come across such cup cone type failure and this material is mild steel which is ductile, but in the brittle their fill it is sudden and then you will have a lot of shiny spots on the surface.

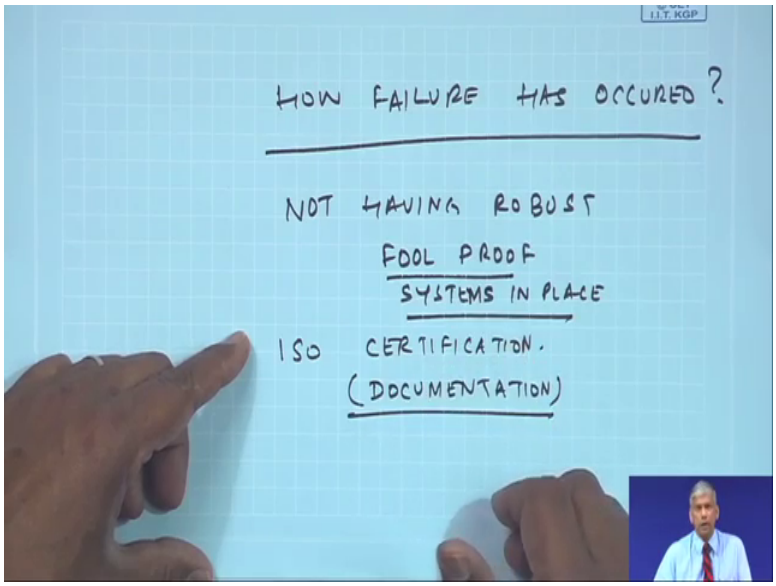
(Refer Slide Time: 04:18)



So, looking at this surface we get some clue as to what kind of fill it is that one. But they will see in machineries many of the shafts are subjected to fatigue load and because there could be a surface defect, surface crack, surface roughness, a fracture would have occurred and they would proceed like this and leave such beach marks and finally, the structure would have come to an area I would have been reduced significantly that the system or the shaft is not able to take the load anymore and then there will be a sudden failure.

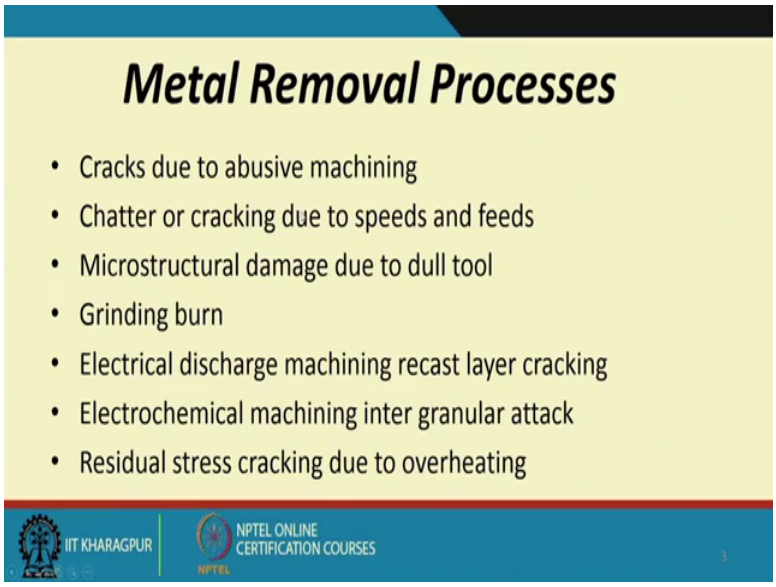
So, looking at the fracture surfaces, one gets a clue as to why it has failed and how it has failed. Of course, there are other methods looking at this fracture surface or the doing the analysis on the fracture component, we can talk about the how the failure has occurred.

(Refer Slide Time: 05:22)



That is what is the importance, but let us see what happens in some of these operations.

(Refer Slide Time: 05:39)



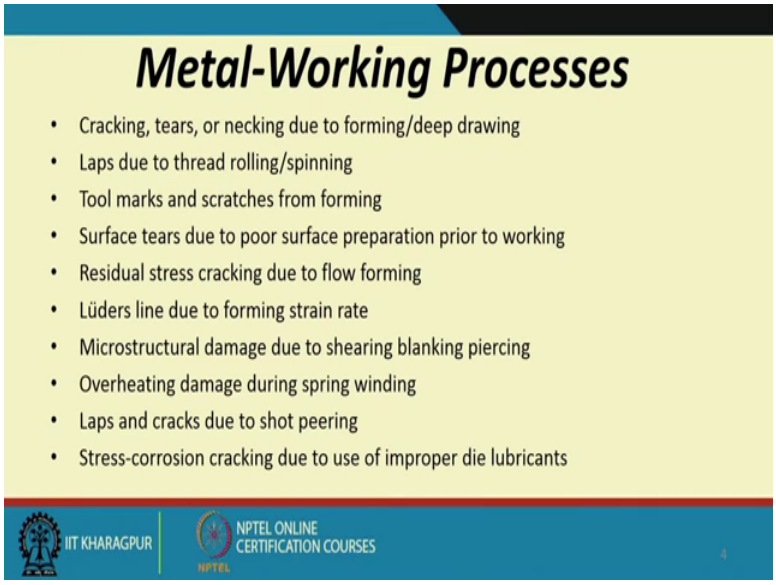
Which perhaps goes unnoticed or which lands up in the final design or final component because our design or our processes they are not robust, not having robust foolproof systems in place.

So, many of the industries where we have ISO certification, documentation is very important. So, that such errors do not propagate and every operation which we do are properly documented and we follow that sequence and if still mistakes are happening we

can take care of it. So, some of the problems which occur cracks due to abusive machining, I mean we are going at a very high speed or depth of cut to each other or cracking to the speeds and feeds.

Micro structural damage due to dull tool, grinding burn, electrical discharge machining recast layer cracking electrochemical machining internal attack residuals cracking due to overheating. So, you see these are processes where a CBM it is beyond a condition based maintenance engineer's control, but had the manufacturing operations been done correctly and these did not happen our machine would have had a better life.

(Refer Slide Time: 07:37)

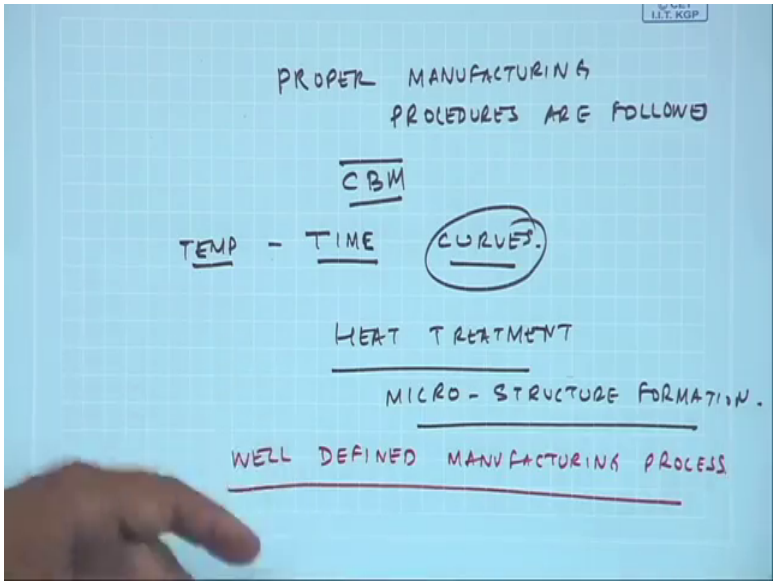


So, one has to be careful about this. Similarly in the other metalworking processes cracking tears or necking due to forming deep growing, laps due to thread rolling or spinning tool marks and scratches from forming, surfaced tears due to poor surface preparation prior to working residual stress cracking due to flow forming noodle line due to form straining forming strain rate, micro structural damage due to shear in blanking piercing, overheating damage during spring winding, lapse and cracks due to short pinning stress corrosion cracking due to use of improper die lubricants again.

In any of the metalworking processes these kind of problems do happen, but sometimes they get overlooked and we may be doing a we would have bought a new machine and a we are doing a very religiously we are doing CBM, but this fallen will occur because we

have not taken into care the problems which has occurred during the manufacturing operation.

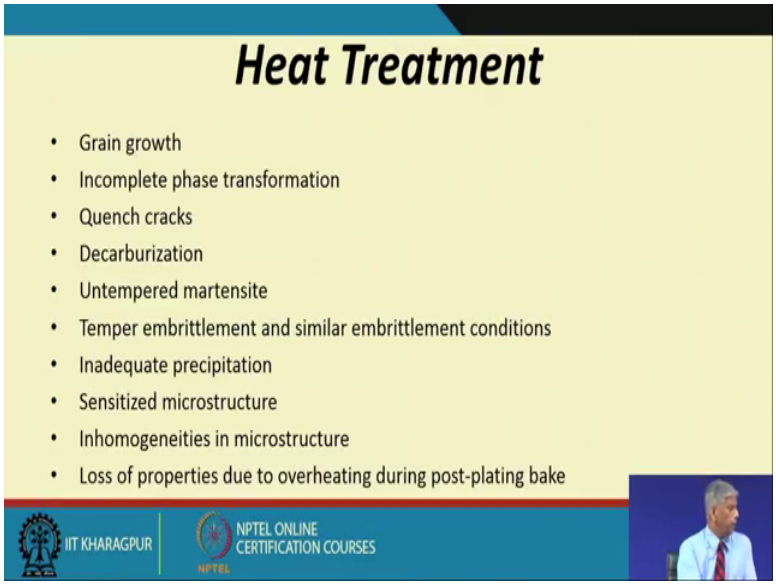
(Refer Slide Time: 08:55)



So, one has to be careful that the proper manufacturing procedures are followed well it is not in the CBM engineers control ok.

But a good machine manufacturer ensures that, these things do not happen.

(Refer Slide Time: 09:25)

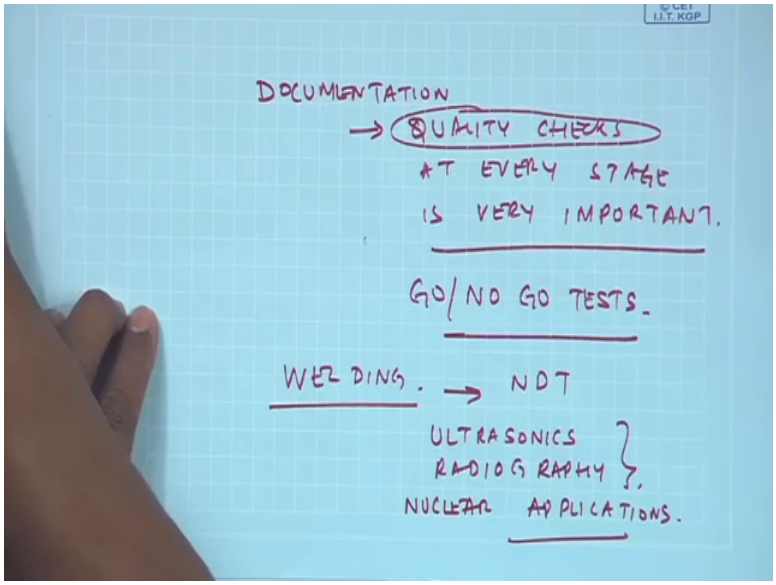


Similarly during heat treatment, you know the time TT time temperature ok. How quickly we bring down the temperature as a function of time helps developing micro structures, where a whether martensite is formed per lattice form it all depends on the cooling rate ok.

So, the heat transfer sorry heat treatment processes control all this grain growth incomplete phase transformations, quenching cracks decarburization untempered martensite temper embrittlement and similar embrittlement conditions inadequate precipitation sensitized microstructure, inhomogeneities in microstructure, loss of properties due to overheating during post plating day.

So, the heat treatment plays a significant role in the microstructure formation ok. So, that is why I know and these are all very set manufacturing process, I i underlined the word they are well defined manufacturing process. Well sometimes because of a production demand some of these operations or safeguards may be overlooked.

(Refer Slide Time: 11:32)



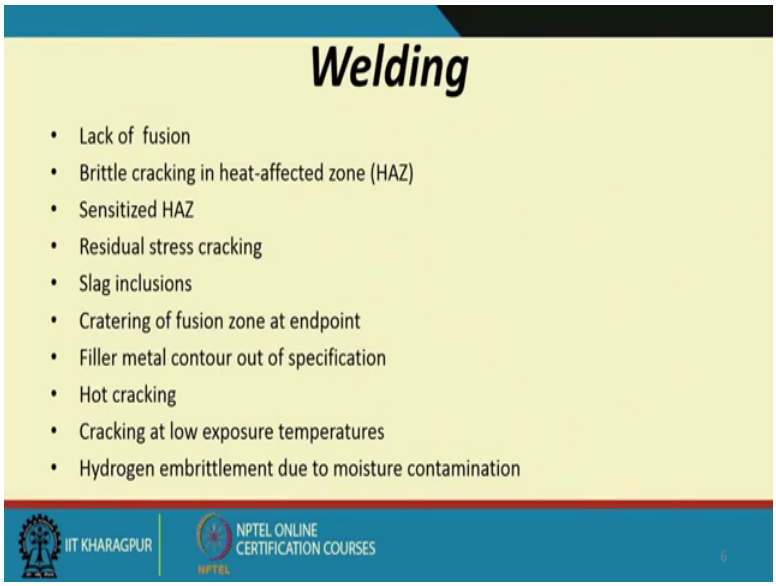
So, that is why in and plant the documentation and quality checks at every stage is very important and we have to ensure that only through proper go no go test.

How was you know if you refer to one of the glasses on dye penetrate test, I talked about using dye penetrate to find out whether the cylinder block, which has been casted as a surface crack. Imagine if the surface crack went unnoticed and we manufactured a nice

engine out of this cylinder block and then we put it in a vehicle and then the customer complains that suddenly, he is losing power and the engine suddenly the coolant boost out of the engine and the engine seized.

So, one stage where we overlooked a crack in the cylinder casting because the dye penetrate test quality checks was not done, we land up with the problem downstream. So, these are to be awarded as good designers or manufacturers.

(Refer Slide Time: 13:10)

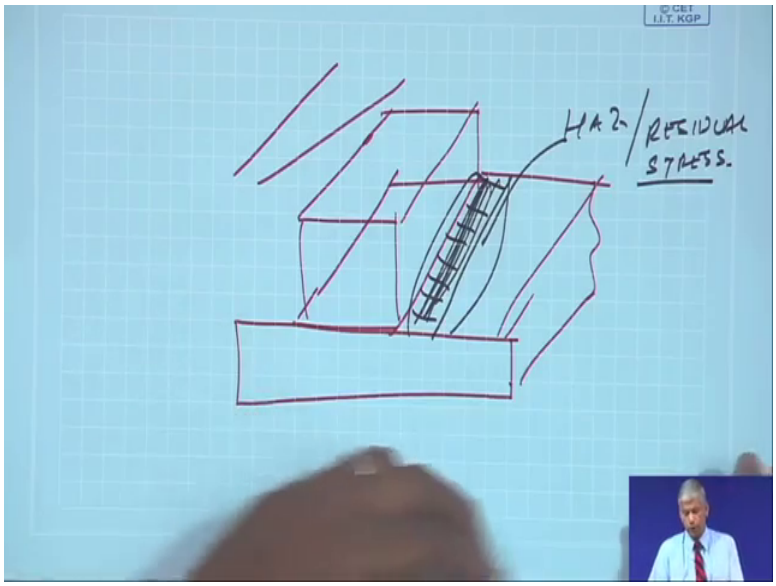


Another important area in a lot of engineering applications welding is done and of course, when I told you when we do NDT ultrasonic checks or sometimes even radio radiographic tests are done.

Particularly in nuclear reactors nuclear applications the checks are very stringent because improper welding will lead to all these problems, lack of fusion brittle crack in heat affected zone sensitized heat affected zone residual stress cracking slag inclusions creating a fusion zone at end point, filler metal contour out of specification hot cracking, cracking at low exposure temperatures hydrogen embrittlement due to moisture contamination.

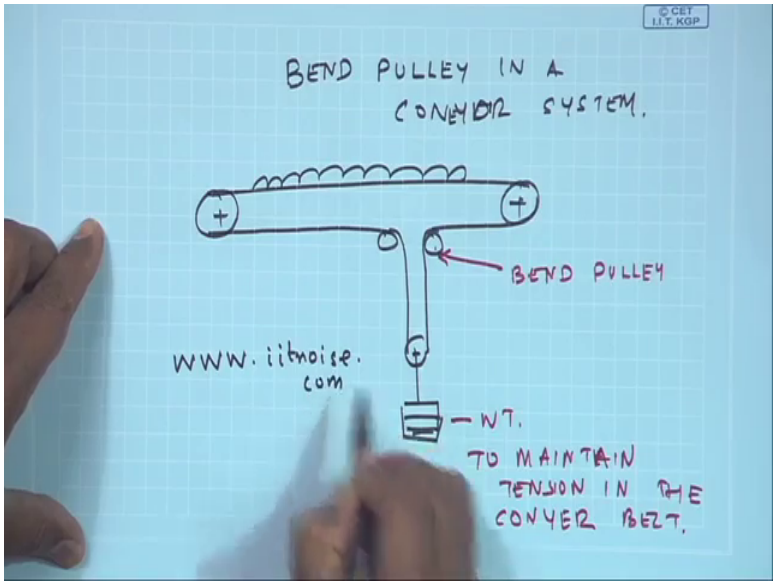
So, these are all issues which happen in which happen in your welding.

(Refer Slide Time: 14:24)



So, again when we weld a structure so, if you put a well band here so, some of the zones they will be heat affected because at the high temperature ok. So, there will be residual stress build up and then on top of it, if it is subjected to residual fatigue loading they will be quick freely, I have seen in my book you can see a filler analysis of a band pulley in a conveyor system.

(Refer Slide Time: 15:21)

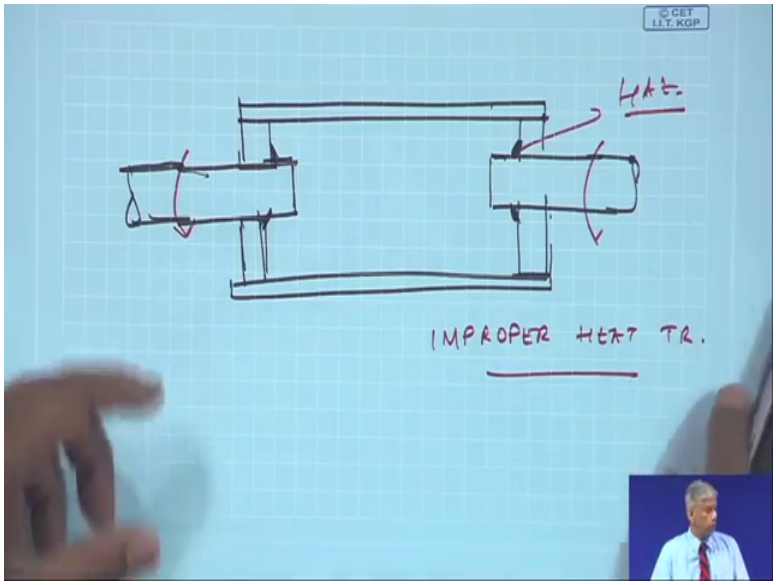


Because if you will see in a conveyor system which is rotating, but you never had a pulley and tail pulley during the return there is a on to this certain weights are given this

is the bend pulley. These weights are given to maintain tension in the conveyor belt. Excuse my typos and spelling mistakes I know that is because in the flow I want rather concentrate on the topic here.

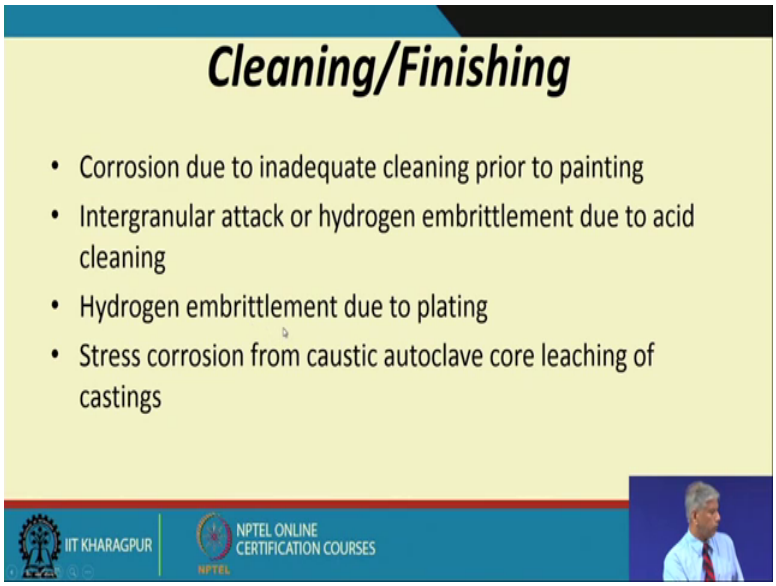
So, this bend pulley failed and you will see in my book, the details of which you can find in the website this failed and we realized and after being a failure analysis it was improper heat treatment done after welding of the pulley ok, the pulley is nothing but big cylinder onto which a shaft is welded

(Refer Slide Time: 17:06)



How go these are again welded. So, there are a lot of failure in this realm and areas and this on top of it this belt goes over it and these are made to rotate ok. So, HAZ and improper heat treatment it was the reason and this was discovered by doing a chemical analysis of the component failed component and again.

(Refer Slide Time: 18:22)



In many of the cleaning finishing operations corrosion due to inadequate cleaning prior to painting, integral under attack or hydrogen embrittlement due to acid cleaning.

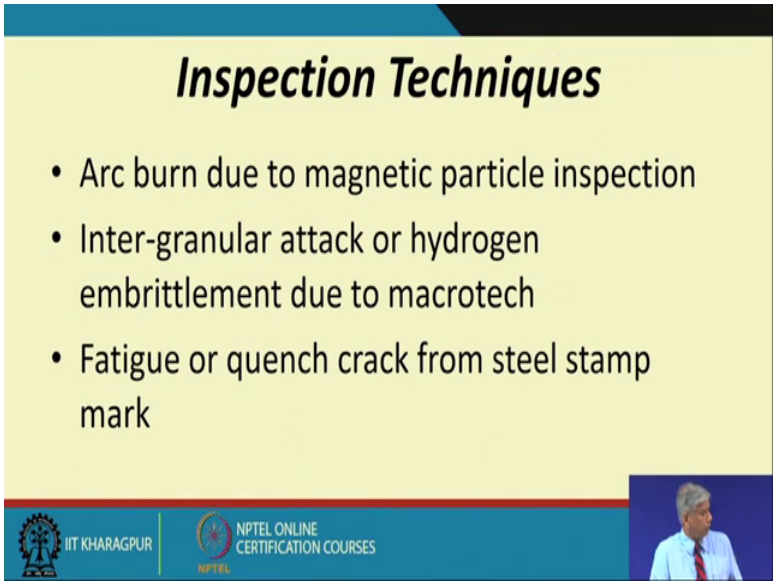
Hydrogen embrittlement due to plating stress corrosion from caustic autoclave so, this hydrogen embrittlement creates a lot of problems.

(Refer Slide Time: 18:44)

Again failures can occur because of assembly at factory installs inside misalignment, missing wrong parts, improper startup, improper inappropriate fasting system, improper

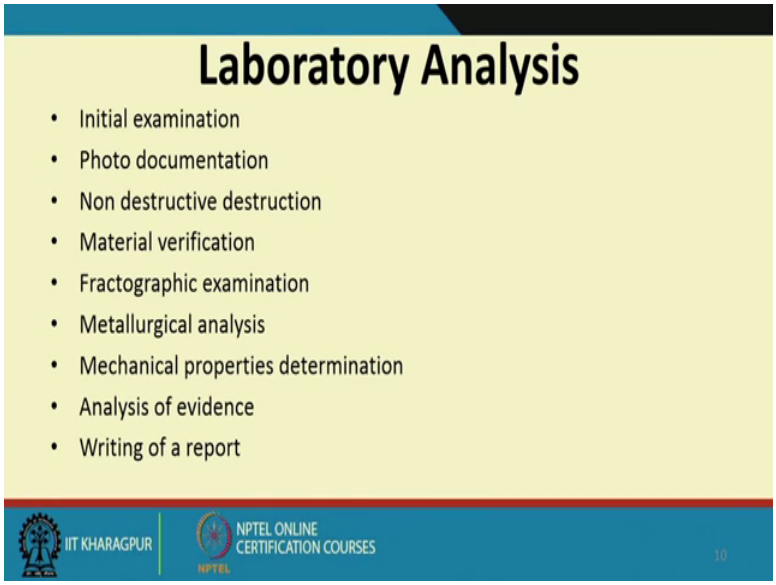
torque improper tools, inappropriate modification inadequate surface preparation so, all these things add up to the failure of the component ok.

(Refer Slide Time: 18:06)



Some of the inspection techniques are burned due to magnetic particle inspection intervener attack or hydrogen embrittlement due to macro tech fatigue or quench cracks from steel stamp mark. So, all this would lead ok.

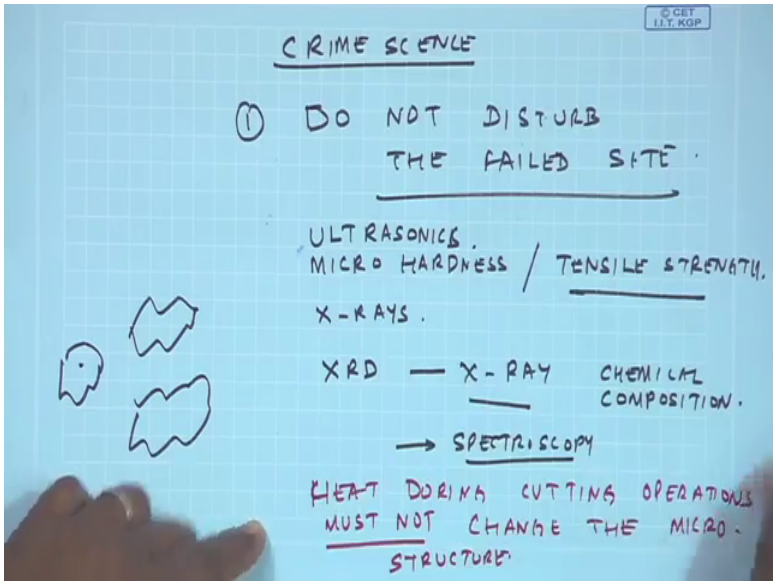
(Refer Slide Time: 19:27)



Now once the failure has occurred what do we do despite. So, these were the reasons by which failure occur.

So, whenever a failure has occurred, I would say this is the procedure which is to be done it is just like a crime scene.

(Refer Slide Time: 19:46)



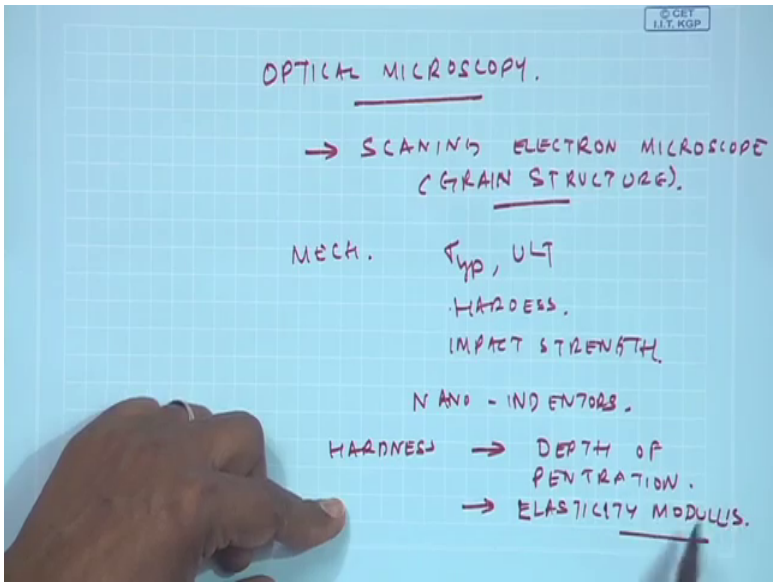
Do not disturb failed site first-up take off photographic documentations or today of course, in nowadays and a people are also doing videography etcetera, but in a good photograph with high resolution camera is good enough to show where the field components have fallen or what is the condition of the surface.

And then immediately some of the components which are failed many of the non destructive testing can be done. So, what are the non destructive testing we can do an ultrasonic with their small fragments we can do micro hardness measurement for some machines we can measure the micro hardness and also the tensile strength. So, whether the component had the desired strength many times we have seen that a material of inferior quality has been done.

Some components we can have an X rays and the material verification becomes very very important in terms of both at the microscopic level, that we to do through and metallurgical analysis like in XRD by X ray to find out chemical composition or we do spectroscopy analysis, but these failed components individual lying around. So, we can take a sample, but many times you know when we take a sample do not use any powered electric saws.

So, there should be you know because when you take a sample, the heat during the cutting operation heat during cutting operations must not must not change the microstructure because when we examine the failed component under optical microscopy either through a scanning electron microscope to see the grain structure.

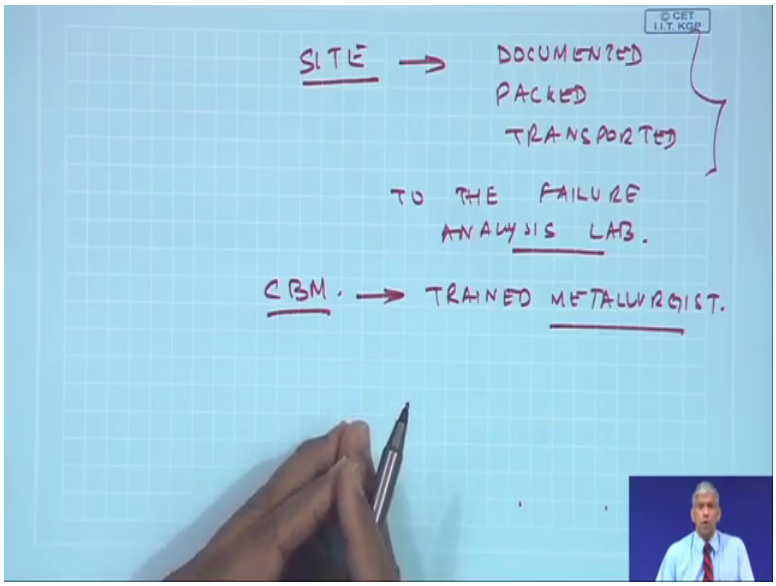
(Refer Slide Time: 22:48)



Any extra heat which has been generated when preparing the sample is going to damage this component ok. And then all the mechanical properties whatever we can measure like yield point or ultimate or hardness impact strength ok, but since the sample is very very small we need to have known nowadays you know we have nano indenters wherein we can find the hardness as a function of depth of penetration.

And during the unloading of the detraction, we can find out the Young's modulus. So, today lot of such techniques and machines are used to find out all these properties, but then question is from a site.

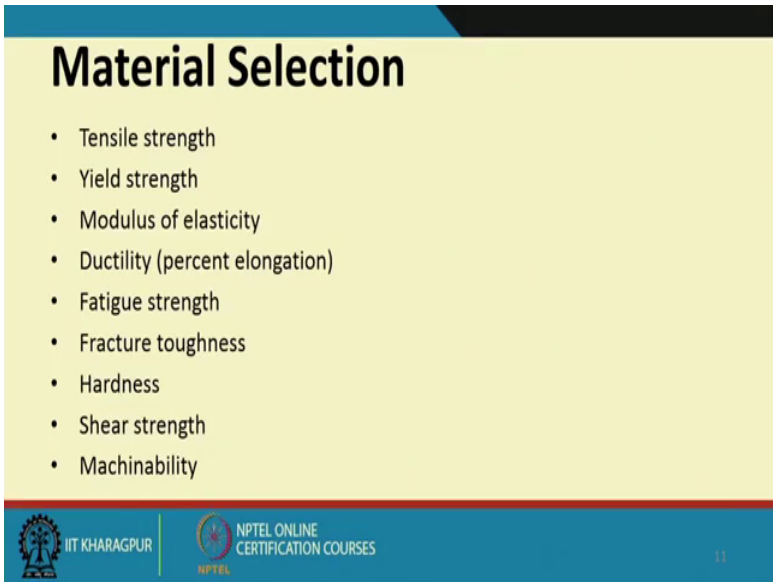
(Refer Slide Time: 24:33)



These components need to be nicely documented packed and transported to the failure analysis lab.

So, sometimes you know the CBM engineer may not be well versed with the technique, but at least he can do this and then this will go to a trained metallurgist who will do such analysis and maybe from the grain structure tell you what was the grain structure from the SEM composition from the XRD analysis, from the spectroscopy analysis tell it the composition of the material the grain boundaries the grain structure the process of heat treatment etcetera and how this has happened and of course, you know you have to write a report.

(Refer Slide Time: 25:46)

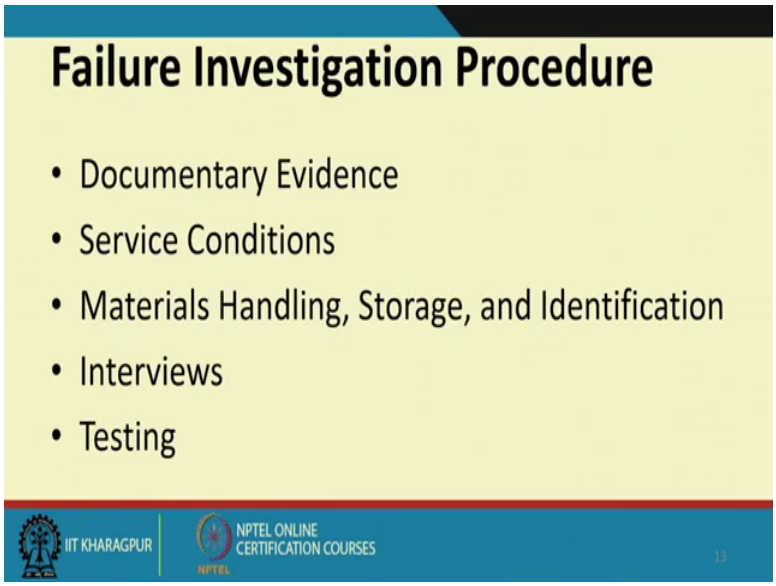


So, some of the material selection which we depends on these we can measure some of these properties, after in the failed component tensile strength yield strength modulus of elasticity ductility fatigue strength fracture toughness, hardness shear strength machine ability. So, all these components or all these factors are parameters.

Let us know the behavior of the mechanical component which has been put in that machine yeah and of course, these are some of the other properties. So, designers would have done that. So, there is always failures occur because there is a disconnect between the materials vendor supplier material sub vendor for the material supplier, the designer the manufacturer the machine installer all these problems happen.

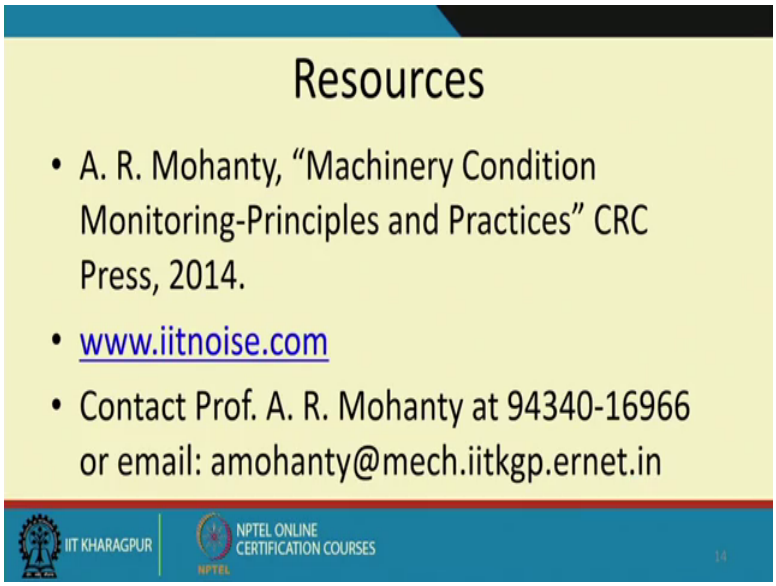
So, somewhere somebody has done a mistake and it propagates downstream because we do not have robust quality control mechanisms in place and failures can occur.

(Refer Slide Time: 26:54)



So, in the failure investigation process procedure, you have to document the evidence service conditions materials handling storage and identification lot of talking to the operators the engineer's website and lot of testing needs to be done ok.

(Refer Slide Time: 27:10)



Thank you.