Principles of Physical Metallurgy

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Lecture No. # 06

Experimental Tools and Techniques (Contd.)

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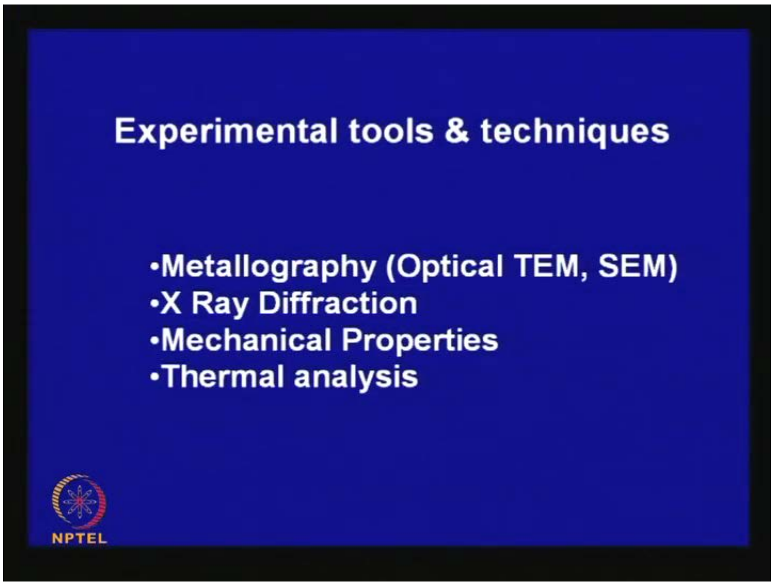

Good morning. Today we continue our discussion on experimental tools and techniques, which we which one uses and the study of physical metallurgy. Last class, we looked at thermal analysis in detail. We also looked at several metallographic techniques, which are use to examine micro structures of metals namely optical microscope, transmission electron microscope, scanning electron micro scope. We also talked about X ray diffraction; and to recapitulate this concept of X ray diffraction may be we look at it let again, because we have talked about stereo graphic projections. And I can show you with one example, how you can understand or interpret X ray diffraction or electron diffraction pattern with the help of stereo graphic projections.

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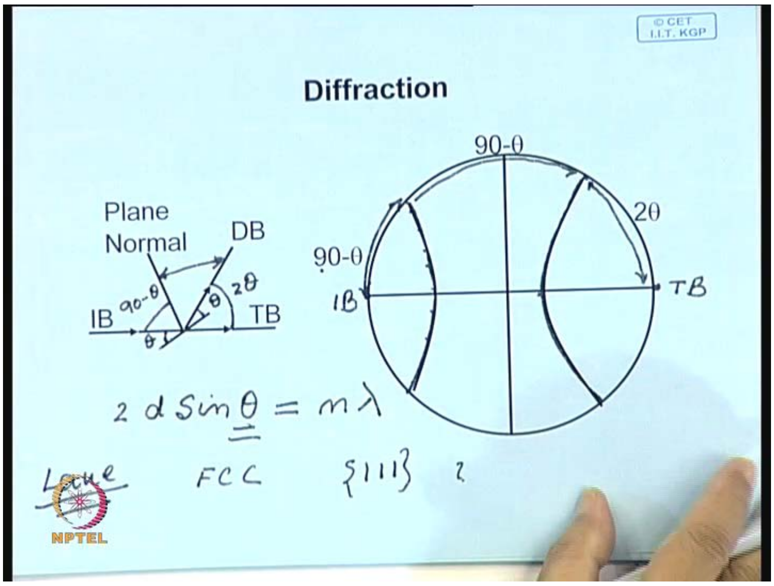

Now, X ray diffraction is diffraction of any electromagnetic wave is guided by Brags law, and which is stated as 2 d sin theta equal to m lambda. Now here, theta is the angle of incident beam on a reflecting plane, this is the incident beam, this is the angle. Now, this is the transmitted beam, and the reflected beam or diffracted beam also which is obtained an angle theta, and this is the normal to the beam, and this angle is 90 minus theta. So, same thing you can represented on a stereo graphic projection, this is the reference fear projection of that reference fear, that is say this is the incident beam; the transmitted beam is 180 degree to this, so basically this is the transmitted beam.

Now the angle between the incident beam and normal to the reflecting plane, this is 90 minus theta. So, what you can do? You can on this grade circle 90 minus theta and draw latitude. So a small circle every point on this obtains angle 90 minus theta. Now when you use powder diffraction pattern their lambda is fixed, but you have large number of crystals. So at least every place there is since there are large numbers of crystal large number of this reflective plane.

So, there will be planes at every point of this and this will satisfy the Brag law and the diffracted beam. You can see it is obtains an angle 90 minus theta local plane normal, so here you check up this is the 90. Now draw this or one can also or good at this angle is two theta with transmitted beam. So you can mark this, so this is this small cycle represents the diffracted beam. So basically every point you will have a diffracted beam so basically it will come out as a cone.

So if you put a diffract meter sensor will sends it whenever it is located here similarly, if it moves along this plane when it goes to the other half it will again record that same way it is also possible to interpret single crystal diffraction pattern. Now, usually in single crystal diffraction pattern what you have, you have theta is fixed because it is a single crystal and I leave this to you as an exercise to interpret, where a particular I mean diffraction pattern from c in a FCC crystal, FCC single crystal where will the diffraction spots from plane 1 1 1 will be located, in case of a lower diffraction pattern.

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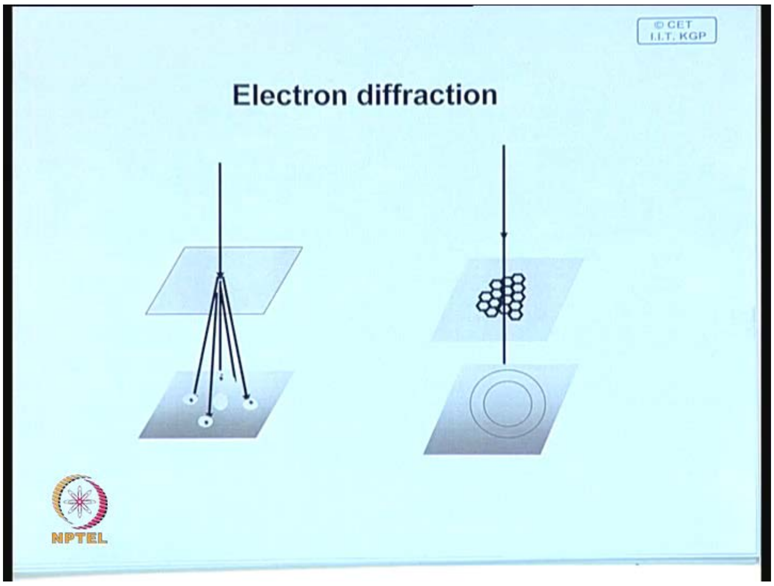

You also looked at electron diffraction; since this electron also has a wave character when it passes through the sample some of the beams will get diffracted. Here also it will exactly follow the same diffraction principle and you can only in the crystal because the electron transmission, electron micro scope you can tilde this specimen and you can always bring the sample to a position where you get a diffraction pattern and if it is a single crystal in that case, here you will get pattern like this spot pattern. If this crystals are very fine something typically represented here then here also, you will get continuous ring.

It is exactly similar to that of an X ray diffraction pattern. In fact this electron microscopes are indeed very powerful not only have you to look at micro structured at a very high magnifications that high resolution. But it also helps you identify precipitates from this or precipitates or some phases, which you see in the micro structure by analyzing the diffraction pattern and also when electron beams sticks the sample number of secondary electrons come out they come out from different shells and if you can major this energy, which also can be done.

In that case, it is possible to find out element and analysis of the area from where the beam is coming out. So most of this microscope this it is whether it is scanning electron microscope or transmission electron microscope they are equal to it sensors, which can detect or which can measure or which can identify the characteristic beams which are getting emitted from the sample and from the intensity of this characteristic beams.

It is possible to do micro analysis as well with this recapitulation let as now move over look at mechanical properties of metals primarily and as has been mentioned it is the mechanical properties, which is most sensitive to micro structure and before we look at how the micro structures can be modified to change mechanical property. It will be good to look at some of the experimental techniques to measure different mechanical properties.

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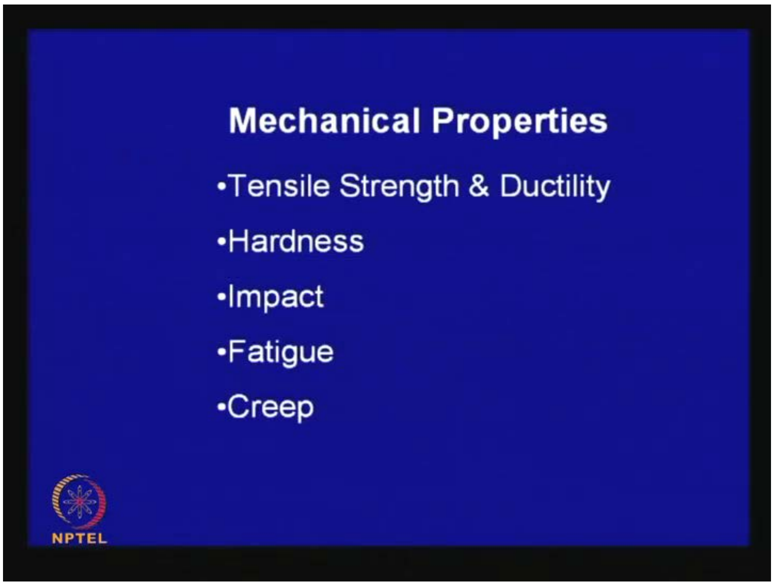

In metallurgical engineering, we often talk about several mechanical properties which are listed here. This list is binomial complete there are few others but in our discussion we will already often talk about these mechanical properties primarily tensile strength, ductility, formability, will talk about hardness, will talk about impact strength, will talk about fatigue and creep.

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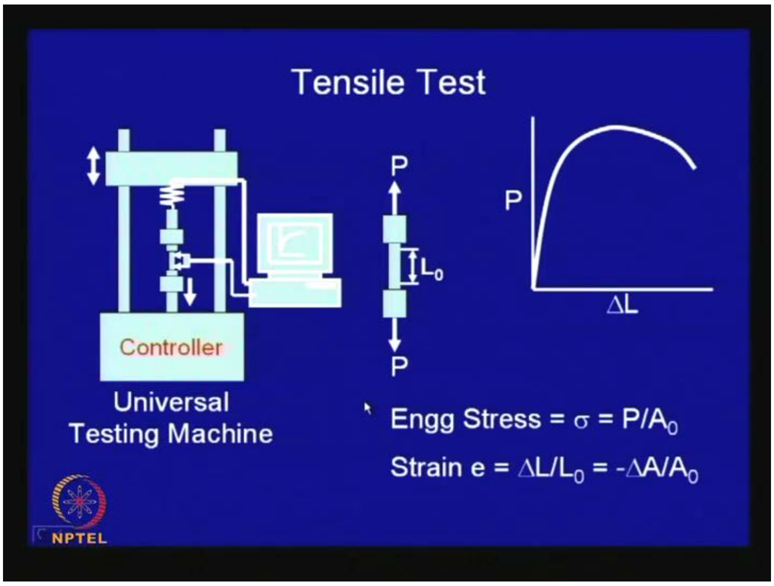

Now, let as look at tensile test in little more detail. How do you perform tensile test? For this you need a specimen which is shown over here a typical shape of a specimen. So this is a gage length position on the specimen, which has uniform diameter or uniform dimensions a width and thickness, if it is flat, if it is round, it has uniform diameter and on this uniform diameter we usually mark a gage length using a marker and distance between the two marker, we say is the initial length L 0 and there is a head potion and the specimen usually this is provided. Because this area is larger width and when we do tensile test, we do not want fracture to take place here.

We want a fracture to take place within the gage length. Therefore, this portion goes into the grip of the machine and so that can be held tightly and it provides more area of contacts as well and also we provide, which is not shown here. Little curvature here to avoid stress concentration, so that failure does not take place here. Now this specimen is mounted on a machine called universal testing machines, which is systematically shown over here. It has to it has a cross head which can move along this reels or along this supports it can move and it can move both phase and there is a pure rode mounted along with a load shell, which is shown in the form of a spring.

So, whatever pull that is applied can directly you will be able to measure the pull that P, that is force with which the sample is pulled and we also fix on the sample a gage a displacement gage, which is fleeted at the marker wherever you put the marker and this displacement gage converts the displacement into vole signal and this is sent to the recorder and it is told an computer disk. Similarly, the load readings this load shell also gives bold signal, which also can be recorded and the computer disk and the mean controller is over here, this controller what it does it moves there is an actuator, which can move this pull rode in a user defined way.

In a tensile test were will be pulling it along this directions. So once this is felt once the sample is fixed into the grips, we start the machine and this force increases with time and we record this force against displacement. So, this plot we called load displacement plot and this can be converted into stress strain plot. Stress is defined as force what original area, area cross sectional area is measured.

Before you start the test A 0 is the initial cross sectional area. So engineering stress is defined as load or pull divided by initial cross sectional area and the strain is defined as change in length. If you define this divide this change in length with original change in length or original length you get strain. Likewise, there will be a relationship between the area and strain and usually that is the reduction in area over original area, this also a strain.

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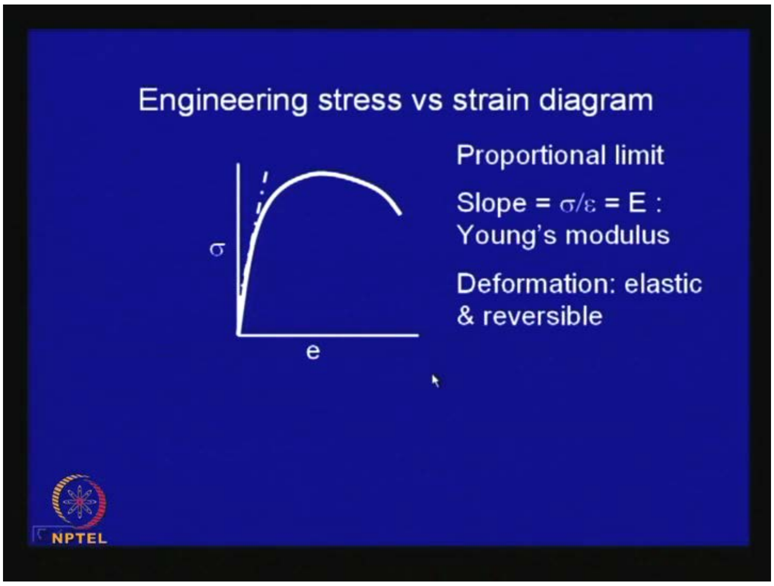

Now let as look at what information, do we get from engineering stress strain diagram? We just looked at how you can convert loads displacement plot into a engineering stress verses engineering strain plot. Now, this has from the several properties can be determined from this particular plot. So for example, if you look at this part which is nearly linear, if you draw a line the slope of this line, which is linear this will give you the elastic modulus. So, basically here stress is proportional directly proportional to strain and this is called Youngs modulus or elastic modulus and this is deformation and this part of the plot is reversible and we also get a stress here you know. There is a point from here it starts deviating from linearity. You call this proportional limit, this also one can say is a measure of ill point.

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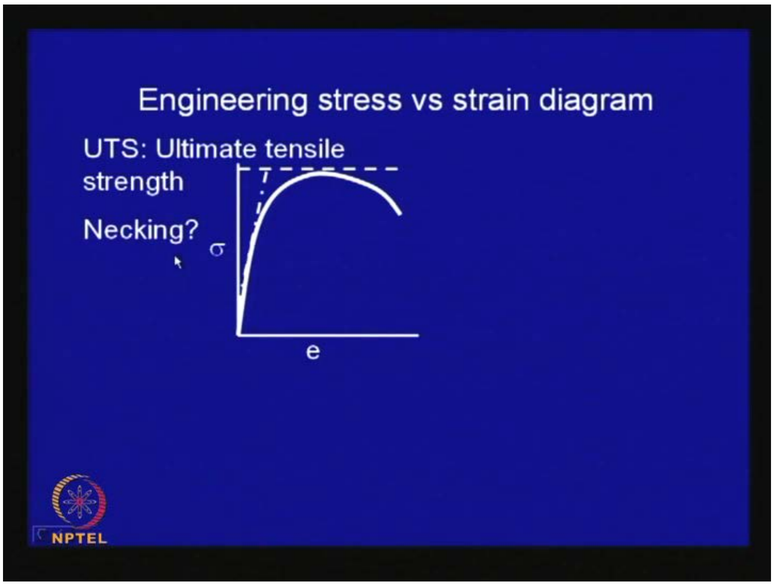

Now, if you look at the maximum so there is a point, which gives you the maximum load or maximum stress the sample can be stand. So, here this is called ultimate tensile strength. What happens beyond this? The load comes down or stress comes down. This is primarily because we are calculating stress based on the original cross sectional area. What happens beyond this point? That will be local deformation called necking, which is shown over here.

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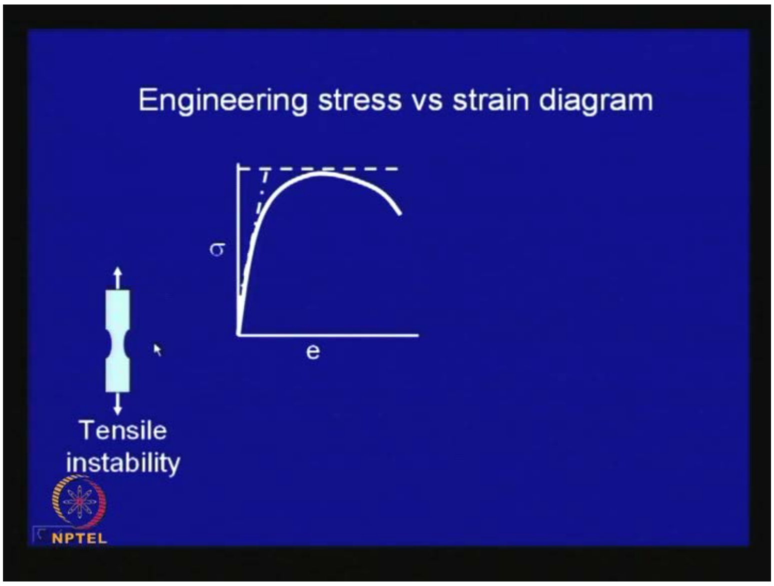

There is a local deformation thus certain area at the may, if in a good well done test will get somewhere in between at the midpoint of that gage length a necking will start and this is called tensile instability.

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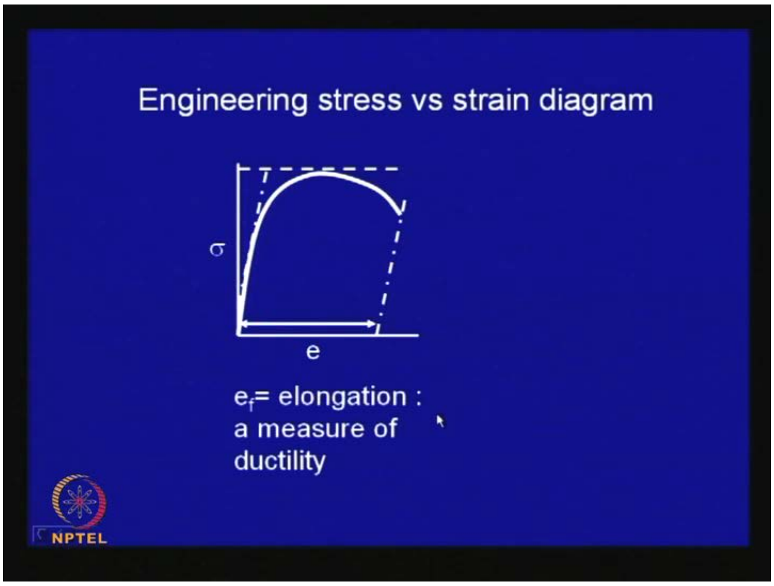

And once this stress comes down when all this engineering stress steps coming down. But truly if you find out the neck area possibly the stress will still go on increasing and once it fractures, there will be some relaxation that elastic part of the stress, which is reversible that is, eliminated. So, that means you move like this and if you measure this distance or this strain what you and you call the strain as ductility or elongation. This is measure at ductility we call it elongation change in length, that is a fracture length at fracture minus original length and you divide this difference change in length over original length will give you percent elongation attracter.

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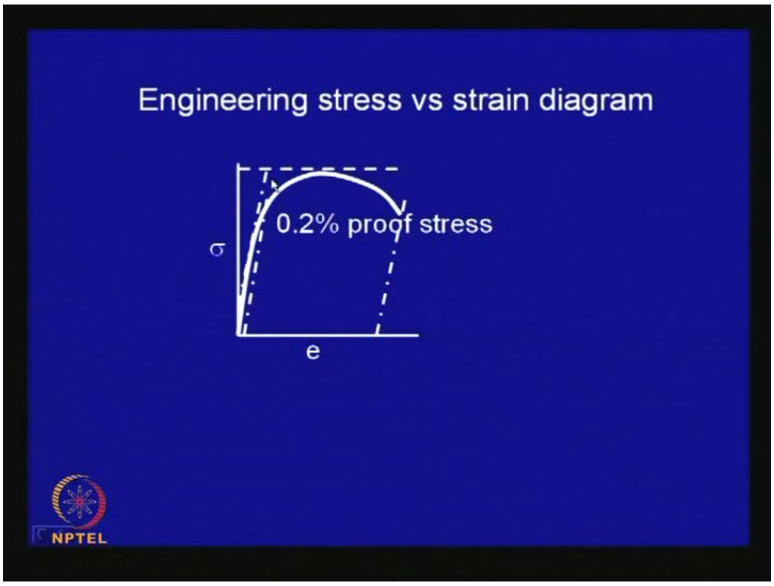

And very often this curves from many engineering material, they are very smooth and it is often very difficult and it becomes little subjective to find out the proper yield strength. So, here now it is customer it would define yield stress as 0.2 percent strain, stress at 0.2 percent stress. So, at 0.2 percent you draw a line parallel to this elastic potion of the plot this intersects this graph here.

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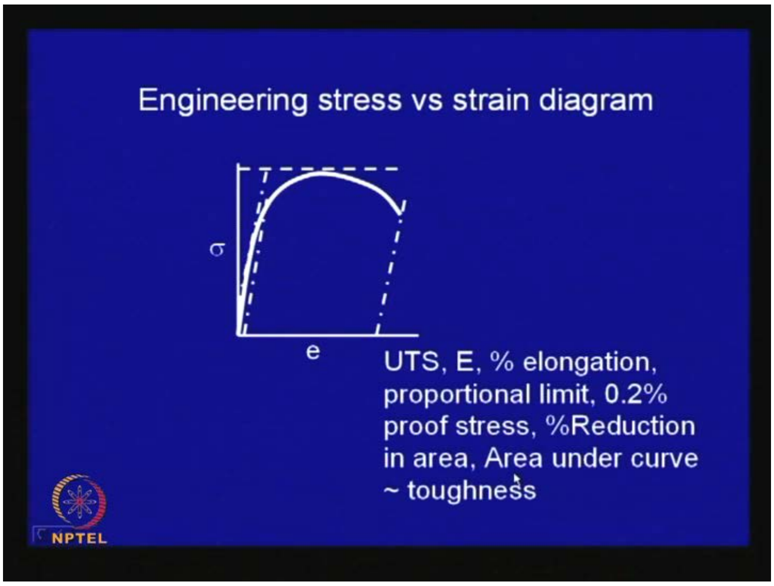

We call this 0.2 percent proof test. Therefore, tensile test it is a versatile test and you get a number from tensile plot, you get a large number of properties, you get ultimate tensile strength, you get yield strength, and you get yields modulus. You get percentage elongation proportional limit reduction in area. You can also get calculate area under the curve entire curve. So, this you can say this is the energy absorbed by the material in cause and fracture, so this is a measure of toughness.

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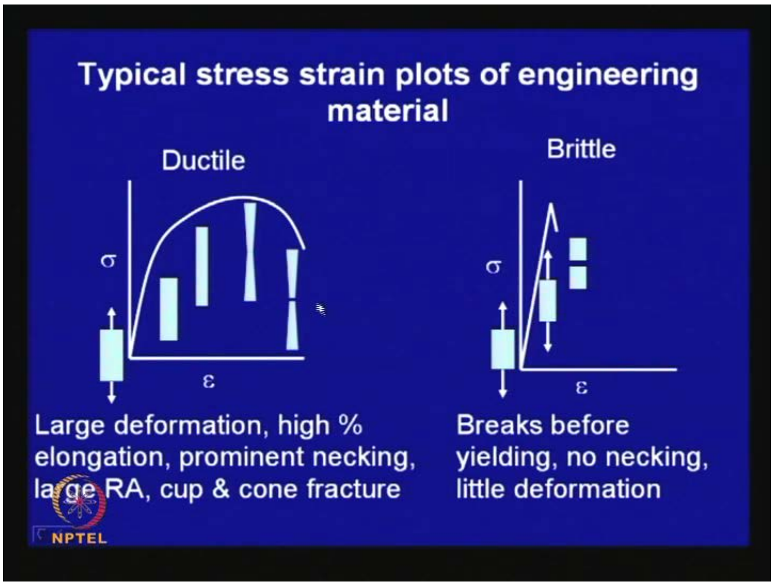

Perhaps, look at some of the typical stress strain plot of engineering materials having widely different characteristic one is ductile, which is shown over here. It is associated with a very large deformation and systematically how the sample dimensions changes as shown here. There is a large deformation there is a pronounce necking and the fracture nature of the fracture is called a cup and cone type of fracture. So can calculate reduction area like measuring the area over here and change in area with respect to original area divided by original area is the reduction in area, whereas, in a battle material that is electro plastic deformation it breaks as you pull within in the elastic region only the fracture occurs. So this is the fractured piece, there is hardly any sign of any deformation.

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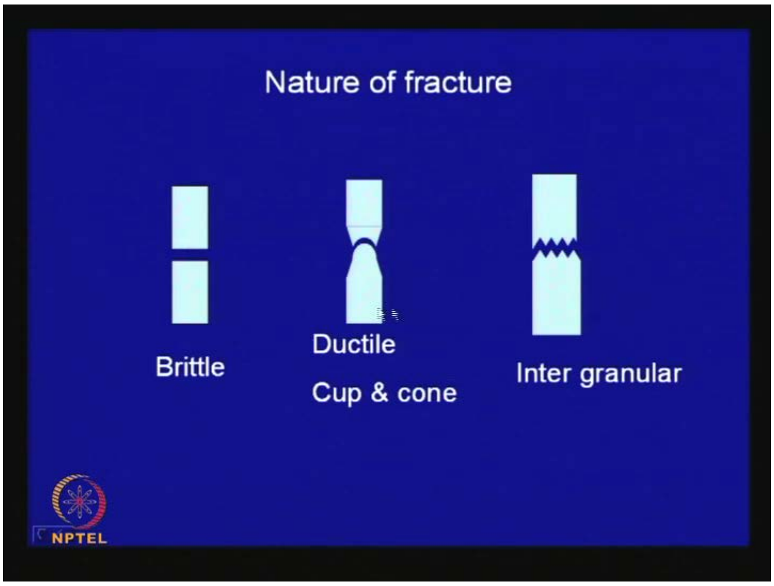

Same thing is explained here is a brittle fracture no deformation a ductile fracture, where you have a distinctly cup and cone kind of a fracture which is shown here, and sometime an materials as we will know they become end brittle and some of these materials they exhibit intergrannular fracture something like this, where the crack propagates along the grain boundary.

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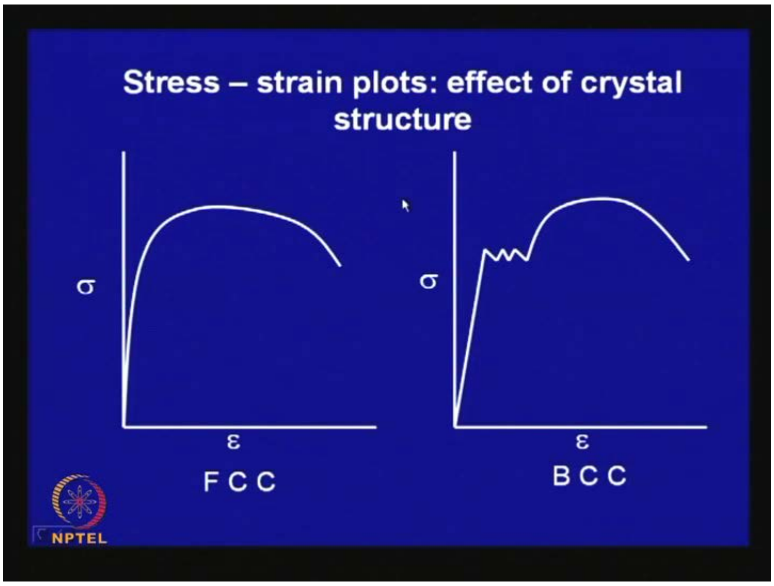

Now, stress strain plot as if is quite some set up to the crystal structure of materials. Most materials they are not pure they will have some impurity, some broadly metal majority of the metals that we use there either face centered cubic or body centered cubic. For example, steel is a body centered cubic material in case of a steel, which as we go along the course where we will find out. We will learn that it is not it is an law iron and carbon, even if the purest form of an adorn, there will be some amount of impurities dissolved in it, which occupy the interstitial sides. And that is why, we get a characteristic stress strain plot which is shown over here, they have prominent yield point, unyield point elongations.

One set is I mean there is some kind of instability. This is called in point elongation here to here and this is called yield point phenomena. This is primarily associated with the interstitial atoms present in BCC lattice and after this yield point them the plot goes like this. An important thing is, if you could work a material steel so if you unload it from here it will come down like this that elastic portion of the strain which is reversible.

So it will come down over here there will be a permanent deformation. If you load it again you will find that yield point phenomena is no longer there, if you load it again immediately after we will later on learn this ion detail, whereas, in case of a phase centered cubic structure the plot is very smooth. For example, in case of copper or aluminum, you will get a smooth stress strain plot as shown over here.

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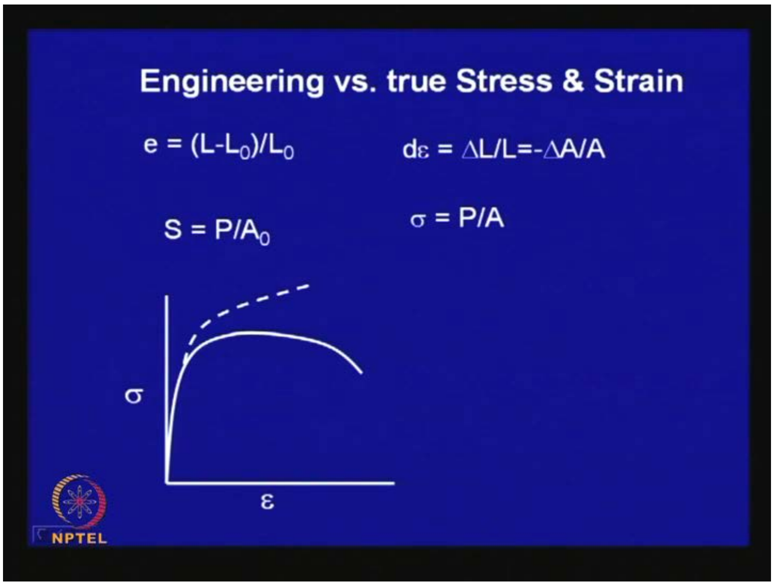

Now as has been mention that is you should make distinction between engineering stress and very often we talk about true stress and strain diagram. So here engineering strain as we have seen is we have defined as change in length L minus original length change in length with respect to the original length divided by the original length. Similarly, stress is defined as force a pull over a normal stress unit area and this area is the original area. As again in this it is possible to define true strain as change in length over instantaneous length. Similarly, you can define true stress as load over instantaneous area. In that case it is possible this is simple mathematics if you integrate this, you will get a relationship between a true stress, a true strain and engineering strain and you quickly I can show this here.

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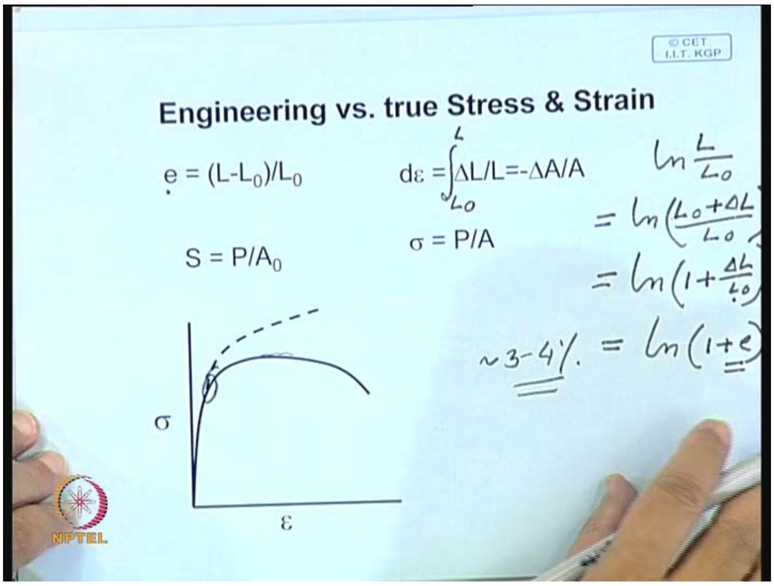

Suppose, I integrate it from initial length to the final length or length attain an instant, then this will be l n L over L naught. In fact this can be written as l n L 0 plus delta L. Therefore, you can say that this is equal to delta L over original length, whereas, this is by engineering strain and I leave it you to convert using this type of relationship, it is possible to convert this engineering stress strain diagram into a true stress strain diagram, which is like this. So here it does not come down.

So there will be but when necking takes place no longer state of stress will be unit actual, you may have to apply certain additional corrections. But nevertheless you must realize there is a difference between true stress strain plot and engineering stress strain plot. But up to a certain amount of strain so may be up to say may be three four percent strain. The difference will be so small little bit difficult to differentiate may be this part it will be difficult to differentiate.

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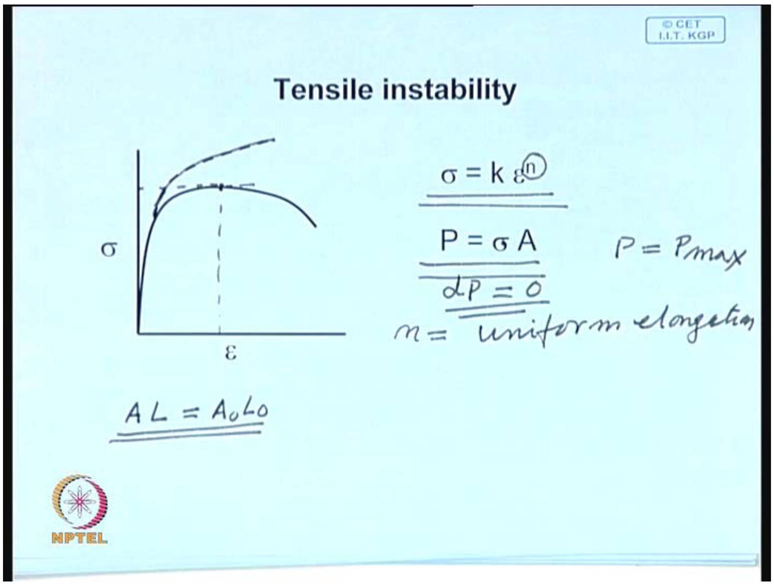

Now, you take this as an exercise. So this part of this plastic potion of this stress strain plot engineering this here true stress strain plot can be represented by an expression like this and here it and show that here, this n is a measure of uniform elongation. So that means you get uniform elongation until this point. Uniform elongation means as has been mentioned this area at any instant times, the length gage length this relationship.

You can make a conversion, I mean from elongation change in elongation change elongation can easily been converted into reduction in area. At once necking starts you have to be careful, although there is no fall in change but this simple relationship will no longer be valid and you try and show that this is an equal to n is equal to is a measure of uniform elongation. As a hint I can give you that P is a low, which is given as sigma times area and when P is maximum, so that is here the differential dp this is 0.

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Now let as look at hardness, how do you define hardness? Hardness is resistance to scratch our indentation. Now scratch hardness is very qualitative that is a scale because more scale of hardness, it is a qualitative index starts from 0 to 10. The talc is a softest material is Moh's hardness zero. Diamond is a hardest with hardness number 10 but this is a more often qualitative index. In engineering, we use hardness indentation resistance to indentation as the measure of hardness, this test is very simple tensile test, you do not have to use standard test piece, which has to be machined properly and your dimension have to be accurate surface furnished as to be good.

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These three common hardness measuring devices, which are listed here. So Rockwell, it uses an indenter which is made half of a diamond cone or it can have a steel ball indenter. You have Brinel hardness tester, where a steel ball indenter is used and Vickers hardness testing machines, where a square based pyramid it is used as an indenter.

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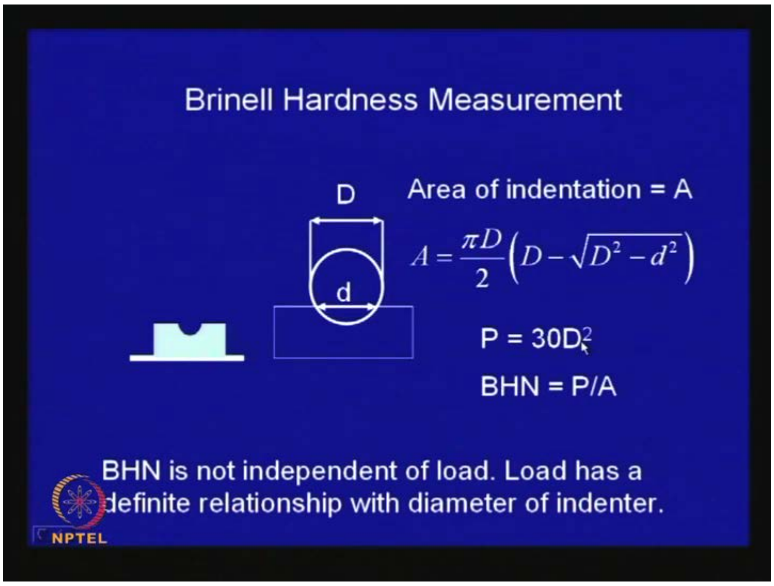

Now, let as look at the concept of Brinel hardness measurement. You have an indenter, which is mounted on a small that cylinder so this is the indenter and this is made up of harden steel ball and this indenter is so hard that it does not deform. It has a hardness level much higher than the material on which measurement is to be taken. Then when you apply load this indenter goes penetrates into a sample and leaves an impression something like this and if you look at it from the top you may get a view something like this is the impression that you get and now what you need to do you measure the diameter of this indentation.

Diameter of this indentation and from this diameter of this indentation that area the contact area of that during indentation A is to be measured and how do you does? It can be done very easily I leave this as an exercise. Assume that this is the indenter with a diameter D and this is the diameter of the indentation. The indentation mark on the sample and to measure this one uses a graduated eye piece and it has some magnifying power and it has it has a graduated scale and on the scale. You can directly read this diameter millimeter or micron and you can show that this is as fear and you try to measure the surface area of the contact area along this indentation, which can be done by simple integration and this comes out to be this and hardness.

Brinel hardness number is defined as load over this contact area and Brinel hardness number is not independent of load there are guide lines for selection of load. For example, in the case of steel you use this expression to calculate what load you need to apply. The load to be applied is equal to 30 diameter to the power 2, 30 D square. So, if the diameter of the ball indenter is 10 millimeter 3000 kilogram load is must be applied to the indenter. Therefore, you can well imagine the dimension of this indentation is quite large and usually the Brinel hardness measurement is used on materials, which are lot of heterogeneity something like cast iron.

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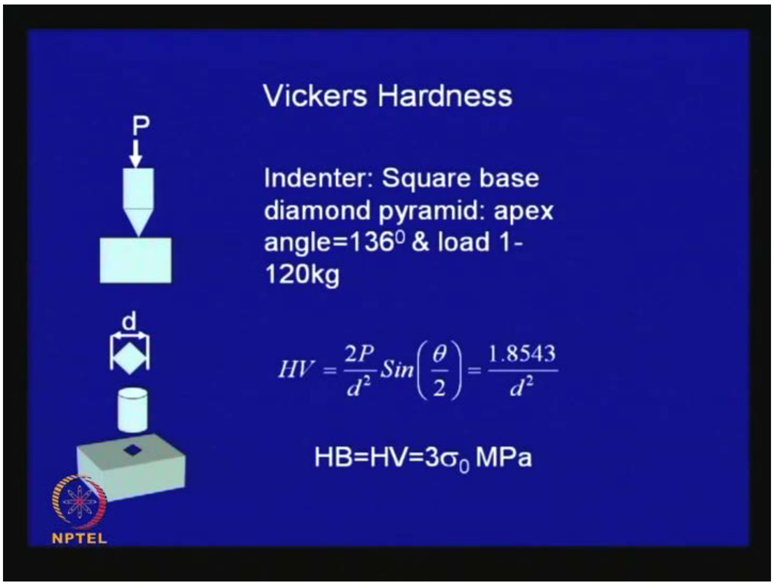

You can also have Brinel hardness measurement with smaller indenter smaller load as well. Now weak as hardness measurement principle is also exactly similar to that our Brinel, only difference is the type of indenter it is different. It is indenter; it is an diamond cone with a square base pyramid. So, this of the square is something like the square base pyramid and the angle is very specific that angle between the two phases of the pyramid opposite phases of the pyramid 136 degree and usually this load is on this range 1 to 120 kilogram. You can well imagine the dimension of the indentation here will be very small and you need in fact microscope with graduated eye piece to measure the dimension of the indentation, which is schematically shown over here.

So, once you place the load here the indenter will go penetrate into the material and after that you will draw the load and then bring the specimen under a microscope, which is shown here schematically and then you sometimes this days you can projected on the screen also of the microscope and then you be can measure the diagonal of the indentation mark. It is customized it to measure both to diameter this as well as both the diagonal that is d 1 d 2 and find out arithmetic average of the tool, then you can week as hardness number HV using this expression. I leave it to you to derive this that is hardness here also is exactly defined as same as Brinel hardness number that is load over the contact area and here theta is the apex angle 136 degree and this hardness measurement as been as apparent is a very simple test.

It does not need a very large amount of material; it can be done on a very small piece of metal particularly, there is weak as hardness and therefore, there is a some direct relationship between weak as hardness and flow stress of the material, which is shown here. Sigma zero is the flow stress which is at you can see this is some kind of an yield stress in between yield stress and u t s. So, this week as hardness number so if measure hardness you will get some idea about the tensile strength of the material.

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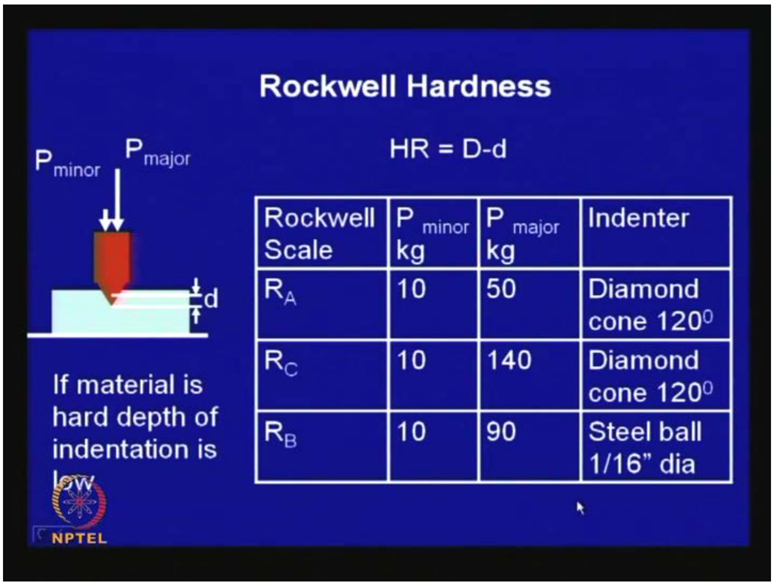

Although also another hardness scale, which engineers very commonly use is a Rockwell hardness scale. This is also this principle is little different. Here you know here that indenter is either a diamond cone indenter with an apex angle of 120 degree and here you initially apply a minor role of around 10 kilogram. So, that the indenter sets on the sample and then you apply the major load; when you apply the major load it penetrates into the material and what you measure the change in this depth of indentation from minor load to the major load and this depth of indentation has some kind of an inverse relationship with hardness.

That means higher the depth of penetration and higher is the depth of indentation, lower is the hardness and thus Rockwell hardness number is something like capital D minus small d. This is some constant depending on the scale that you use a minus d. So, it is a linear function of this depth or penetration and depending on the choice of load and indenter you have hardness is measured in different scales which are listed here like Rockwell A, Rockwell C, Rockwell B.

Out of this Rockwell C is most commonly use for harden steels and here the minor 10 kilogram major load is 140 kilogram and indenter is a diamond cone indenter with apex angle 120 degree, whereas, for softer material one prefers to use Rockwell B scale and here also the minor load is still 10 kilogram but major load is 90 kilogram and a steel ball indenter is used with a diameter one over sixteenth of an inch.

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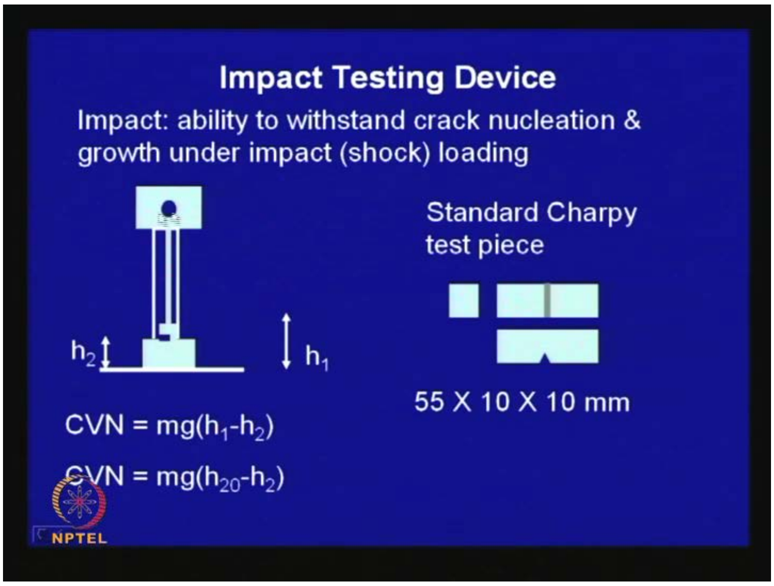

Now, irrespective of which ever unit or whichever machine in use for hardness measurement. There are nowadays conversion tables are available and you can convert hardness measurement from one scale to another and many of these module testing machines they come with a loaded software, which does this conversion automatically. Now let as look at you have looked at tensile test in tensile test load is applied gradually.

Now what happens to a material if the load is applied at a very high strain rate? So, suppose you something like a hammering then is it steel ductile.

Now we find that particularly BCC metals, it is highly sensitive to the strain rate of testing. So, particularly for steel a test method has been devised which is called impact testing and let as look at impact testing this is a typical impact testing machine which is schematically shown. Now question comes up, what is impact property? It is the ability of the material to withstand crack nucleation and growth under shock loading or impact loading. What we do here, we use specimen something or a standard test piece is shown over here.

So, this is square cross section by 10 millimeter cross section 55 millimeter long and on this we make a V notch V grows. V notch this angle is 45 degree and that notch depth is 2 millimeter and what we do we keep place this standard notch specimen over here and strike it with a hammer, which is attach to a pendulum I mean which is shown over here and this hammer will strike the test piece in this phase opposite the V notch and we try to measure that energy that is required to cause fracture and this notch test piece and this value is called Charpy impact value, which is and what we do is that there is a little animation and this tensile impact testing revised, there is a pendulum kind of arrangement.

This is a rod on which a massive hammer is attached this is the head of the hammer, which sticks the test piece at this particular point. Now you raise it to a particular level there is a indicator usually there will be a pointer, which indicates that height up to which it has been a raised and then you place the sample here at the base horizontally and then you so this is the sample which is placed horizontally and thus you release this hammer this height is measured you release the hammer the sample fractures it falls off. Then you measure this height and after it goes to the other side the pendulum it will come back to its initial position and this text hardly a fraction of second for the test to conduct and what you do is you convert this height into energy the mass of hammer is known.

So, mg times this h 1 this height minus this height will give you the Charpy V notch value. So, this gives you this is a measure of the energy that is needed to rupture fracture the test piece and usually it is better to calculate it this gives the little better method of finding out this height. What you do is you find out you first do not keep a specimen release the hammer from a height and see to what height it goes. So, this is without specimen and then you keep this specimen and then repeat the test. So, this will possibly by this will be able to eliminate some of the energy loss, which is absorbed by may be improper lubrication etcetera over here.

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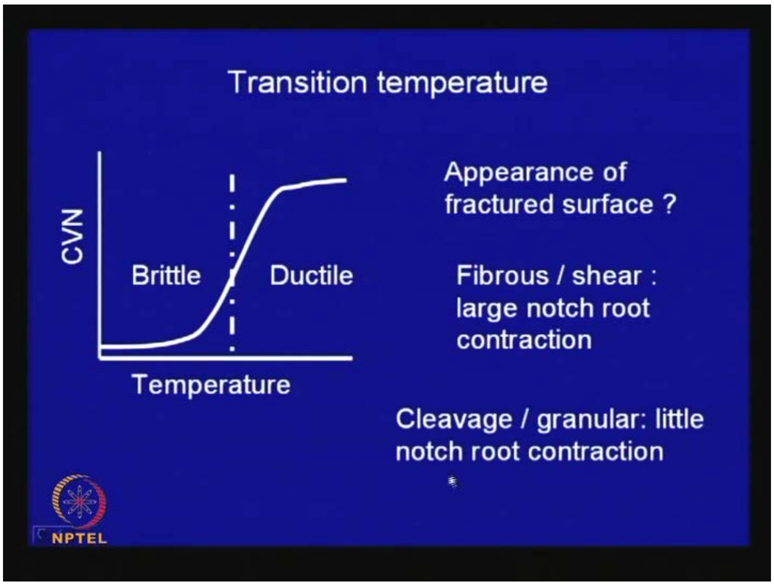

Now, steel has a very important characteristics many of this failures of steel structure has taken place in a brittle manner. We all know about the failure of titanic ship, which failed when it went to a region where and it struck an ice bridge. So, basically it the temperature was very low. So, at low temperature steel in many instance steel structures have failed in a brittle manner in fraction of a second. Getting to lot of life and a particularly the liberty ships during the Second World War failure as also been related to this kind of a brittle failure.

Now if you do the test at a particular temperature and then you plot the Charpy V notch value what you get is this type of a plot. The steel under goes a ductile to brittle transition. At a room temperature it may show good ductility it may have high impact value but as you conduct the test at lower and lower temperature. You will find that Charpy V notch value goes down to a minimum value something over here, which is virtually nearly zero so may be at room temperature this energy level may be around 200 joule, so at low temperature it may go down to may be for 5 for 10 joules and this temperature is called the transition temperature, where the fracture moves over from ductile to brittle fracture.

Now the appearance of these two fractures are entirely different the fracture at room temperature in steel is fibrous, it is primer it is associated with a large plastic deformation. You can receive with a neck head die that notch root contraction, whereas, at a low temperature fracture occurs with very little notch root contraction and this type of fracture is called cleavage or granular fracture.

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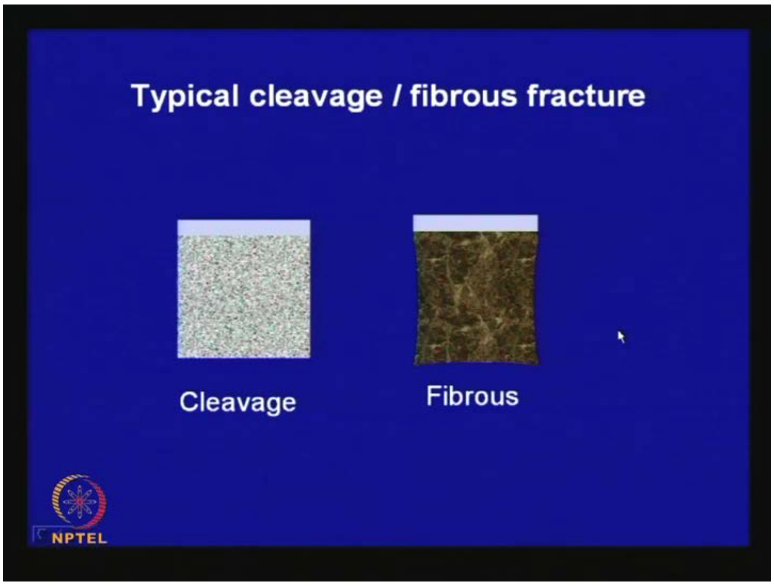

And typical the surface of the fracture, which is shown here this, is the typical appearance of the fracture and particularly looks at this. There is a large deformations around this around that notch root. There is a large deformation, so which is the sign of plastic deformation in ductile fracture.

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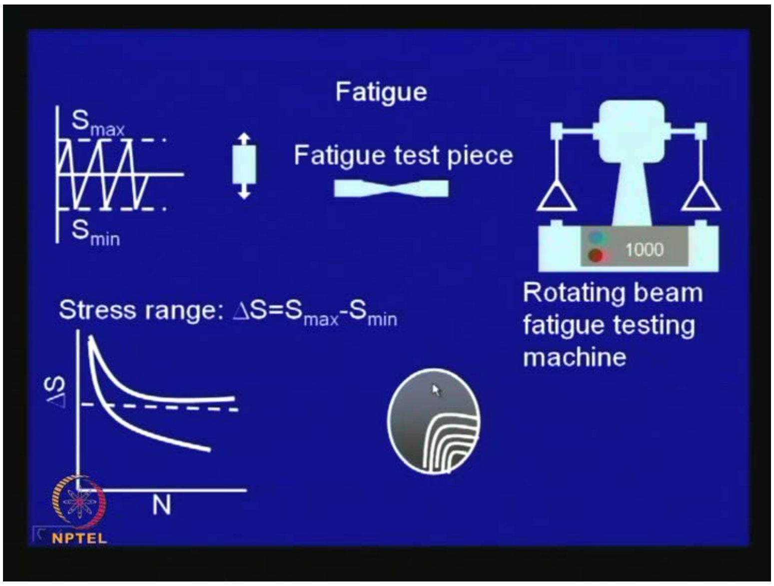

Now, let us look at a fatigue property. Now any component, when it is subjected to cyclic loading it is subjected to fatigue. Something like aircraft when it flies at a flies at a height says 30000 feet or higher. There you know the inside the fuse large has to be pressurized. So every time the air craft goes up it acts as a pressure vessel but when it comes down the pressure outside and inside the same. So, similarly, think about rail of a car of a railway carriage wheel or rail. So, basically these components they are subjected to cyclic loading stress at a point keeps on varying it is not subjected to a constant stress, which is pictorially which is shown over here.

So, any component the stress if it keeps on fluctuating something likes this. It goes to a maximum stress and goes to a minimum stress, it can be tension it can be tension compression and diagrammatically, which is shown here. So, when you subject to such a loading so the sample will keep on fluctuating that means strain at a particular point once it will increase, decrease and as a result so crack will nucleate at a certain point and then you will propagate through leading to fractured and this can take place fractured in such case and take place at a stress level much lower than the yield strength of the material and to find out the resistance to fatigue kind of a loading such cyclic loading, a simplest test is a rotating rotate beam fatigue testing and which is done and machines are available, which is diagram schematically shown here.

There is a motto on which standard test piece is mounted test phase is something like this. It has a reduce section over here this is primarily because it is loaded like a candy liver. So, reduction in this section size in is design in such a way that you have maximum stress over here. So, when failure takes place it will takes place at his particular place and this is how the test is done you can mount a usually on the you can mount two sample simultaneously and this is the load which is given and the stress on this particular sample as it rotates a particular point. Let us say outer point when it is here up then it is in tension when this when it as it rotates when it goes down it is subjected to compression.

So, this point is subjected to a stress something like this and what you do is you try to find out how many cycles this sample takes for failure to takes place. When the sample fails this load will fall on a micro switch here and then this will stop the machine. You can note down the counter reading and then this test can be done as if at different level of stress range. Stress range is defined as this maximum stress minus minimum stress and if this test is done at different stress range and then you plot number of cycle withstands in x axis and y axis. You plot this stress range, and then you get a plot like this if it is a BCC metal.

So, like steel you get a plot like this so it has a certain limit, which is called endearment limit. So, beyond a at stress range below this it has infinite fatigue life. Whereas aluminum copper they will have plot like this they may not have a definite endearment limit and appearance of this fracture it has a very typical appearance. It starts it with a nucleation and it propagate slowly, which is shown here it starts at this point and you can often see this marks as a starvation marks and later on when this area remaining area becomes very less not able to obtain this a this load, then this ductile fracture takes place.

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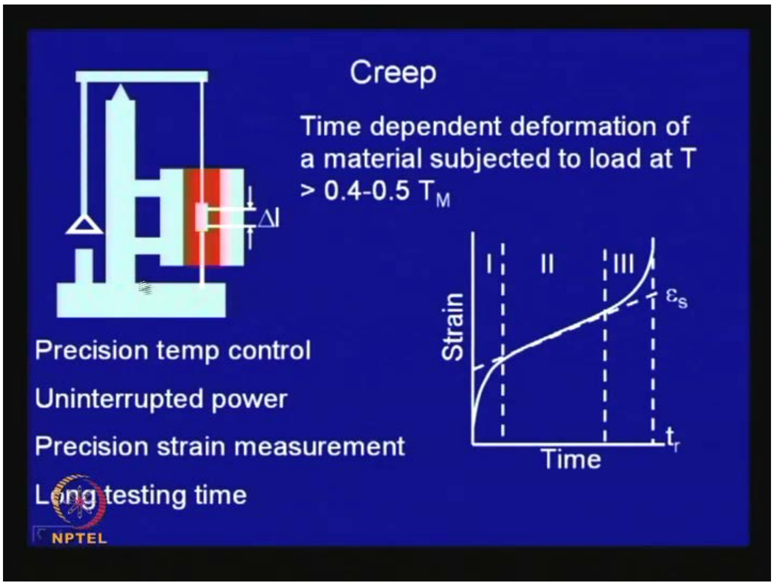

Now, let us look at creep property if a material strength is a function of temperature if a material is subjected to a load at a high temperature, even if the load is much lower than this yield load, it continues to deform. This load time dependent deformation is known as creep and usually this strain is measurable. If the temperature is around is greater than 0.4 to 0.5 of melting point of the metal, where this T M is the melting point in degree absolute and this is done by loading a sample intension. There is a lever kind of arrangement this is the sample you can fix some extension gage here and measure the change in length of the test piece and you can apply the load through the lever.

It meets a very precision temperature control, so this is the farness and if you measure the strain and plot this strain as a function of time you get a plot like this. There are three distinct stages, stage one, stage two, stage three. This is the stage, where strain rate goes on decreasing, then you have a region where strain rate is nearly constant and before failure taking place, there is a local deformation takes place and strain rate goes on increasing and leading to failure at this particular point. So, creep test can lost for a very long duration and it is an important property for any material which is use to be which is to be used at high temperature.

For example, any boiler components, super heated tubes or stream turbine blades, aero gas turbine blades. So where ever this material is subjected to high temperature it is important no creep properties but problem is to ensure life of a power plant you have to ensure that component last for several thousands of hours. So, may be 25 year also, to generate this kind of a property the test that you need to do are very long term test. So, you need a little sophisticated equipment with precision temperature control, uninterrupted power supply, precisions strain measurement system.

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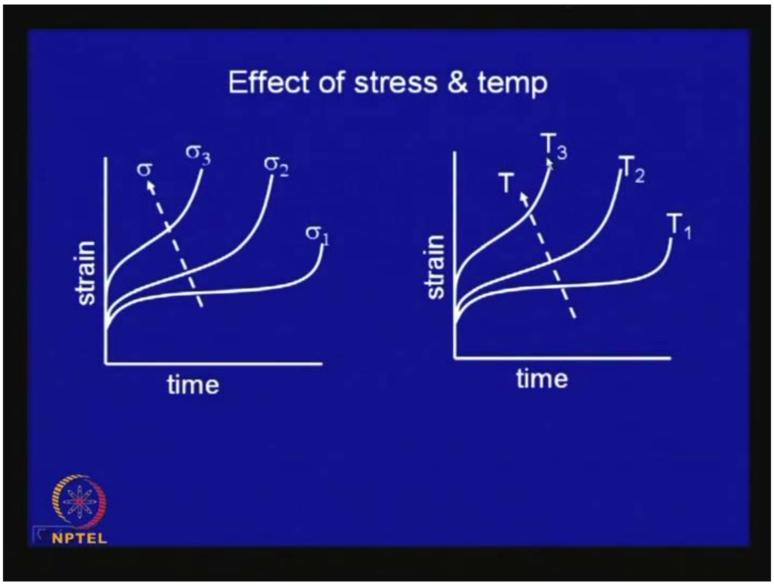

Typical nature of stress was strain verses time or quick plots are shown here. This shows the effect of stress. You increase the stress in stress it fails at a shorter time. This is the fracture time to fracture you increase the temperature then also with increase in temperature actual time goes down, so that means it is a strong function of stress and temperature.

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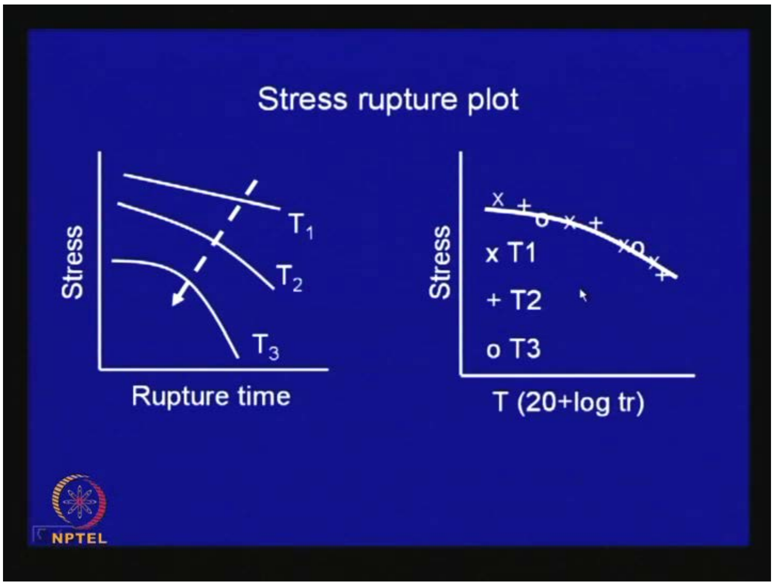

Since a monitoring strain over a very long period is often difficult. So for engineer so it is often good enough if we know the time to rupture and which is shown the time to rupture can be determined with a little less sophisticated equipment, you do not need to measure the strain and this rupture time also is a strong function of temperature and stress which is shown over here and it is quite easy to show that if you plot this against a combine time temperature parameter.

This type parameter is known as log similar parameter. You get a master rupture plot. This type of plot is very helpful because you do not want to do a very long term test. So, normally if a material is to be used let us say at 600 degree centigrade may be you will do a accelerated and 650 and then you find out time to rupture and from that using this can several master rupture plot. It is possible to estimate the lightly design life of the material.

With this we come to the end of this topic on experimental tools and techniques, and what we learn in this course is basically, the metallographic techniques, techniques to look at the micro structure, we looked at x ray diffraction technique to identify phases. We looked at mechanical properties, and also we looked at thermal analysis, which helps us to move the transformation temperatures in materials. And with these we finish this second chapter, and in the next class we look at evolution of structures in pure metals. Thank you.