Strength of Materials
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Lecture - 12

Hi, this is Dr. S. P. Harsha from mechanical and industrial engineering department, IIT Roorkee. I am going to deliver today lecture twelve of the topic of this strength of material, this course is developed under the national program on technological enhanced learning. I just want to refresh those things, that and they are in the previous lectures we have discussed, many, you know like things about the stress and strains. There many aspects together, that if you know like say uniaxial stresses are there and if you know like the parallel stresses are there, and then we termed as normal stress and normal strains, as well as you see, if, if any plane stress is there or plane strain is there, then we termed as the shear stress and shear strains.

And then, what exactly the relation is there in between those, the stress and strain, if there is a combined loading is there. That means, you see you know like if we have the normal, the forces as well as the shear forces are there, then what exactly the interaction is there in between these stress strain components.

This kind of, you know like interaction we discussed and also we analyzed using the two main methodologies. One is the analytical method you see through which we developed the relations based on the, using the trigonometrical relations like that. So, you know like we found that actually if we cut the plane, then at the inclined thing, then we we at we use the term as the oblique plane. So, you know like we found that what exactly the normal stress component is there at the oblique plane or what the shear stress component is there at the oblique plane.

And how we can correlate, you see, what the, you know like the influencing components are there to calculate the normal stress and normal strain, you see or the shear stress and shear strain at the oblique plane. So, that kind of relations, you know like we developed. And also we found that you see, wherever the stresses, this normal stress components are maximum, the shear stresses are 0. And we termed as the principle stresses for those, you know, like the stress components and also we found that actually wherever these principle stresses are occurring, those planes are nothing but the principle planes.

So, you know, like and then, so this kind of relations we developed using analytical solutions and the simultaneous part was there for graphical solution that was we termed as the Mohr's circle. And also, we found, that actually how we drawn, you know, how we can draw the Mohr's circle using what they are, you know, like the stress component is there and the normal stress component is there on the x axis and the shear stress component is there on the y axis. And then, you see, how we can find out the stress, you know, like and you know, others, other strain components if you know the center point, if you know the radius or if you know the abscissa and all that part, you see.

So, we, we developed both things and we found, that actually both solutions are, you know, like unique in their own features, like you see, if we have the absolute values, then we, we would like to go for the Mohr's circle kind of analysis, and if we have, you see, some sort of, you know, the point values are there and then, it is not easy to round up those values and it is not easy to measure the angle as well as the other stress component using the radius or the diameter or the angles part especially. So, then we would prefer to use the analytical solution because it will give you the exact part in terms of the digits also, two digit, three digit like that.

So, this kind of, you know, like the relations we set up in the previous lectures and then we found, that actually, though you see are the stresses, strains are there, we can find out the maximum stresses, maximum strains, you know, like at different points if you know the final output like that. But you see, it absolutely depends on what exactly the material is.

Then, you see, you know, like we found, that if there is elastic deformation or there is a plastic deformation, then what exactly the unique, you know, like the characteristics are coming from the material side. Then, you see, we defined, that actually what type of materials are there: perfectly elastic, perfectly inelastic material, elastic, perfectly elastic, you know, like it means perfectly rigid elastic part, you see. So, this kind of five types of material, which we discussed.

And we also drawn the stress versus strain curve, idealistic like that and we found, that you see, you know, what the proportional limit is there and what you see the non-linear relation is, relationship is there in between the stress and strains. So, and after that, you see, we found, that if we are dealing with, you know, like the elastic material in which the stress is proportional to strain, then there are certain parameters, which are readily available to calculate the other parameters, like you see, the Hooke's law is there in which if the stress is proportional to strain. Then, there is a Young's modulus of elasticity.

So, we, we can define this thing only within that elastic proportional and then you see, we, you know, like developed the generalized Hooke's law in which you see, there were six stress, stress components are there, three normal stress component, three shear stress components. And then, also we just tried to, you know, like correlate those part also, that if you see the uniformity is there, then how can, you know, like go for the other different, this other stress components to calculate.

And then, you see, you know, like after that all those things we found, that there are some of the important parameters, like the Young's modulus of elasticity, shear modulus of rigidity, bulk modulus of elasticity and the Poisson ratio. These are the key four elastic constants and we need to make the relationship in between those things, that if we know the two parameters, in the last lecture we just, you know, like discussed about, that if we know the two parameters, we can also find it out the two, other two parameters. Then, we found, that yeah, actually at, at different planes, which parameter is maximum at, at particular. If, if at all dealing with the different place, then which parameter is dominating.

So, this kind of, you know, like the relations, which, which we set up in the previous lectures.

So, in this lecture now we are going to deliver, we, we are going to, you know, like, discuss about the other key issues about those, you know, like the material properties. And if we see further, then we will find, that actually if we have, you know, like the brittle material, if we have the ductile material, like you see we discussed, that actually have a mild steel or a high carbon steel, high speed steel, then you see, how we can measure the elastic deformation region and the plastic deformation region, means how we can segregate those different components in a special single test. That kind of, you know, like analysis, which we are going to discuss in this lecture. And also, you see, we see, that actually, what exactly the microstructure of a material will give an impact on this kind of test. So, here it is.

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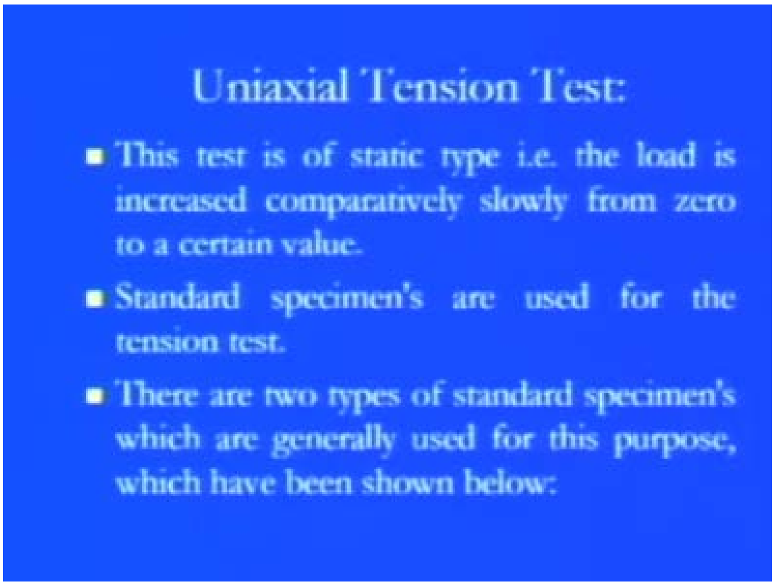

The first part is the uniaxial tensile test because you see, as we discussed, that actually the normal stress component is always along the axis. So, what we need to do always, if we are saying, that the tensile test is there or the compression test is there, it has to be uniaxial one.

So, you see, the first part as it is termed as the uniaxial tension test. In this, you see, what we need to do. It is of a static type because you see, at the two extreme corner or any bar, rectangular, circular or any kind of bar, at two extreme corner, you see, there are, you know, like the pulling forces are there towards the out, out, outward direction.

So, you see, when you are pulling always the kind of extension is there and we can measure the strains by using strain gauges, which we discussed, you see. And if you want to measure all three types of stresses, then the strain rosette was there and you see, there are two types of strain rosettes, which we discussed, rosette as 45 degree and the 60 degree and they will give the optimum value of normal stress as well as the shear stress component.

So, here it is, you see, you know, like this, this test is of the static type as we discussed, that is, the load is increasing this comparatively slowly from the 0 to a certain value. Because you see, we just want to see the clear picture about that what exactly is happening to the microstructure as well as the behavior of the material. Because as we are keep on increasing the load, that means, you see, we are increasing the load with the static nature, then we just want to see, that actually what kind of deformation is going on. And then, you see, you know like towards the x direction, what the, the extension is there towards the y direction or the z direction, what the contraction is there and how we can make the relationship in between those things, that, that kind of relation, you see, we want to set up.

For that, you see, it is essential to apply the static load, so that we can clearly, you know, like visualize the kind of behavior of the material. So, the standard specimen are used for the tensile test. You see, you, we need to make the, you know, like the specimen, a specimen so that actually in this uniaxial tensile test, which is to be, you know, like developed under the this, this tensile testing machine. So, in that, you see, we have to, you know, the standard, this specimen so that they can grip easily from the bottom as well as the top, so that when we are applying the load towards the outer outward direction, it can be easily applied.

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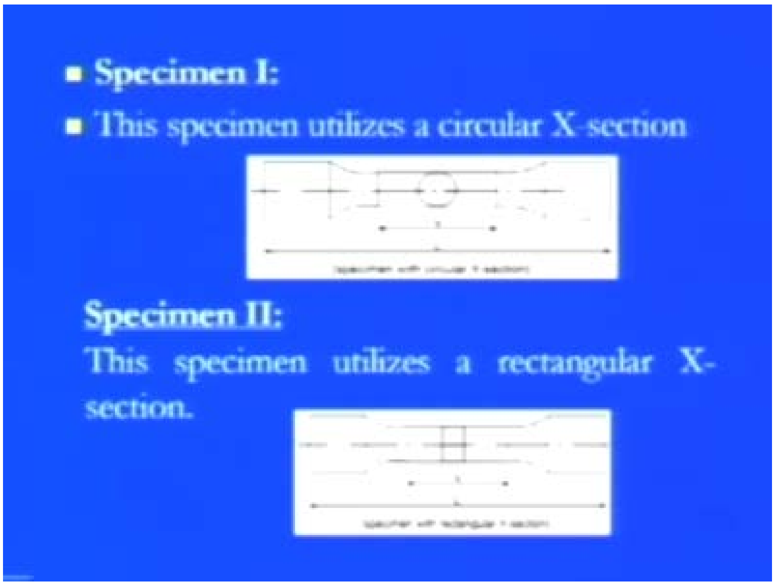

So, there are two types of standard specimens, which we can generally, you know, like using, which are generally, you know, like, used for this purpose, which have been, you know, like as one is, as I told you, that the, it has to be, you know, like the cross-section of circular. So, as this figure shows, that we have these two specimen, so this force. And you see, this outward direction and this, the right hand corner outward direction always given to grip the specimen, so that you see, because we have this kind of, you know, like the chucks are there. So, these chucks can easily grip these two extreme corner. So, we need to develop accordingly.

So, these two, you know, like the portion, which has to be gripped in this universal, this tension, tensile, this machine UTM and in that, you see, whenever we apply the load the load, will be applied exactly along this center line and that is why we are saying, that it is a uniaxial load. So, this uniaxial load will be applied through these things.

And whatever the cross-section will come, this is the circular one, so we have this one and you see, there are two lengths, which are showing, that this is the total length and this is the effective length, which we just, we are basically concerned about, ok. So, you see here, this is the main length, gauge length, because lg is there, the gauge length or we can say, this is the main, you know, like the effective, disturbed length, which you see, when you apply the load, that kind of distortion or the deformation will come effectively within this length. That is why we are saying, that this is the lg.

A second kind of specimen is the rectangular cross-section and then, you see, you can clearly visualize this thing, that if you cut that any portion, then you will find, that this rectangular part. And also, you see, it has the similar kind of structure as we have seen in the previous diagram, that there are two extreme ends are there, which, which are always given, just to, just for easy grip.

So, these, this kind of, you know, like the extreme corners are just available. And then, you see, this, the two extreme lengths are there. This is the total length of the specimen, this is the gauge length of the specimen or we can say, the effective area with distortion or the deformation will come under the application of any load. So, here you see, there are the two standard specimen. Always, you see, if you want to see any kind of elastic or this plastic behavior of any material, always we just try to put any, you know, like kind of, material into these two kinds of specimen and then we would like to put in the UTM machine.

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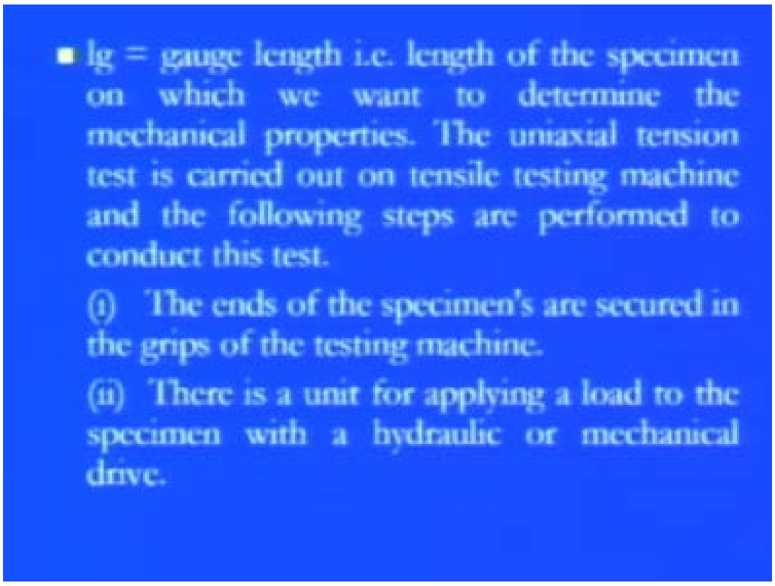

So, you see here, as I told you, that lg is nothing but the gauge length, that is, the length of the specimen on which we want to determine the mechanical property because you see, you know, like whenever we apply the load, always the kind of deformation will be there. So, we, we can say, that this is the effective length.

So, if you want to measure any kind of property, like you see, if you want to see the modulus of elasticity or if you want to see the shear modulus of elasticity or if you want to see even the Poisson ratio, that actually how the deformations are taking place towards the x and y direction, we can easily visualize if we know the gauge length of a specimen.

So, the uniaxial tension test is carried out on a tensile testing machine or generally termed as the universal tensile machine, UTM, and the following steps are performed to conduct this test. So, you see, there are some certain steps, which we need to follow just to conduct the experiment in a perfect way, otherwise you see, there are some impact loading is there. Other stresses components are also be, you know, like induced if the different kind of loadings are there. Then, we cannot say, that see, it is a uniaxial tensile test.

Then, you see, you know, like because if any kind of other part is there, then the stress concentration are also, you know, like be there, they, they can play an important role in that. Then, whatever the stress components, which we are, you know, like taking or whatever the strains are there, which we are measuring, that that will not be the perfect stress or strains accordingly. So, the, these steps are really important.

First of all, the ends of the specimen are secured in the grips of a tension machine. As I told you, there were two, you know, like the extreme corner grips were there and it has to be, go into the chuck of these two. One is the movable chuck in the UTM machine and one is the fixed chuck. So, as far as the fixed portion is concerned it has to be rigid on the UTM part.

UTM is nothing but the vertical machine and it has two main, you know, like movable jaws are there. One is the fixed jaw, which, which can also be movable, but generally we are keeping this jaw as a fixed one.

So, in that, you see, we are keeping one portion fixed and other portion will simply applying the load, so that the extension will be taking place in the specimen. So, first is, you see, you know, first step is we need to put the two extreme end into the proper grips, so that there is no clearance. There should not be any slip is there, otherwise whatever the readings will come, it will, it will be, it, it is having the truncation error in that.

Then, second step is, there is a unit for applying a load to the specimen within the hydraulic or the mechanical drive. So, you see, we have a load machine associated with a UTM through which we are applying the load.

So, load can be, since we just want to apply the load in a very static manner, so we have to be very careful, that whatever the load is going, it has to be go with the gradually increasing. It is not, that you see, sometimes you are giving 5, 5 ton and then, suddenly it is 10 ton or suddenly it is 15 ton.

Then, what will happen? You see, the jerks will come and other stress components will be induced or the material can also fail in during that part. So, that is why, you see, either we are using the hydraulic drive through which you see, you know, like we have a lube oil and there are due to the different, the pressure difference is there, the load is transferring to, towards the machine.

And then, you see, this, the pulling is there. So, this is through any oil hydraulic, you know, like the drives are there or we have a mechanical drive in which you see, you know, like what we are doing here. We know, that actually there is a time dependent load we are simply giving, like you see, right now whatever this CNC UTMs are coming, always we are applying this kind of loading in which you see, the time dependent loads are there and they are, you see, the load is keep on increasing as the time is increasing. So, you see, you know, like either we can use the hydraulic drive or we can use the mechanical drive to apply the static load on a specimen.

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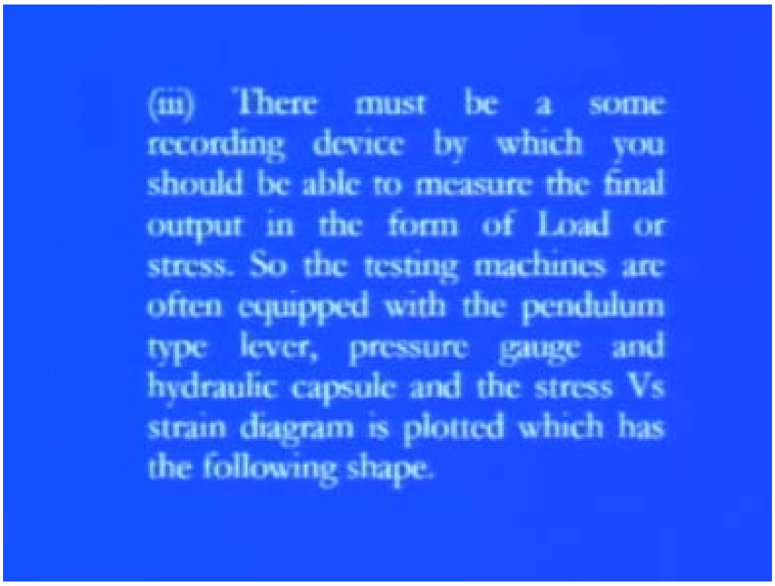

Then, you see, the third step, there must be some recording device by which you should be able to measure the final output of the in-form of the load or the stress because our ultimate aim is, that how much load is applying and up to. You see, let us say if we are applying up to 10 load or 20 load, whether it is showing the elastic limit or the plastic limit or the transient part is there in between the elastic and plastic limit.

So, all these, kind of, you know, the reasons, which we want to define within this, you know, like the, the stress-strain curve. So, for that we, we, must need a device with, through which we can measure either the load or the stress otherwise you see, generally it is giving the load because stresses cannot be directly measured. So, load will come and then we simply divide it by the effective area. It will give you the stress component, the normal stress component.

So, this testing machine are often equipped with the pendulum type lever. So, you see, as you keep on increasing, there is a balanced pendulum is there through which we can easily get, that how much load is applying and this is, you see, you know, like at the extreme end of this machine is there through which this, you know, like the dial will move as the pendulum will move. So, it will give you a clear indication that actually up what the load is not applying. And now as we are increasing the load it will simply, the dial will move accordingly.

So, first is this set, this pendulum type lever can be used or the pressure gauze because you see, we are applying the pressure through hydraulic one. So, we can use the pressure gauze through which we can say, that yeah, this is the pressure and you know, like this much stress is applying. Because you see, if you compare the pressure with the stress, then you will find, that you see, pressure, what is that pressure is also the force filled area. So, it has the unit of the Newton per meter square or Newton per millimeter square or the Pascal and similar kind of, you see, the stress is there. The stress is also the force filled area, force filled effective area I should say, and but there is a difference, we cannot put the analogy.

So, if we say, that the pressure is applying, it is due to the hydraulic pressure and we can put the analogy towards the stresses. But both are not the similar properties, both are different properties altogether. And then, you see, because the, why difference is there? Because pressure can be applied to a system and through which you see, the system is behaving differently.

But the stresses are always inducing in an object by the application of force and whenever the force application is there stresses are always, you know, like occurring within the object because of the internal intensity of the load. So, that is what we, you know, like though it is, if you, if you compare numerically, then you will find, that it is a force filled area altogether.

But the one force is the applied force, one force is coming due to the application force, that is, the internal, you know, reactive forces are there and the intensity of that internal reactive forces are the stresses. So, this is the basic difference between the pressure gauge the pressure as well as the stresses. And the third one is the hydraulic capsules are there and the stress versus strain diagram can be easily plotted with the following shape.

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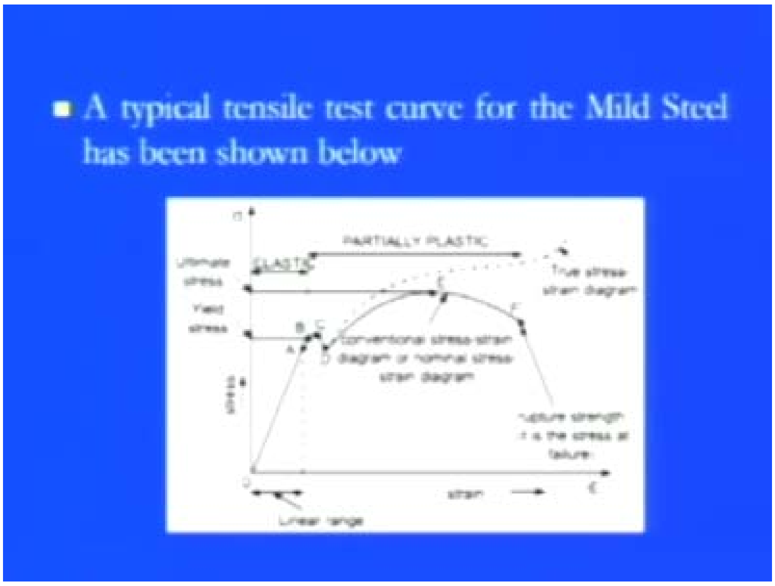

So, you see, now we have stresses, we have the strain, ok, on the both of the component and this is, you see, we discussed for the different kind of materials. So, if you are saying, that how under the tensile test if you are using a perfect ductile material, that is, the mild steel, so this is for the mild steel, we have the stress versus strain.

So, you see, on the x axis we have the strain component. Always remember that actually, always generally, if x and y we are talking like in the time responses, the time is on the x axis displacement or velocity or extrusion is there on the y component or generally, in the stress strain component. Always, whatever the controllable and the measurable quantity is there we just try to put the on the x axis, so that you see, if you want to go for only, you know, like if you want to measure the strain, we can only measure the strain, we cannot measure the stress.

So, you see, we just, we can easily visualize, that actually if you are going up to, let us say, 0.1 micrometer or 0.1, just up to the strain part, what is the stress level. So, it is pretty easier to control and measure the strain component rather than the stress. So, that is what you see, always it is preferable, that better to put the, you know, strain on the x axis and stress on the y axis.

So, you see, for mild steel component, now if you look at those things, as you apply the load, the stresses are starting to form and the strain means the deformation is also start going on. So, as we start this thing you can easily see, that now there is a straight line is coming right from 0 and as we keep on increasing the load, the stress, you know, like increasing. So, the stress, you know, like the stress will, here on the x axis it is just increasing and the strain will increasing on the y axis and up to O to A. So, you see, up to, if you go up to point A we will get the straight line.

If you see the straight line equation, we have y equals to mx plus c or we can say, y equals to mx; m is nothing but the slope of the equation. If I am saying, that it is exactly, you see, this kind of nature that means, we have the 45, means m is equals to 1 or we can say, theta is 45. So, we have a well straight line.

Here this is the straight line and the straight line shows, that that linear relationship between the stress and strain. That means, we can say it, that the stress, this stress is, this stress is proportional to strain or I should say, you see, the sigma is proportional to this epsilon. The Hooke’s law is very much valid for this point and we can define all those points, like the Young’s modulus of elasticity, shear modulus of elasticity, bulk modulus of elasticity and the Poisson ratio for this well-defined region because here, the elastic region is there because, and generalized Hooke’s law is valid for this kind of thing.

And then you see, if we move further, then you will find, that there is some sort of, you see, you know, like the non-linearity is starting. It is an onset of, we can say, the nonlinearity is there, that it is going. But again, you see, up to, if you move up to B point, which is nothing but you see, you know, like the yield stress is there or we can say the yield point.

Yield point is nothing but the point where you know, like the yielding starts, that means, up to this point if you release the load, means you see, you know, like if you just remove the load, body comes to its original shape without any permanent set of deformation. So, what will happen? You see, you know, like up to this point, up to yield point we can say, B point, we can even defined all those elastic region constant, elastic constant, which we defined in the previous lecture up to that.

So, now you see, we have the two main proportional part, I should say. One is the proportional limit, we can say, and second is the yield limit under which we can apply, you know, or we can say, under which the stress is proportional to strain. The linear relationship is there and the elastic properties of any material can be well-defined. So, you see, here this elastic region, that we can clearly see here, this is the elastic region, ok, within that.

So, whatever the, you know, like the things will come, the properties or any kind of thing we can easily, you know, like put, like the E mu G or whatever like that under this region and that is why, you see, we are clearly written, that this is the linear range. Hooke’s law is perfectly valid, all those components are perfectly applicable.

Then, you see, again, after that if we apply the load again, there is a kind of clear, the nonlinear relation is there. Nonlinear relation means, the stress is not proportionally, you know, like vary with the strain. Here, you see, you know, like the kind of distortion is there, the curved part has starting and this is showing the maximum, you know, like under the elastic region the maximum stress, which is known as the upper ((Refer Time: 17:23)) limit and it, it is always coming.

You see, that if you apply the load, you see, it is increasing and up to a certain limit the stresses will increase, but it is just you see, you know, like the strains are, due to the microstructure the strains are just, you see, trying to balance that. Because as we move, you know, like as we, as we keep on increasing the load, the microstructure of or we can say, whatever the elements are there, there are three types of, we see, we can say the microstructures are there, the BCC, FCC and HPS, you might have discussed in, you know, material science. So, whatever the structures are there within this mild steel component, it is disturbed as you apply the load. So, it will, you see, if you go beyond the elastic region, then all these microstructures are disturbed perfectly because there is now a permanent set of deformation starts here.

So, what will happen? Once we, you know, keep on increasing in this region, this plastic region, then you see, they are just trying to set up their own structure and due to that we, you know, like this region, which is a very small region, you see.

This C to D, in this region conceptually we are saying, that the stresses are reducing though you see we are keep on increasing the load, but stresses are reducing due to the set up, internal set up of the microstructure of the object. But strains are there, that means, you see, here C to D we have a decrease in the stress, but there is a strain is there. That means, the permanent set, you see, that means the, whatever the depressions are coming, they are well set within the structure. They are increasing, but the stresses are reducing.

So, C to D is nothing but it is a small, we can say, the segment is there, which is coming due to the internal set up of the microstructure when we are starting or we can say, when it is the onset of a nonlinear region or we can say, the plastic region.

Then, you see, again if we keep on increasing the load, then you see, the nonlinear, then you can easily see, that this is the nonlinear relation is there between the stress and the strain component and it is going, going, going up to the point E. Point E is nothing but, you see, you know, like as we have noted here, it is the ultimate tensile strength because if you just go, you know, like and trust to on y axis because the stress is on y axis, that you will find, that this is nothing but the ultimate stress. Or we can say, that whatever the, the strength is coming from, you see, the internal strength is coming from the material.

This material is, because we are applying the tensile part, so it is known as the ultimate tensile strength of a material. But it, it is always defined and this is, we can say, the maximum strength, which can a material provide against any application of load towards the tensile. So, you see, here this is the maximum, you know, like if you see here, this is the maximum stress, which we can get through any material before fracture.

So, you see, as again if we keep on increasing, then again, you see, there is a nonlinear relations are starting. This is because it is, you see, the nonlinear part is there, so the curve curved part is coming, coming and then, up to, if you go up to a certain level, then the rupture is coming, that means, the failure is there.

So, this is the, whatever the stress component is coming here, because as if you go up to a, you know, up to ultimate tensile strength, then the material, you see, this, because this ultimate tensile strength will give you the maximum, you know, strength from a material. Then, whatever the layers of a materials are there or whatever the structures are there within the material, then they are starting loosing the, whatever the cohesion is there in between that.

So, when you see this, they are, you know, like detaching from each other. So, they are showing the less stresses because then, they are showing the less resistance against the application of load or we can say, see it is going, going to, you know, decrease, keep on as we keep on increasing the load and the same time you see, it is the deformation is going on rapidly.

So, we have, you see, the deformation means, the strain is there. Strain is nothing but the change of length divided by length. So, the deformation is keep on increasing, but there is a slight decrease in the internal resistance of a load. So, that is what we can say, that the stresses will reduce right from E to F as we move on from ultimate tensile strength to the, to the, this rupture strength, but always it gives you, you see, a kind of deformation. And then, you see, you know, like because the area reduction is increasing, increasing and at a certain point it will detach and it will fail.

So, whatever the rupture, you know, like the point will come, this will show the rupture strength or we can say, the fracture strength. And we can get, you see, a kind of, two different kind of, you know, like this parts of the specimen where a specified shape is there within those things. And generally, we termed as, it is a cup and cone because the material, when they are detaching to each other, you see, they will simply at one point, you see, they are showing the cone kind of, that you see, because these, these you know, like the structure of a material, which, which tries to you know, like release their microstructure. And you see, the other part was the cone, so this was the cone, you see, you know, like under which whatever the components of the materials are there, they are detaching.

So, if the mild steel or any ductile material is failed or we can say, the rupture, you see, at point F always we are getting the cup and cone structure, which we are also discussing later on. But right now it is sufficient to tell, that it is, you know, like cup and cone structure will come because of, it is very good, whatever you see, the mild, mild steel or high speed steel or the ductile material is very good in the tensile strain. So, they will detach in a specified shape while you see, any other material is there, they will not give you any specified shape as ductile materials or this mild steels are given.

So, you see here, this again, if you go focus on this particular figure, then we find, that this is the elastic region, this is the plastic region in which the nonlinear relationship is there in between the stress and strain. This is, you see, you know, like the linear relation is there, so we can apply all those Hooke’s law, generalized Hooke’s law, all those Young’s modulus, shear modulus, bulk modulus, Poisson ratio and the stress and strain. You see, all those kind of relations, which we defined in the previous lecture, they will only define within this elastic region. This plastic region is somewhat different in which the permanent set of deformation is there starting and ending up to the fracture. So, this is one.

And then, you see, we have one dotted line, which will give you a ((Refer Time: 27:29)), that means, you see, you know, like as we keep on increasing, truly the component will exhibit, you know, like more and more the nonlinearity. Because you see, when, when the permanent set of deformation is there, this as we apply, keep on, you see, you know, like increasing the stress. It will go towards this direction, but the microstructures are, you know, like they are releasing their energy in such a perfect way, that actually the, whatever the detachments are coming, as I told you, you see, starting right from the tensile strength.

So, you see, whatever the tensile material is there, they cannot give more than the ultimate tensile strength, any kind of strength, you see, or we can say the restraints, they cannot go beyond, you know, like up to point E as far as the strength is concerned. So, this is the realistic figure, which we are getting in any of the tensile testing machine and this is the true, you know, like we can say, the idealistic part should be like, that that it should go in this way and it should give you see more and more stresses as we apply the load and the stresses.

So, this is, we can say, the perfect stress strain diagram for, you know, like the mild steel in which we can clearly, if you see, if you visualize this figure, then you will find, that there is a very, you know, like all those, the elastic and plastic regions are well established, clearly visible, all those points, right from O to A proportional limit, A to B or O to B the elastic limit. B is a low yield point, C is an upper yield point, that you see now onset of the plastic region, then C to D is a very small region and it is coming very rapidly because of the internal set up of the microstructure. D to E always we can get because of the, E is the ultimate tensile strength and it will give you the maximum strength in the nonlinear relationship and E to F is the rupture part or we can say, the failure region is there at the F.

So, all these, you know, like the points are well established and you see, that is what if you apply the static loading, these points can be easily pointed out on any of the graph. And that is why, you see, you know, like if you any, if you apply any kind of impact loading or any kind of other jerks or any kind of, you know, like the shearing part, then these kind of points, which is not easily visualized or whatever the internal microstructures are being disturbed, we cannot say, that these points can be easily located on a, on to that, that, that particular or we can measurable that part.

So, that is what always, these are the, whatever the stress, which we discussed in the previous part it has to be followed carefully to get this kind of information, which is very fruitful to analyze any kind of this tensile testing.

So, you see here, you know, like in the previous figure, which is very important and which is, we can say, the base figure of a strength of material because if you want to understand any strength of material concept, then stress-strain diagram is a must. And that is what you see, right from previous level lectures, you see, we discussed about the stresses, strains and all those things.

And if you want to compute for the stress and strain combinedly, because always whenever we apply the load, the stresses and strains are coming combinedly and if you want to set the relationship in between that, then always, you see, you know, like this diagram is the basic diagram for strength of material. If you understand easily this diagram, you can solve many of the internal issues of this particular subject.

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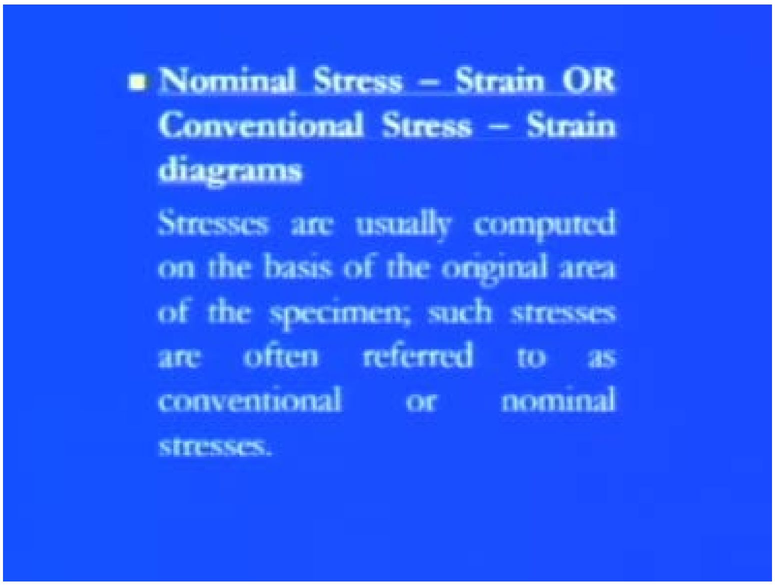

Now, come to the normal, this nominal stress or strain or we can say, the conventional stress-strain diagram. So, we have seen in the previous figure, that actually in a single, this uniaxial testing is a tensile part actually. We have all those regions, the elastic and the plastic regions, in this, you see, there are different five points, say from O to A, A to B, B to C, C to D and D to E and then, you see, you know like up to the fracture part, F part.

So, you see, this stress, which is coming, you see, this is known as the normal, nominal stress and the strain, which is coming on the x axis, that is, the nominal strain. Or we can say the conventional, we, which we are calculating, the stress per divided by area, the force divided by area or the change of length divided by the original length, that conventional stress strain, you see, the part.

So, whatever we are showing in the previous figure, the conventional stress strain diagram, we can again generally utilize those things. You see, you will find, that the firm line was there for the conventional one and one dotted line was there in the previous figure that was the shear stress. So, we just want to define those particular two different types of stresses, first is the nominal stress and strain, which was showing in the previous diagram by the firm line. So, the stresses are usually computed on the basis of the original area of the specimen.

So, you see, you know, like we, we, you know, that now whatever the, this rectangular part or the circular part is there, what we are doing here, we know the magnitude of the applied force, whatever you see, as I told you, 5 ton, 10 ton, 15 ton, like that. And we know, because of the specimen, you see, prior to put this particular spacemen into the machine what we are doing here? We simply measure the, if it a circular bar, then the diameter of that or if we have the rectangular bar, then whatever the, you know, like the sides are there of those things.

So, from that now what we can get? We can get the original area of that specimen. So, stresses are usually computed on that basis particular, that what original area of the specimen is there and such stresses are often referred to as conventional or the nominal stresses, which we are generally using, that you see the sigma or you see, for the normal stress component irrespective of the, this, this, this tensile stress or the compressive stress or shear stresses are there. So, these stresses are known as the nominal stresses. But there are, you see, you know, like the shear stresses and the shear strains are there and what these are like.

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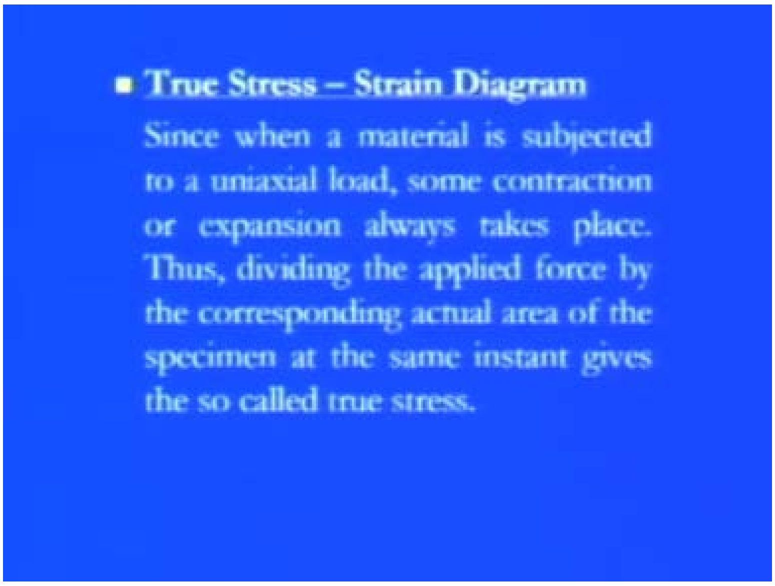

Since when a material is subjected to a uniaxial loading because you are applying the load, some, you know, like the contraction and the expansions, expansions, are always taking place in, in, during that you know, like the applying load. Because you see, if you apply the tensile testing, then the expansion is starting from in towards the x direction and contraction is there towards the other perpendicular directions. Or if you are applying the compressive load, then you see, you know, like the compression is there towards the x direction, but the, there is slightly, you know, like the increase is there irrespective of width or breadth or whatever like that.

So, meaning is, that in a realistic way some sort of distortion is there in any of the axis. So, thus dividing by this, you know, like the dividing, this applied force by any corresponding actual area, whatever the actual area is there, because the area is now, with the time the area is now changing.

So, what in the nominal stresses, what we are doing here before, you know, starting the application of load? We measure the diameter or any parts of this bodies and calculate the area. So, that is not the true area, but whenever the, under the application of any load the area is changing, so whatever the actual area is there, if you divide this, you know, like the force divided by this actual area, this, this what are the stresses are coming.

These stresses are always called the true stresses and these stresses are always instant stresses. Because as you keep on increasing the load, whatever the area concerned will changing, keep on changing. So, we cannot say, that the stresses at certain point is shear stress and beyond that it is applicable. No, we need to make, you know, like and that is what generally, what we are doing here. We are simply taking the steps, you know, like for small, small element, the true stress and then combine those things. So, this is the true stress.

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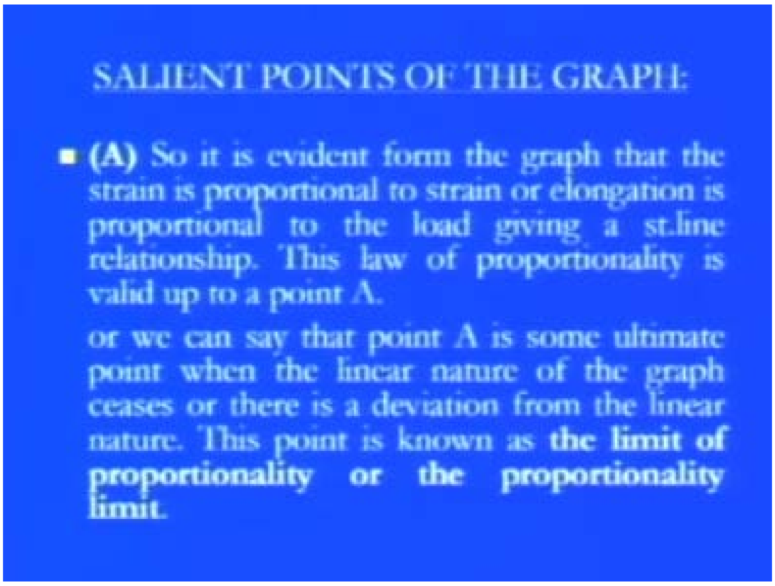

So, whatever this graph, which has come in the stress strain diagram, there are some salient points in those things, like you see, first of all the first point. It is evident from the graph, that the strain is proportional to the strain or the elongation is proportional to the load giving a, you know, like whatever the load applying is there a straight line. You know, like relationship is there and that is what we are generally saying, that the proportional limit is always gives you a linear relationship between the stress and strain and Hooke’s law is valid within this. And this, the law of proportionality is valid up to point A. So, there is a linear perfect relationship and sigma is proportional to epsilon, sigma equals to a modulus of elasticity to epsilon and is varied within this region.

Or we can say, that the point, a point A is, you know, like some ultimate point, whatever you can say. When a linear region of the graph, you know, like ceases or we can say, there is a deviation from a linear nature and the point is known as the limit of proportionality or the proportionality limit and that is what you see. Everyone talk about the proportional limit between the stress and strain, only we can apply the load, right from 0 to A point. And that is what you see, this Hooke’s law, which is a well-known law. Generalized Hooke’s law is valid within the limit of proportionality or we can say, the proportional of limit.

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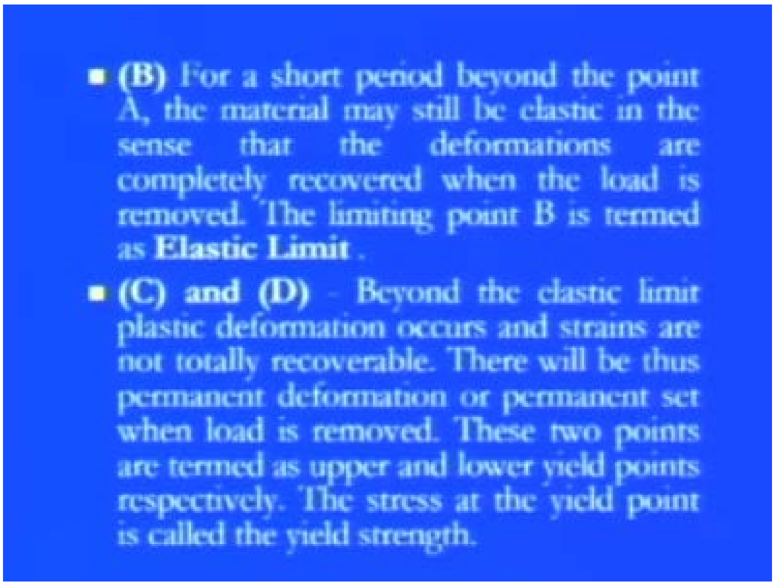

Then, you see, if you go, move up to certain limit, as I discussed, for a short period of beyond point A, the material may, you see, still be elastic in the, in the sense because you see, up to, if you go up to point B and release the load, as I told you, the body comes to its original shape without any permanent set of deformation with the body, that means, it is the elastic deformation in that. And we can say, that the deformation are completely recovered when the load is removed, so that the limit point B is termed as the elastic limit, ok.

So, again you see up to that point, as I told you, that it is pretty easy to define all those components and the Hooke's law within this O to B elastic region and that is what you see, we are simply on top of that. In the figure we have shown, that actually this is the elastic region for a material.

And then, you see, there were two points, one is on the top of that, that is, the C point and the below is the D point and I termed as it is upper lower, upper limit and D is the lower yield, this lower yield limit. So, the lower and the upper yield limit are, can, can be easily detected from the point C and D. So, beyond the elastic region the plastic deformation occurs and the strains are not totally recoverable. That is what you see, you know, like some sort of the cracks, spares or anything, you see, start a formation. So, we can say, this is the onset of the plastic region and there will be thus permanent deformation or permanent set of the, you know, like this kind of cracks are starting when the load is removed.

And these two points are termed as the upper and the lower yield limit respectively. The C is the upper limit and D is the lower limit, as I discussed. And the stress at yield point is called the yield strength and always, you see, the yield strength will give you a perfect reason, that okay, if you apply below this region, then the, whatever you see, this deformation is there, that is the elastic deformation within this. So, this is, you see, the one strength, which gives you the elastic, you know, like region strength and you see, we can well define those points easily.

So, a steady, you know, like up to this point, stress-strain diagram shows, that the yield point is so near the proportional limit or we can say the elastic limit, for most of the purpose the two may be taken as one. So, generally, as I told you see, the yield strength is always defined the maximum strength in the elastic, this elastic deformation. So, generally, we are preferring, that actually the yield point and this, this last elastic point, this point B and C are so close.

So, we can take, you know, like we can coincide those things for, you know, like some purpose or the layers are not exactly. So, the layers of a material, they are not so transferring, so that we can easily taken as the coinciding part of the proportional limit as well as this yield limit particular.

So, however, in much, you know, like is much easier to locate the former one because it is pretty, it is easily coming in the particular point and for, you know, the material, which do not pauses a well-defined yield point. Then, in order to find the yield point or yield strength an offset method is always applied because you see, sometimes you see the material is, whatever the internal characteristic of material or internal microstructure of the material, which cannot allow you to, you know, like easily ((Refer Time: 38:46)) about those points. So, it can easily visualize those points.

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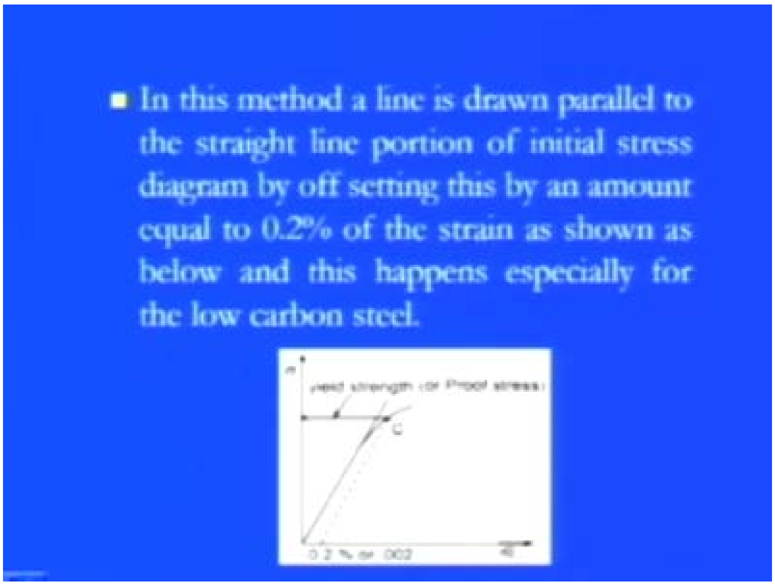

Then, you see, what we are doing here, there is the another method called the offset method. Just look at the yield point or the yield strength in the material and here, you see, this is the figure, you see, you know, like as you keep on apply, this is the strength strain. And as you apply the load, you see, this is a kind of straight line is coming and then, later on, you see, as the curve part is starting and up to that point we can say, this is onset of the nonlinear relationship or we can say, this is the onset of the plastic region.

And that particular point, at this particular point we can say, that the yield point is occurring and if you just, because this point is the starting of yield, yield point or the yield strength, I should say. So, if I just make an offset to the bottom part, which is nothing but the 0.2 percent of 0.002 of this strain will always gives you the yield strength or we can say, the approved stress or the yield particular point at the, for a particular specific material. So, these are only applicable for those material, which cannot exhibit clearly the, this proportional limit, elastic limit and the yield limit in different manner.

In this method, you see, if I told you a line is drawn parallel to the straight line portion of initial strain diagram by offsetting, you know, like this thing. You see, as I told you, this is just offsetting of these things in this diagram equal to 0.2 percent of the strain, as you see in the, in the diagram, it has clearly mentioned about that, ok. And happens, especially for low carbon steel because for high speed steel, high carbon steel, mild steel.

We can, as, as we have seen in the previous diagram also, for mild steel it is pretty easy to identify the reasons of A point, B point, C point, D point, E point and F point, even up to that.

But for low carbon steel in which, you see, showing, you know, like less percentage of carbon and showing more hardness towards that, so they are not perfect we can say, perfect, so called the ductile material. And this kind of always properties are coming and for that, you see, this offset method is well applicable to locate the yield strength or the elastic region in that.

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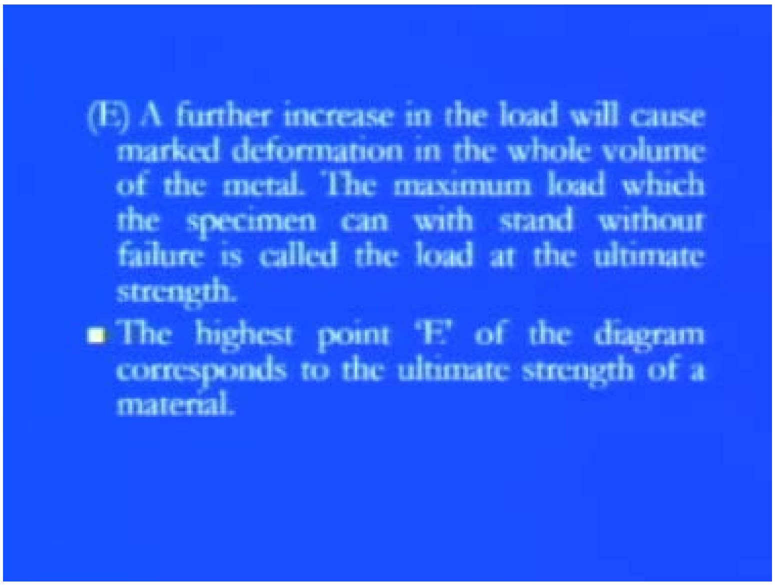

And then, you see, if you move further to point E, right from D to E, as I told you, a further increase in the load will cause, you know, like the marked deformation, the permanence of deformation. The whole volume of material and the maximum load at which the, in the specimen can be withstand, you know, like without failure is called the load at ultimate strength or this is the ultimate tensile strength, as I told you.

The highest point E of the diagram corresponding to the ultimate strength of a material is a maximum strength, which a material can provide against the load application and we can say, that yeah, this is the maximum strength before failure the material can provide you.

So, if you want to apply this material under the application of this kind of load, you can apply the load up to this thing and this will give you, you know, like even it is a permanent sort of deformation is there, but it is exhibiting the maximum strength of a material.

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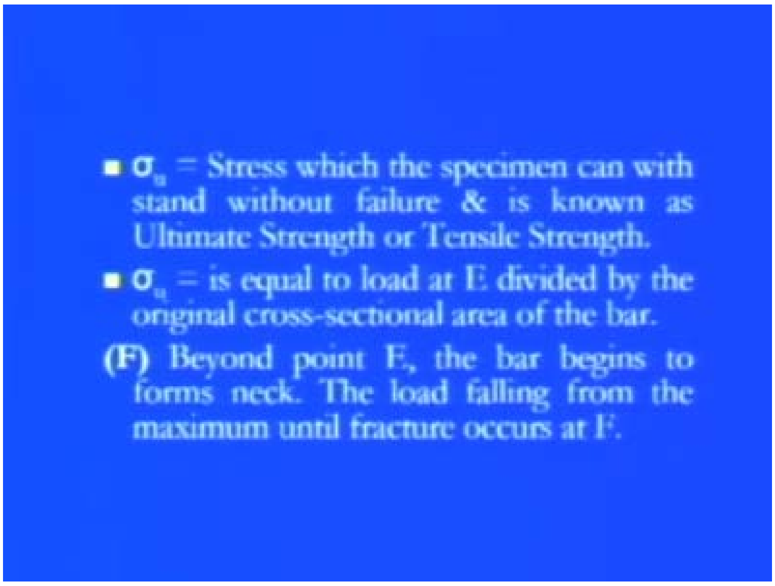

And then, you see, you know, like this sigma U, which is generally we are, you know, like this ((00:41:47 min)) because it is ultimate tensile strength. So, sigma U is the stress, which you know, like at, at, which the specimen can withstand without failure, you know, like and it is known as the ultimate tensile strength or ultimate strength or tensile strength, whatever you can say, and it is equal to the load at point E divided by the original cross section area of a bar.

So, once we know, that you see, we are applying the load up to the point E, so this is the maximum load, we can say, before the failure. And whatever the original area is there, the cross sectional area, as we are measuring, like you see, so this will give you the nominal ultimate tensile strength is there. And as I told you, there is a difference between the nominal strength and the ((Refer Time: 42:30)) stress is there.

And then, you see, beyond, if we go beyond point, as I discussed, you know, like beyond, beyond point E there is F and bar begins to form, you know, necking. So, necking starting at the point E, you know, like E and then load falling from which it gives you a fracture at point A. And as I told, you see, always whenever we have this kind of material, the perfect ductile material, a specified shape is coming as a cup and cone.

So, now you see, this diagram, which is as I told you, the basic diagram for a whole subject strength of material and if we can understand those things easily, probably it is pretty easy for us to understand the stress and strain component for any specific kind of material.

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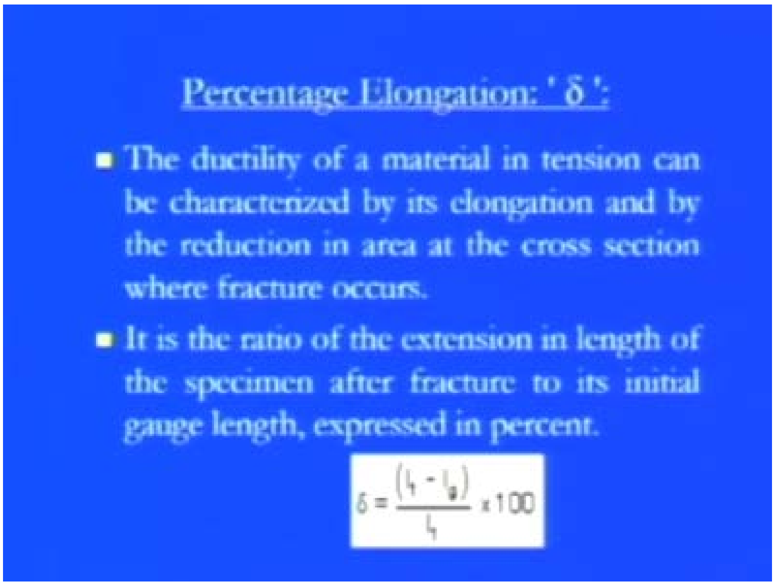

So, next is the percentage elongation is the delta. The ductility of a material, in tension particular, because if a material is ductile, then particular it is good in the tensile part, can be characterized by this elongation, that how much, you see, you know, like when you apply the load, how easily it is elongate towards x direction, ok.

Because it is, the uniaxial loading is there and by the reduction of, reduction in the area in the cross sectional part, particular where the fracture occurs, so how much reduction of the area is there up to the fracture and how we can, you know, like characterize these things by its elongation. This is always defined by how much ductility is there in this material or if you go into the other, further, you know, inside that, then how much percentage of carbon is there and how it is supporting towards the elongation, that whether it is towards going to the harder or softer part towards the, you know, like the axial loading is there.

So, what it is the ratio of the extension in the length of the specimen after fracture to its initial gauge length? So, whatever you see, you know, like that, ok, up to fracture, now this much total extension is there and before that this was the effective gauge length was there. So, whatever the difference will come, because you see, as we are keep on increasing there, it is, clearly the extension is there in, you know, up to the fracture in the specimen.

And then, previously we have discussed, that actually there are two, you know, rigid bars are there, but there is a gauge length. So, this, if you measure the gauge length and after that if you measure the, up to the gauge length, up to the fracture, so what is the difference is there in between that?

So, l 1 minus l gauge and if you divide by that, the total extension, this will give you that percentage elongation and percentage elongation will give you that kind of ductility that how much ductility is there in the material particular. So, it is the ratio of the extension, the difference is there in the length of a specimen after fracture towards initial gauge length is there expressed in this particular percentage. So, it is always coming in terms of percentage.

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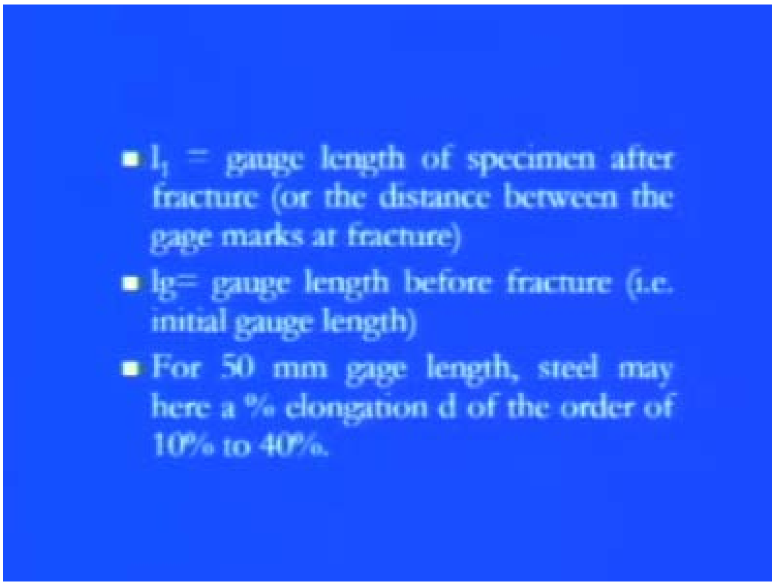

So, l 1 is nothing but you see, the gauge length, only particular gauge length, the effective length of specimen after fracture or distance between the gauge marks, whatever the gauge marks are there, prior to that if you go up to a fracture point because always it is more than the previous gauge length because of the extension part.

And the lg is nothing but, as we have defined already, the gauge length before fracture, that is, whatever the initial, you know, like the gauge lengths are there. So, you need to mark those things before fracture and after fracture and you need to measure both the extreme points within this structure only.

So, for a 50 millimeter gauge length steel, whatever the mild steel, which we have discussed in the previous figure may, you see here, you know, like show the percent elongation up to the point E of either 10 percent to 40 percent depends on how much percentage of the carbon is.

So, if we are talking about mild steel or if we are talking about high speed steel or if we are talking about high carbon steel, then you see, the percentage is vary, but it is always more than 10 percent and less than 40 percent because if you go for more than 40 percent, then this material is perfectly, you know, like the elastic and rubber kind of thing is there, which is not, you see, you know, like this this carbon or whatever the other materials are there within those microstructure. They will not allow you to go beyond this thing because of the hardness and all like that.

So, this was, you see, you know, like the proportional limit was there and we can simply, you know, like put the elongation. Also, within that elongation what are the percentage elongation is there, this will give you a clear idea about the ductility of a material.

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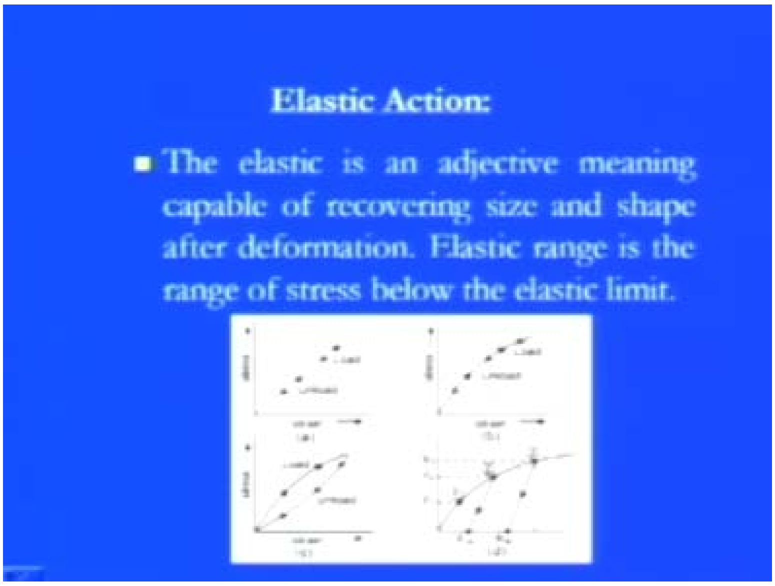

Then, we have one more thing, that is, elastic action. We are talking about all the elastic deformation, plastic deformation and we are saying, that within the elastic region the stress is proportional to strain. The proportional limit is there, the elastic limit there is there and the yield limit is there. So, all those kind of, you know, these points are well applicable if we can see clearly, that what exactly the elastic actions are happening if we apply the load on a material.

So, the elastic is, then you know, like adjective meaning, I should say, basically the elastic plastic, you see, it is due to a clear idea about the things what exactly going on with the microstructure as well as the material. So, it is the adjective meaning, capable of recovering size and the shape after deformation.

If you are saying, that more elastic like rubber, whatever the load you apply, you see, you know, this will show you under the load application, the distortion and of any nature, but once you release the load, it comes to its original shape. You see, that means, nothing has happened after the application of load. So, if I am saying, that more elastic, more you see chances of recovering of whatever the distortion or the deviation is there.

If you see, if you apply and suddenly you see, as we have seen, you know, like this if you take the small pin, if you apply those things, you see, straightway it will deform. That means, it has a less elastic properties in that. It is always, you can say, the inherent property of a material itself. So, elastic range is the range of the stress below the elastic region where we apply the load, the deformation is there, release the load, body is in original shape.

So, you see, here there are four different kind of, you know, like the graphs, which is showing here. First is a perfect thing, that you see the stress and strain, as we discussed in the previous part, apply the load, the linear relationship is there, you know, like as you keep on increasing the load showing exactly, you know, like the straight line, y equals to x we can say or m is 45, whatever the things are there. And then, second figure, which is showing some sort of the nonlinearity.

But again, you see, you know, like a kind of rubber, which we are saying, that this is perfectly, this is perfectly for a mild steel. But if I am taking a rubber or that kind of, you know, like sort of this, not exactly the ductile, this, this kind of the, the, this iron component. But if the nonferrous components are there and you see, here also they can exhibit the elastic region though it has some sort of the nonlinearity is there. But as you keep on increasing the load, you see, even the sort of, you know, the nonlinearity is coming. But if you release the load, body comes to its original shape without any sort of permanent deformation.

And then, you can also define by this one, you see, the cycle, as we have discussed in the any, lots of the thermodynamic processes are there, that if you, if you go to any reversible path, you see, starting from that a cycle is there, go to this. So, this is, you see, one when you see, you, you apply the load, a kind of deformation is there.

Then, it is not necessary, that actually either in the previous two diagram, that it has to follow the same path at is it is being, you know, like going through in the forward motion while in reversible motion or we can say while recovering the part it may come by this path or it may come by this path or it may, you know, like form a cycle, that closed loop or we can say the limit cycle in that. So, even in the limit cycle, as we are in the dynamic part we are saying, that actually it is a perfect, you see, you know, like the stable miniature is there or we can say, it is a perfectly elastic action is there.

Or if you go to the fourth part also, you, you can see that, you see, we have this kind of the deformation is there or even if we go up to this region, this is the elastic region for 1 or 2 or 3 is there or we can simply, taking those things by offsetting part. So, these four kind of actions can be happened under the elastic action.

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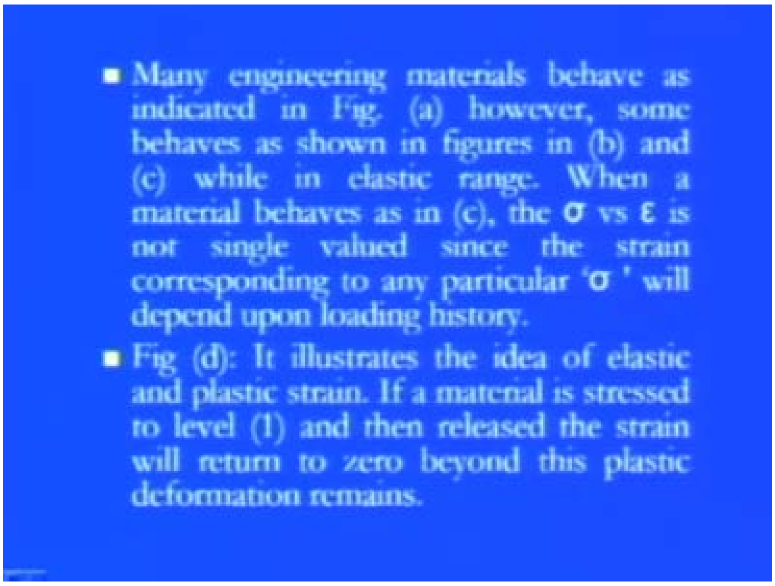

So, many of the engineering materials behave as these things as we discussed. However, the same behavior can be shown in the figure B also while the straight or the, this nonlinear part is there while within the elastic region and the material behaves in the, see, as you see the cycle form cannot be, you know, single valued. It is just a limit cycle is there, so it can be shown, you know, like the two different stresses at two different points with the strain part. A figure d, which we have shown, there are many of, you know, like the points are there, can be illustrated the idea of the elastic and the plastic strains within those things. If a material is stressed up to a level 1 or level 2 or level 3 because if you, you know, like release the load, it cannot come exactly on the same point as we discussed in the previous part.

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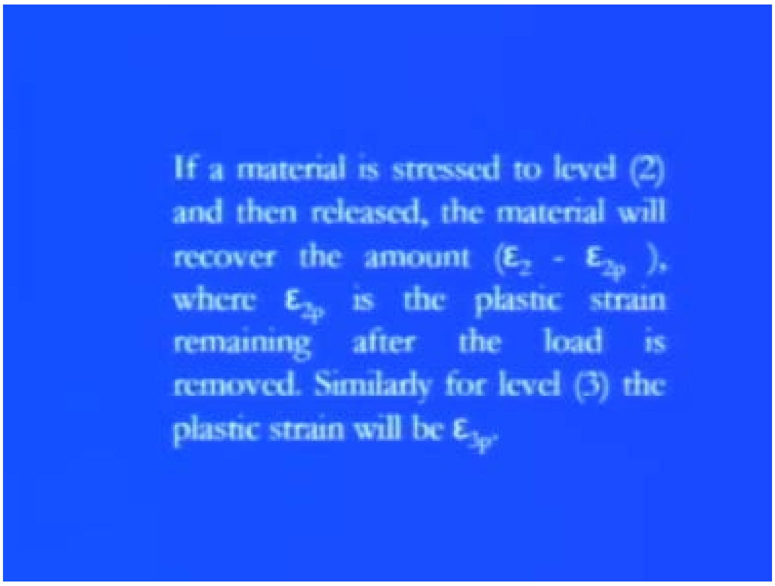

So, if a material is stressed to a level 1 or 2 and if, then released, then material will recover some portion. And the amount is, you know, epsilon 2 as we have shown in the fourth part of this figure, epsilon 2 minus epsilon 2p, which is, you see, you know, like remaining after the load is remaining.

So, it is removing some sort of the deformation, but not exactly, and we can also compute, that how much it can recover by simply offset method, as we discussed in those things. So, this is there, you see, in which this, e the epsilon 2 minus epsilon 2p was there in the second case, ok. And then, epsilon 2p is nothing but the plastic strain, you know, like which can be, you know, regaining after the releasing of load. And if we are talking about point 3 part, then also you see, this is the plastic region, the plastic strain is there of the third part and we can say, it can be also regained by epsilon 2p minus epsilon 3p, that how much it can be regained by that.

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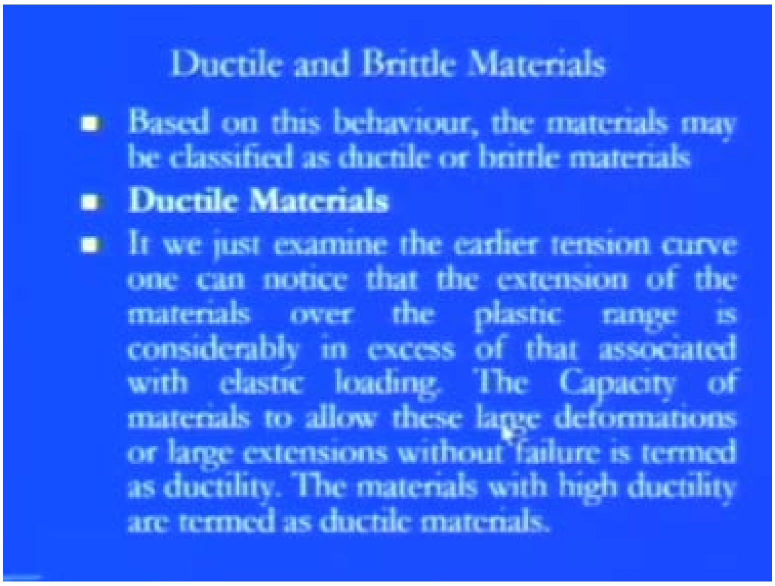

So, the meaning is, that you see, now whatever we discussed in those things, there are four types of the, you know, the elastic regions can be come under the action of elastic actions and we can simply categorizing both the things. Now, you see, here we have the two main types of material, as we discussed, based on what are the behaviors are there, one is the ductile material like mild steel, high carbon steel, high speed steels and they are.

And if we just examine the earlier tensile test, whatever we discussed for the mild steel, one can notice easily, that the extension of any material over a plastic range is considerably in excess of that associate with the elastic loading. So, whatever you see, the elastic loading is there. If you extend those part it can be easily predictable, that ok, now it will go up to that point and it can be easily located.

And the capacity of material to allow these large deformation or the large extension or the large distortion without failure is termed as the ductility, as we have shown and the measure of the ductility is nothing but the elongation, that how much elongation is there under the action of the tensile part. So, the material with the high ductility are termed as the ductile material, as we have discussed. And the layers are so formed in that way, so they are always supporting in towards the, the tensile test and that is why, you see, all ductile materials are having a good capability of the tensile testing.

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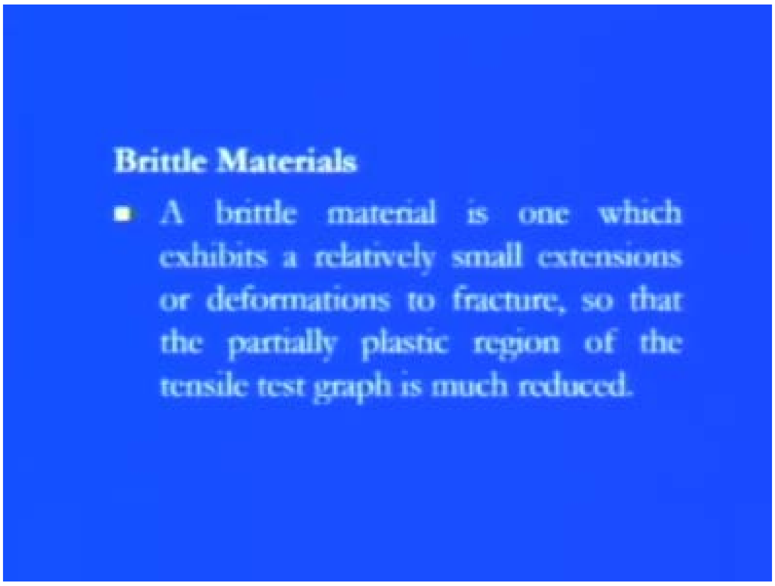

And while the other part is the brittle material, which is, you see, one of the exhibit, relatively small extension of the distortion to fracture. So, if you apply the load, it will show some extension in that simply fracture. So, it is pretty tough to define all those regions, the elastic and the plastic regions clearly if we are taking the brittle material, like you see, the cast iron or brass or bronze and all those things, so that you see, you know, like partly plastic region of the tensile graph is much reduced. So, you see, all that nonlinear part is absolutely, you know, like reduced and even it is, it is not clearly mentioned, that actually where the linear relationship can be occurred within that material like that. So, this is there.

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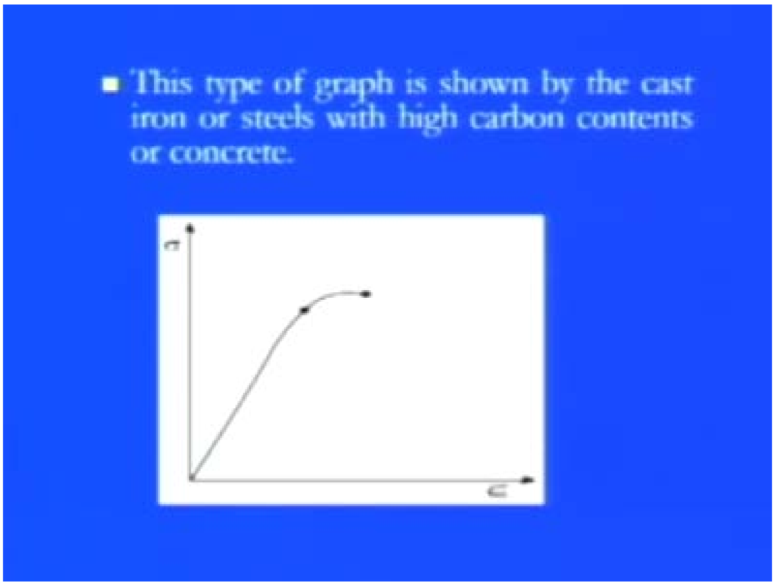

And the last part, which you see here, that the type of graph is shown here for a cast iron, as I told you, or the steel with the high carbon content or the concrete kind of that in which more and more percentage of carbon is. So, here it is there, you see, you know like this kind of stress strain relationship are there and then, skip, you see.

So, as we move further in the plastic region, simply fracture is there. So, we cannot, you know, like get all those clear points as we discussed in the mild steel. So, that is what you see the cast iron or any of the brittle material, they are not capable of having good tensile testing and that is what they are not putting for those, you know, like the application as such. And that is what the cast iron, because of, they have high content of the carbon and it is always gives you the hardness, more and more hardness towards that, that is what they are having good compressive strength towards that.

So, do you see this part, you know, like we discussed about, you see, that what exactly the type of materials are there and if we have a simple mild steel or we can say, that the ductile material, then how these, you see, you know, like the extension and the contractions are coming and what exactly the relations are there in between the stress and strain and how we can define clearly the reasons that, okay.

This is my, you know, the elastic region; this is for plastic region and these are, you know, like the proportional limit all across. So, meaning is pretty simple, that if you want to characterize any, you see, material, always we need the basic information about the stress strain diagram and for that, you see, you know, like we need to define that what exactly is happing with the microstructure as well as the magnitude and the direction of the stresses with the corresponding strains.

So, this kind of, you know, like always an informative, we can say, the knowledge is there for the strength of material is concerned because this is the basic diagram for any kind of, you know, like the material of ductile material. I should say for in a, if you want to study, you know, like this kind of stress and strain relationship for this.

In the next lecture, you see, now as, as, as we discussed the last part, that actually there are two main broad categories of the materials are, one is the ductile material and one is the brittle material. So, now you see, if we have a ductile material, then what will happen, you see, what exactly the properties are associated, the mechanical properties are associated and how they are affecting, you know, like the, these properties if you keep on increase the, keep on increasing the carbon contained in that.

And the later part, as we have discussed, that actually we have either the cast iron or the steel, which is having a high carbon like that or the brass or the bronze or if we have this concrete. Then, what kind of, you know, like the properties are associated with that and how, how they can impact on the real, you know, like the applications if you want to apply, you see, on the base or if you want to apply, if you want to apply those material towards the RCC or any kind of application, you see. So, these are the real basic inputs are there through which we can, you know, like apply those things or we can design any material by using those information.

Thank you.