Failure Analysis and Prevention
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Lecture – 22
General Procedure of Failure Analysis: Destructive Testing

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention. And you know we are talking about the general procedure for the failure analysis, and under this heading we have talked about the background information, collection preliminary examination of the failed component, and nondestructive testing of the material which has failed.

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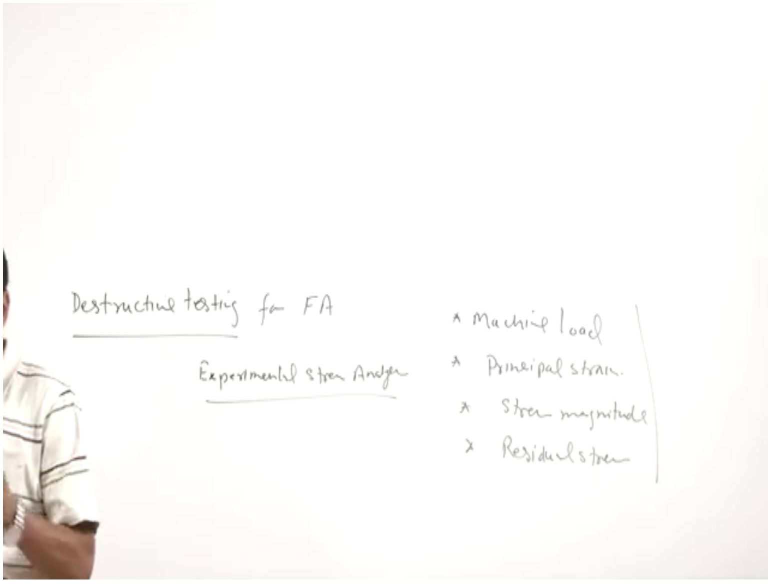

Today we will be talking about the destructive testing, and it is role or relevance in the failure analysis. So, destructive testing for failure analysis. there is a one technique which is called like experimental stress analysis, which is which combines both destructive as well as the nondestructive tests for a determining the some very important aspects like determining the machine load, determining the principle strain, determining the stress magnitudes, and the residual stresses.

So, stress analysis basically involves determination of these components which can play a big role in estimating the possibility of the failure, as well as the kind of conditions which has been experienced by the component during the service. And for this purpose, there are number of techniques which are nondestructive in nature.

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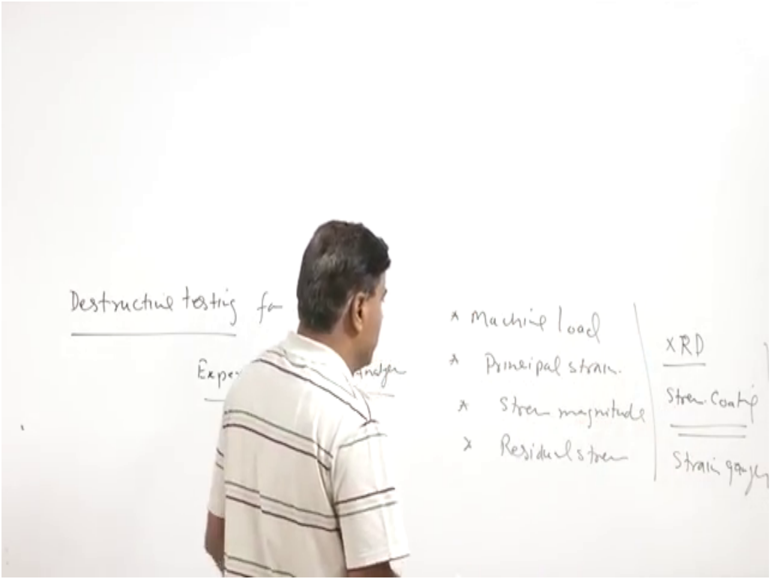

Like x ray diffraction analysis, XRD is used for the residual stress analysis, as well as there are like a stress coatings; which are used for determining these strain magnitude over a is very small area which can help us to see the kind of the strain distribution, and which indirectly can be used to calculate the magnitude of the stresses.

At the same time, the common other methods like strain gauges and the raw sets are also used for a calculating the strain as well as the stress magnitudes which will be experienced by the component during the service or the kind of the conditions which have been experienced by the component, which has failed so, that maybe relevant to the failure analysis. As far as the destructive testing is concerned, destructive testing why it is called so, because the sample or the component which is being tested is actually destroyed.

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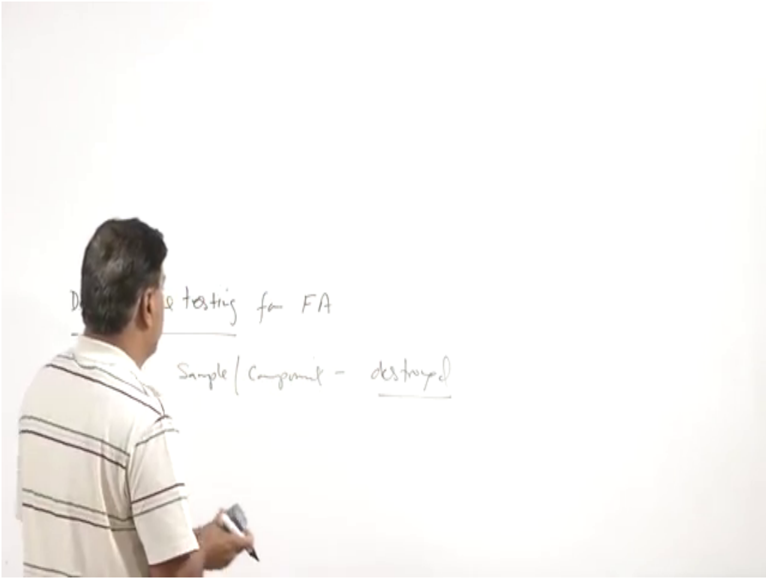

And it cannot be used for any other for further useful purposes, and that is why such tests are called destructive tests; where the sample is broken or damaged to such an extent that it cannot be used for any other useful purpose.

And there are and these tests in case of the failure analysis are carried out for variety of regions.

And so, the main objectives of carrying out the destructive testing in the failure analysis are to evaluate the mechanical behavior of the material, behavior of the material which is being investigated.

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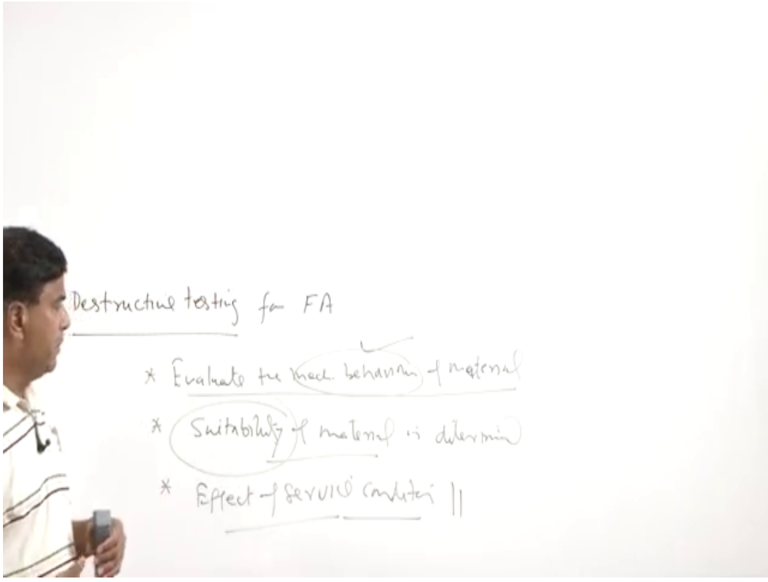

So, we get basically the numerical values in terms of like say toughness in terms of the joule or the Newton per mm square for a the strength yield strength, or ultimate strength percentage elongation ductility or a fatigue and the number of cycles, or like the time in case of the crew to achieve a particular strain value.

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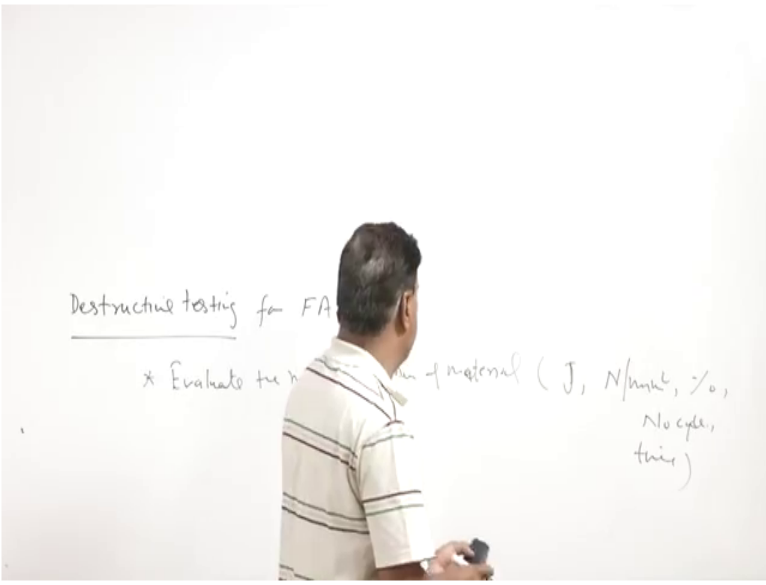

So, the numerical value is identified in terms of a their capability to take a load under certain specified conditions. So, it helps us to assess the numerical assess the mechanical behavior of the material, which can be used to see whether it has been suitable or not. So, suitability of the material under the given set of the application condition is also determined, when we are able to identify the numerical value in terms of the, for the mechanical behavior of the material. and the third one is also to see.

So, first is to assess the behavior of the material second is to see the suitability for that particular application under which it has failed. And third one to check or to observe the effect of the service conditions if it has been there. Effect of service conditions, sometimes the due to the work hardening the material may be hardened or a strengthened due to the loss of the alloying elements it may be soft. And so, so, the effect of the service conditions is also assessed to see if the service conditions had played any role in performance or in the failure of the component under a specific set of the conditions.

So, these are the 3 basic objectives of performing the mechanical tests related with the failure analysis. So, these destructive tests in the failure analysis helps us to see the possible contribution of the material aspect in the failure if they have failed it to the deterioration in mechanical properties or the if material was not suitable for the given application or the material in general was deficient to survive under those set of conditions.

Now, we will see what are those tests, which are normally carried out to assess the behavior of the material. So, there are number of the destructive tests which are undertaken.

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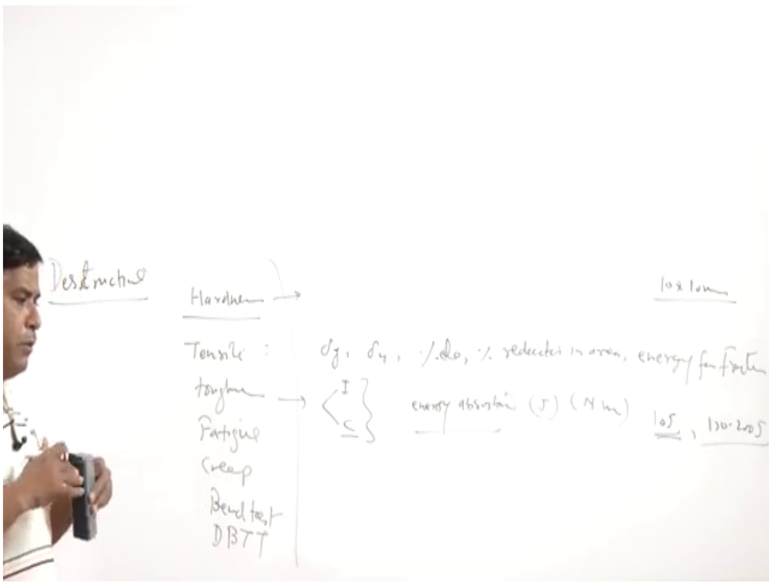

Destructive tests which are under taken, like this there is one hardness test, then tensile test, then toughness test, then fatigue tests, then creep test. And then a there is a kind of the bend test and after that there are number of the specialized or unique tests like determination of the ductile to brittle transition temperature.

So, since all these are the destructive tests where behavior of the material under the external load conditions will be assessed. And each test indicates the behavior of the material in unique kind of the conditions. Like, for the hardness test, it shows the resistance to the indentation. So, which indirectly shows the resistance to the abrasion or the resistance to the adhesive wear similarly, the tensile test shows the 3 important parameters or the they can be more also, like the yield strength of the material ultimate strength of the material or percentage elongation, and the percentage reduction in area, reduction in area and the energy it has a taken energy for a fracture during the tensile test modulus of elasticity.

So, there are a number of parameters which can be obtained through these stress, and this may be of the relevance. And the toughness test this is important to see that how the material will behave under the impact conditions and for that there are like a one ISO test another charpy test. And in both the cases the amount of energy absorbed energy absorbed during the test, in terms of the joule or the newton meter is quantified; so that we can see how much resistance it offers to the impact resistance a resistance to the shock loading higher is the amount of energy absorbed greater will be the resistance to the impact loading or the resistance to the shock.

So, like the low toughness material may be shown like the 10-joule like cast iron or a high carbon steels may show the 10-joule like the kind of the toughness, value for standard sized specimen which is actually 10 by 10 an mm in cross section and while the very tough materials may offer like 150 to 200 joules also. So, depending upon the amount of energy they absorb to cause the fracture under the a high rate of the loading or a impact load conditions, that is what is assessed through the impact tests. And then there is a fatigue test which indicates the behavior of the material under the fluctuating load conditions, and we try to see how many number of cycles a material can withstand before failure so far this like the stress ah.

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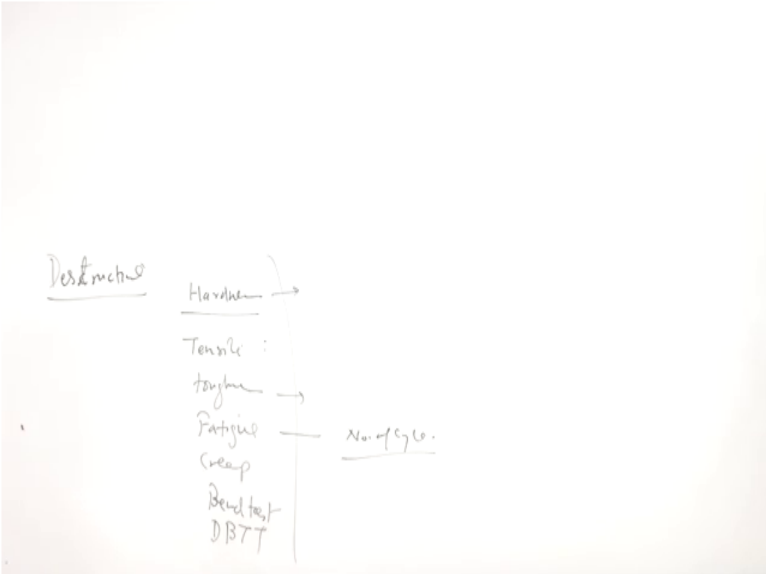

Amplitude or the number of cycles it can sustain for given stress amplitude, or what will be the stress amplitude for which a component can withstand for a given number of cycles.

So, there can be num both ways wherein like the stress amplitude is determined for n number of cycles.

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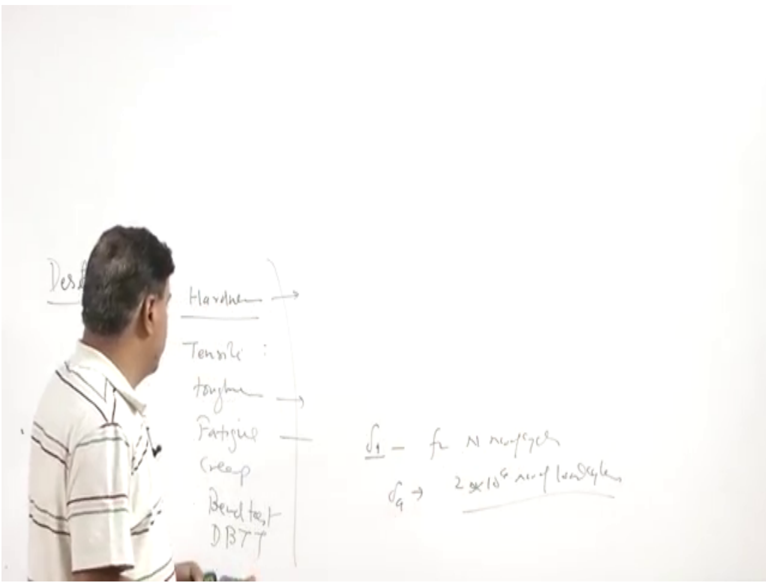

Or for a or we also determine that what will be the what that what will the endurance limit of the material means what will be the stress it can sustain a fluctuating load it can.

So, fluctuating stresses or stress amplitude it can sustain for 2 into 10 to the power 6 number of a load cycles. So, the these are the parameters of and using which the behavior of the material under the fatigue load conditions is assessed. So, next is the creep rate creep rate is used to see that how much how much resistance is offered by the material to the a strain at especially at the elevated temperature as a function of time.

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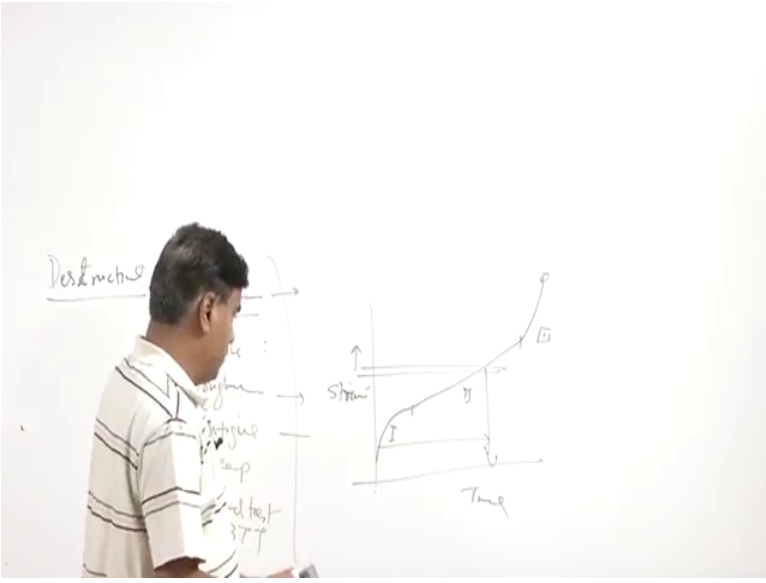

So, for this typical curve like this is obtained where in the material shows initially the decreasing rate of the strain as a function of time in the y axis we have a strain ah, a strain here, and then it becomes constant rate of a strain becomes constant, and then it occurs set of a increasing rate. So, these are the 3 phases, this is the first phase second phase, and third phase. So, this is the portion where the stress rupture will be occurring. So, if for a given service conditions this is the strain limit, then this time will indicate the creep life of the component.

So, means in this case creep life is determined by the time it takes to achieve that much a strain, or it may be stress rupture if it is though if the component can sustain. Continue if the component can continue to work until the rapture, then it with a stress rupture life so, the time. It takes for complete suppression at a high temperature is called a stress rupture and that will be indicating the stress rupture life of the component.

So, a strain a creep life is one thing and a stress rupture means when the complete separation of the component at elevated temperature takes place. That is a different thing normally the creep is for a creep is a creep life is obtained through the using the time, it takes to come achieve a particular strain value at a high temperature and given a stress value. Bend test is also one of the indicators where it shows that the extent up to which it can be bent without cracks and it also it is an also indicator of the ductility of the material. And the ductile to brittle transition temperature this is one typical behavior of the material which shows that how the material toughness will be changing as a function of a time.

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So, in a x axis we have temperature here increasing value of the temperature, say, this is room temperature, and this is say 50 degrees centigrade temperature; on the other hand, minus 50-degree centigrade temperature. And a said for typical carbon steel like medium carbon steel or mild steel the typical behavior which is a observed becomes somewhat like this; where at about like minus 20 degree centigrade. It loses it is toughness very drastically. And therefore, you see it may be reducing from say about 80 joule to almost like 10 to 15 joule in magnitude. So, y axis shows the toughness and x axis shows the temperature.

So, what it shows that there is a sharp drop in the temperature a sharp drop in the toughness as a function of reduction in temperatures. So, this particular value of the temperature where sharp reduction in temperature is sharp reduction in temperature takes place that is called transition temperature. Or it is also called ductile to brittle transition temperature, because in this band material behaves like a ductile material and in this side, it behaves like a brittle material.

So, the temperature in between where this sharp transition from the ductile to brittle behavior takes place, that is called ductile to brittle transition temperature. It may be required to conduct such kind of tests in order to see the behavior of the material especially under the low temperature conditions. So, these are some of the typical destructive tests which will be indicating the behavior of the material under the different type of the loading conditions.

Ah now we will be going through the some of the unique information or the kind of useful points or a information which can be obtained through the different kind of the tests, like the first one is the of hardness test. Hardness test is very simple test sometimes it does not require any sample preparation, like, especially the Rockwell test Rockwell hardness test where we apply first a minor load and then measure load. So, it does not require a proper preparation of the samples while it in other tests like Brunel test where some kind of the preparation is needed.

So, it is very easy to perform it does not require very big size of the sample. So, by enlarge hardness tests are the fall in although they fall in the destructive test category, but no major damage to the sample takes place whenever hardness test is carried out. And whenever hard hardness test is carried out it gives us very useful information with regard to the confirmation of the manufacturing process which has been used for making a particular component which has failed.

So, this is first useful information which can be obtained, like a hardness test helps to confirm the manufacturing process used to develop the component used to fabricate and manufacture the component. It also helps to confirm whether the particular kind of the heat treatment was properly performed or not. it also helps to determine the or estimate the value of the tensile strength. So, these are the 3 important points, I will elaborate little bit.

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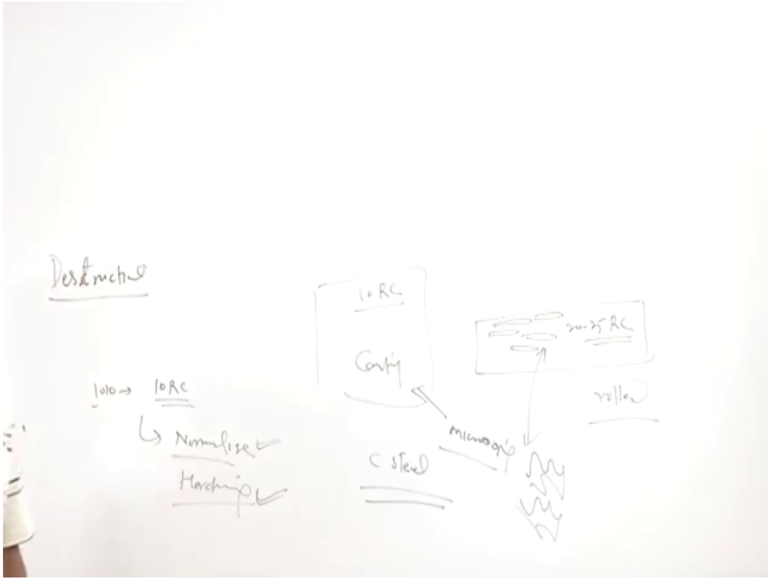

Like a component made by simple casting and component which has been after the casting has been rolled.

So, these 2 metals will be showing completely different behavior. We know that for the same material in cast condition it may be showing a very limited hardness value like 10 or a hrc, and after the rolling it may increase to like say the 20 to 25 RC. So, this increase in this change in behavior is attributed to the way by which material has been treated in course of the manufacturing. So, it can be come confirmed if it has been just made by the casting process or after the casting it has been further processed through the deformation based approaches.

So, this kind of confirmation can easily be done through the hardness tests, where it will indicate the possibility whether the particular product has been made by the casting or by the rolling process or a any other deformation-based process or it has been made by the machining process. So, there is a another way to confirm that not just the hardness test will be sufficient if it take just a one sample and do the microscopy of the s caster sample then it will be showing us a lot of dendritic structure. These will be the another confirmation, while in this case material will be showing elongated the structures which are elongated and align in a particular direction say that is the rolling direction.

So, these are the features will which will be further confirming the kind of the process which has been used for manufacturing a particular product. similarly for the heat treatment purpose, we know that a particular a steel of like 1 0 1 0 which is offering hardness of like say the very low 10 RC. And if it is supposed to like say the normalized it. So, it will offer another kind of a hardness and after the hardening it may offer another type of the hardness. So, there may so just a measurement of the hardness will indicate whether a particular kind of the heat treatment was properly performed or not.

And so, a measurement of the hardness can be used to assess whether the correct kind of manufacturing process or what kind of manufacturing process which was applied, whether the correct kind of the heat treatment was applied or not. So, it will help us to confirm whether a particular heat treatment was performed or not. It also helps to ask to estimate the value of the ultimate strength because there are some empirical equations where in like use of the weakers hardness value or the Rockwell hardness value, or Brinell hardness value can be used to estimate the value of the ultimate strength.

Ah we know that whenever component is subjected to the.

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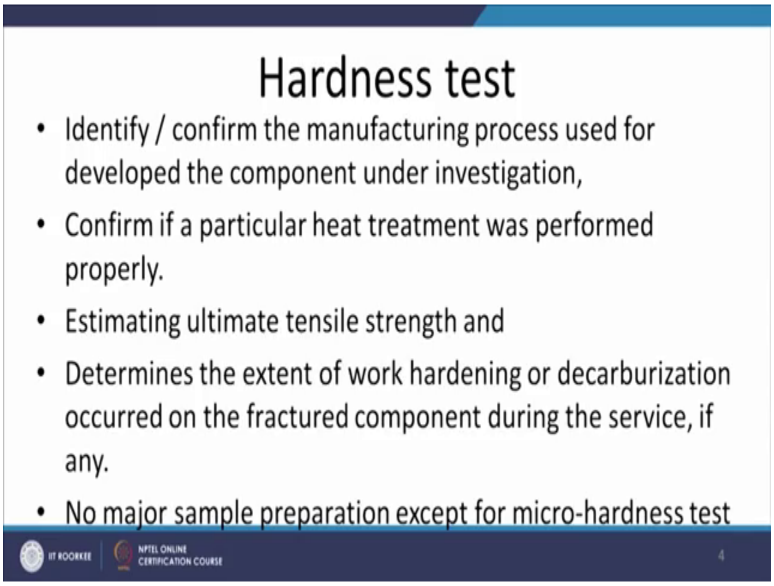

Deformation surface layer deformation says this component has been in service for a long.

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So, during the service if it has it is surface has been exposed for a some kind of the deformation at the surface. So, the deformation will be causing the work hardening. So, increase in work harden increase in hardness at the surface hardness as compared to the core, can easily distinguish the work hardening effect is there at the surface or not there is another thing which can be checked if there has been the loss of alloying element due to the exposure at a high temperature during the service, or if it has been decarburized, or carburized, or oppositely like if it has been carburized.

So, in both the cases there will be change in the mechanical properties of the component especially hardness. So, if the component has lost the alloying elements then it will be it is hardness will be reduced. So, that is what we can easily check through the hardness measurement. Similarly, if it has been carburized then it is hardness will increase. So, if it is hardness has increased after the exposure during the service. So, this will be one indicator that either the component has been exposed, component has been subjected to the change in alloying elements either it comes of the loss, or the addition of the alloying elements or if it has we, or it has been subjected to some kind of the deformation, because of which work hardening has taken place.

So, such kind of the property variation related with the service conditions can be easily assess it to the simple test that is the hardness test. And for the if we have to carry out the micro hardness test, then certainly it requires some kind of preparation because we need we should be able to see the kind of phases in the kind of the grains; which are whose hardness is to be measured. So, one simple sample we cannot see the grains of the simple sample without polishing.

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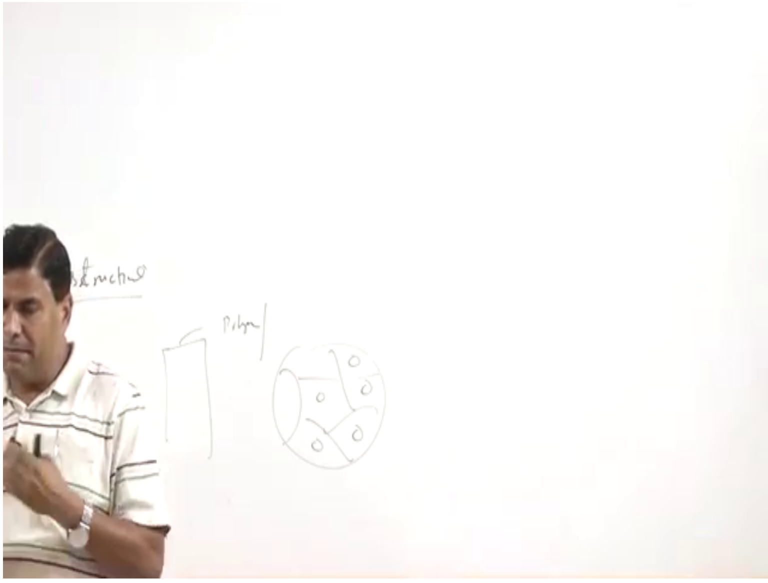

So, we need to polish the sample, and after polishing when a little bit etching is done then we can see the grains, but certainly the etchant effect is removed before making the hardness test.

So, simple high-quality pulsing also under the microscope can help us to see the different micro constituents. And once we are able to see the micro constituents in the and at low magnification, then each one can be selected each constituent can be selected for the measurement of the hardness. So, whether the different constituents are of the same hardness or of the different one, that is what can easily be accessed through the micro hardness test methods.

So, micro hardness test is basically for the for measuring the hardness of the micro constituent's in individual micro constituents hardness can be measured while other hardness tests; like, the Rockwell test or weaker test or a Brinell test these are the macro hardness tests where large size indenter is applied on to the surface of the specimen. And using the standard load we try to see the kind of effect which has taken place on to the service due to the surface due to the indentation.

Now, related with the destructive test, there are many other things which we need to do. And a sometimes we need to carry out the tests under the simulated conditions because simple tensile test may not be that much useful to show the behavior of the material under the actual service conditions. So, if the component has failed, if the component has failed under the conditions which are different from the ambient condition like either they are of the low temperature or of the high temperature.

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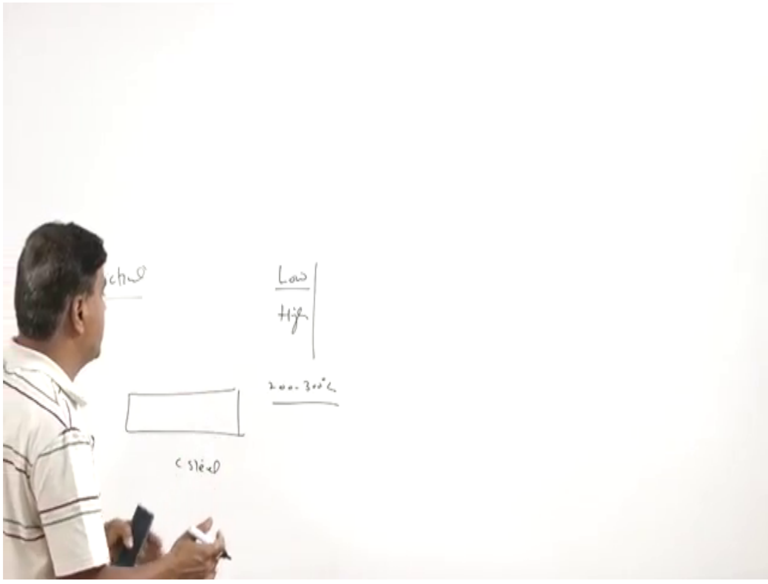

So, it is possible that the, if like say a particular component when exposed to the high temperature, say, one simple carbon steel is exposed to the temperature of like say 200 to 300 degree centigrade. So, this kind of the temperature is not good for a certain kind of the steels, because if they are having the enough nitrogen and oxygen, then they will show the then they will show the embrittlement behavior embrittlement.

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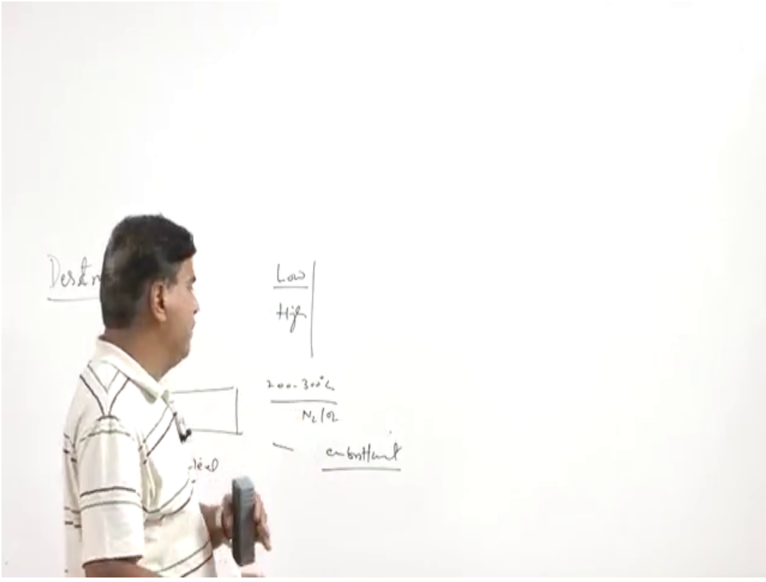

So, the temper embrittlement blue embrittlement, these are some kind of the embrittlement's which will be causing the loss of the ductility there are a loss of the toughness of the material at a high temperature.

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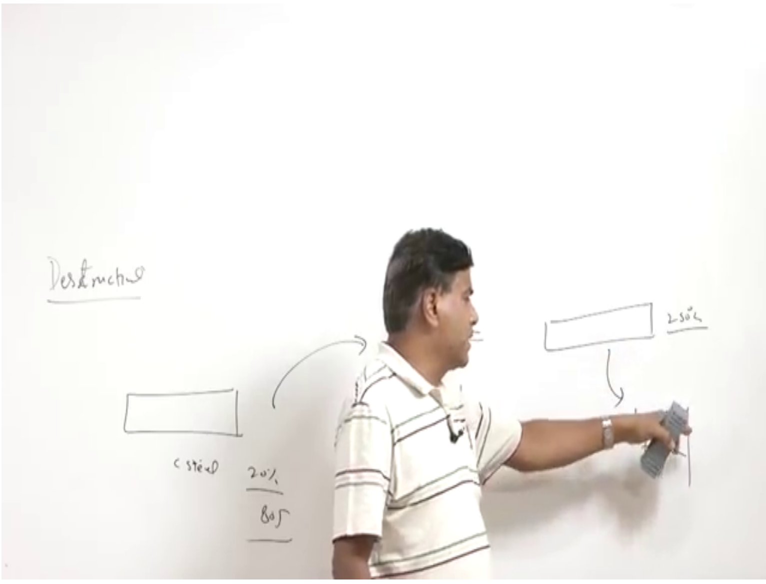

So, in order to see if our component which was showing a very good ductility, like say 20 percent and was showing good toughness like 20 joules, when it is exposed to the service conditions of like say 250 degree centigrade.

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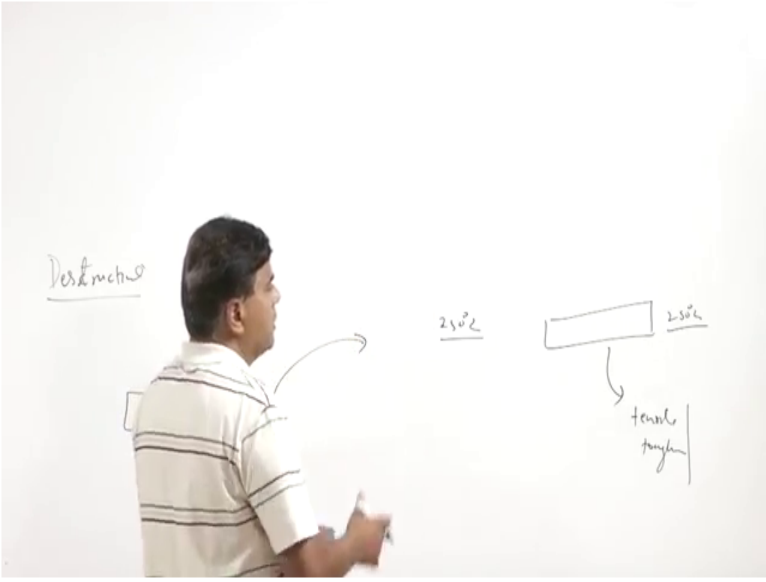

It failed in brittle manner. So, to confirm why it has failed in brittle manner, we may have to conduct the test under the simulate simulated conditions.

So, wherein the same sample will be taken and it will be exposed to the 2-degree centigrade, and then we will be checking it is behavior after the exposure for one hour or 2 hours. And then we will try to see what kind of the, what kind of change in it is like the tensile properties have taken place what kind of change in the toughness has taken place. So, any kind of the variation will indicate the possibility of the embrittlement means if the material is a sensitive for embrittlement in this temperature range, then it will show the increase in a strength reduction in ductility reduction in toughness etcetera.

So, those behaviors will be attributed to the exposure to the exposure of the material in that particular band which is sensitive for variation in properties of the material. Similarly, there is another possibility; a steel may so very good behavior like a simple mildly steel.

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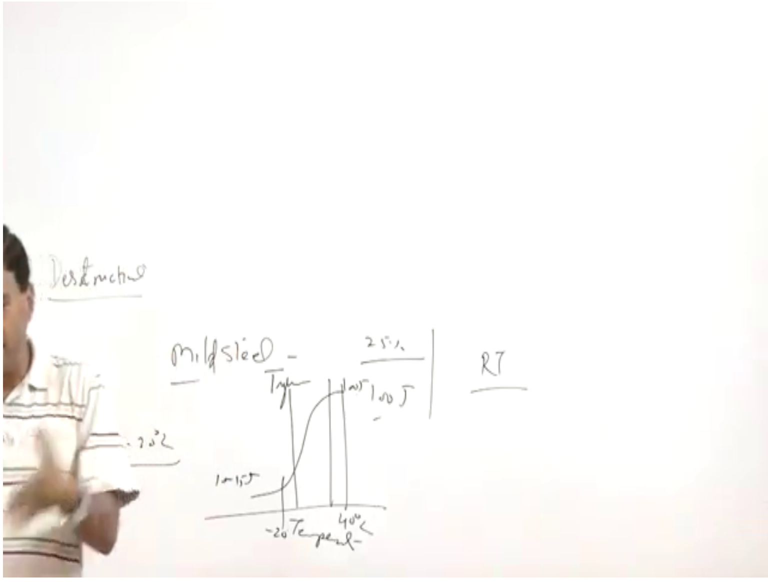

So, a very good behavior of a like 25 percent elongation and a 100 joules of the impact toughness but when the same is subjected to the this is the these are the properties under the normal room temperature conditions. Say if this steel is exposed to the room means sub0 conditions were like say minus 20 degree centigrade.

And under these conditions if it is a failing in very brittle manner, then we need to see really how the material behave under those conditions. And for that we may have to conduct the ductile to brittle transition temperature which will easily show, the conditions under which it is showing the loss of the toughness as a function of reduction in temperature. So, here this is temperature behavior, of like say 100 joule at like 40 degree centigrade. And it is losing it is toughness completely like 15 10 to 15 joule, in the range of temperature say minus 20 degree centigrade.

So, such kind of studies may be required to see how the material will behave when it is exposed to the conditions. Other than the a room temperature conditions. So, these are called like a performing the a mechanical or destructive test on under the simulated conditions so, that the change in behavior of the material can be assessed under the conditions which are different from the room temperature conditions. And these kind of the tests are especially useful if the very low carbon steel material which normally shows very good toughness good ductility.

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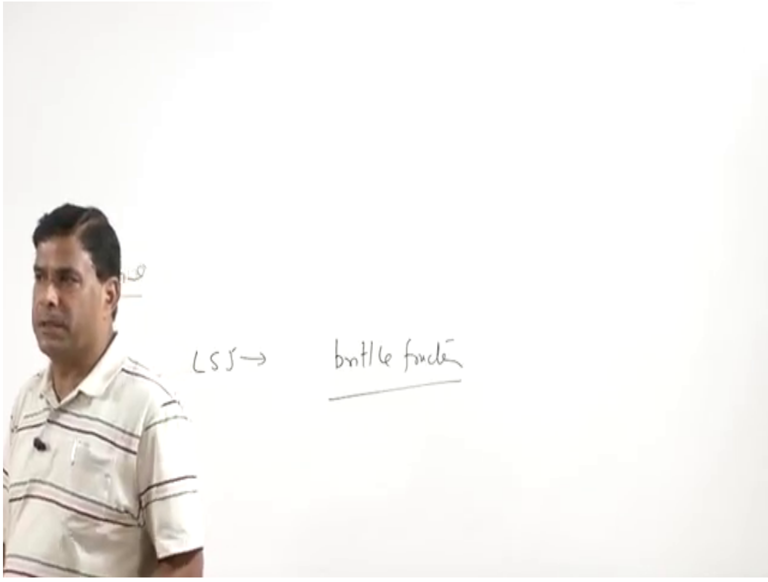

But still if the failure is occurring in very brittle manner. So, if the brittle fracture is are clinging under such kind of conditions then it is good to see the behavior of the material under those simulated temperature conditions. Because normally such kind of the steels are expected to show very ductile and very tough behavior tough behavior, and if they are not showing the behavior corresponding to those established values under the conditions other than the room temperature then it is always good to perform the test under the simulated conditions.

So, this is the importance of the conducting the test under the simulated conditions. Another aspect is also important regarding the destructive test. Like, we may conduct a number of tests like the harnessed is conducted and we have found the value of 20 RC for a particular steel.

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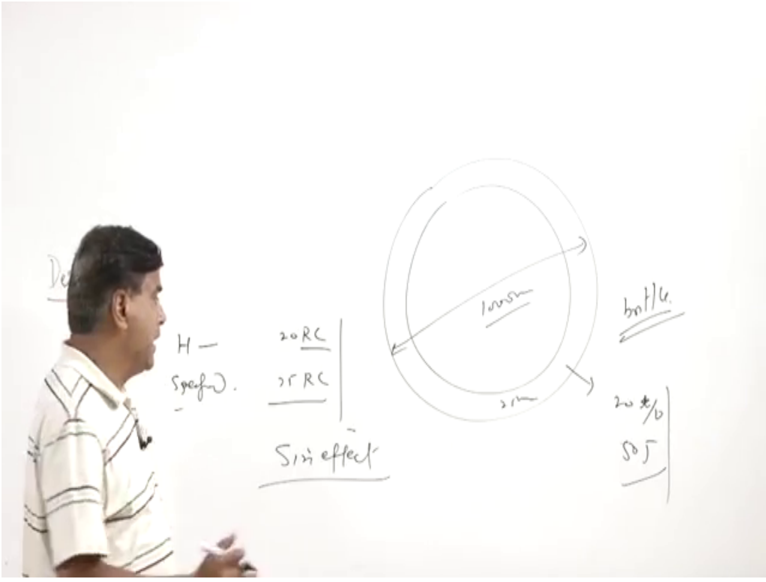

And a specified value of the steel for a given services like say 25 RC. So, this minor difference a minor lower value of the hardness as compared to the specified value should not directly be attributed to attributed as a primary cause of the failure.

So, here is a caution. Caution is that, little lower strength or lower mechanical properties then the minimum specified values should not be considered as a primary cause of the failure. The reason for this is that there are 2 regions one is like the lab data; lab data do not represent the correct behavior of the material as compared to the actual largest structures. The material in actual largest structures behave completely indifferent manner as compared to the small lab size samples. So, this is what can also be seen like a component, a large component like this having the thickness of 25 mm, and the diameter of say one thousand mm, or this was made of very ductile metal like 20 percent elongation and like 50 joule of the toughness.

But the despite of a reasonably good toughness and the good ductility this material failed in very brittle manner. So, it is not necessary that if the failed if the component which has failed in very brittle manner, if we take a small size sample then it will show very good ductility and good toughness. So, this is a direct contradiction, and a reason for this is that material in large structures behave in completely different way then what is of tends to the normal lab test data. So, and here in only the size effect come into picture.

Normally, with the increase in size of the component the chance resistance to the certain kind of the failure decreases despite of having the same properties of the material. So, we know that the material property we can identify through the standard tests which include like, we can mention that hardness value in particular range.

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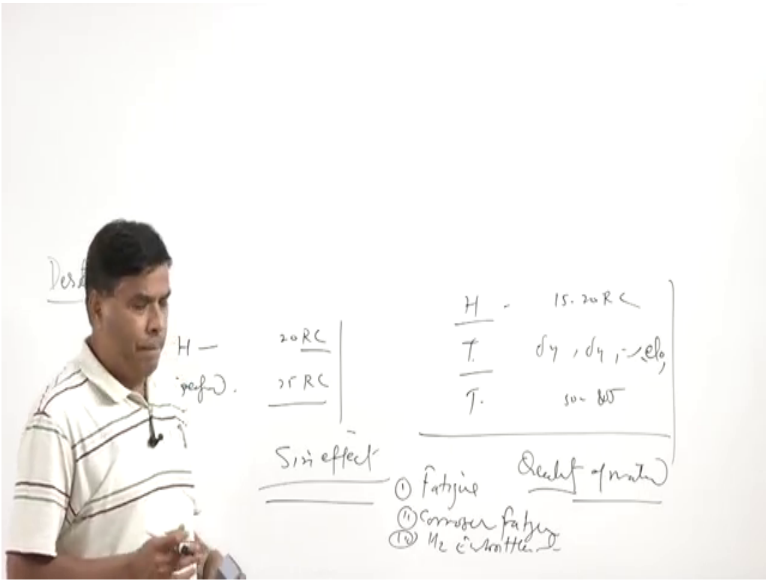

Tensile values, like a sigma y sigma u a percentage elongation percentage reduction etcetera in a particular range a toughness of particular value, like say, 50 to 80 joule and this hardness of like say a 15 to 20 RC.

So, we can specify the values for different things using the standard lab data tensile using the data operand from the tensile. But these tests are good for quality assessment of the material, quality of the material.

But if same material when it is used in form of the large structures, then resistance of the material to certain kind of the failures decreases with the increase of size. And this kind of the factors include fatigue, resistance to fatigue decreases with the increase of the size resistance to the corrosion fatigue also decreases with the increase of size. And the same is also true for the hydrogen embrittlement, hydrogen embrittlement. Resistance to the hydrogen embrittlement also decreases with increase of increase of size.

So, since the material tends to behave more like a brittle material with the increase of the size. So, we need to be more careful with the interpretation of the data. Especially, when the material using the standard samples may show good ductility good toughness, but the same may not reflect and replicate when the component size is large. Now here I will summarize this presentation. in this presentation basically I have talked about the need of conducting the destructive test, and what are the common destructive tests which are conducted, and what kind of caution we should use when interpreting the data of the destructive tests in the case of the failure analysis.

Thank you for your attention.