Strength of Materials
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Lecture - 16
Tension Test

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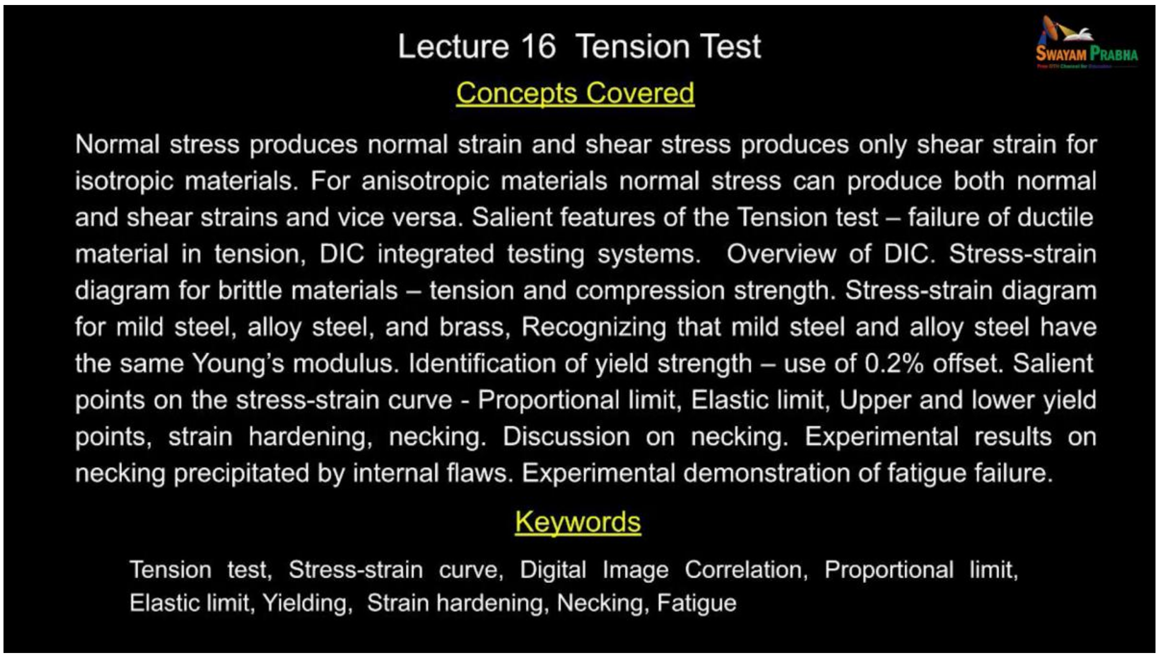

See, so far, we have developed concepts related to stress followed by concepts related to strain. Now, we have to graduate to the next step. If I have to use a material, I should know its characteristics. Only if I know the characteristics of the material, I would be in a better position to make a decision, which material should I use for a given application. And the test I should do should also be simple enough and the number of parameters that I need to characterize the material should be manageable. These are all the two requirements.

And one of the very famous tests that is done in strength of materials is the tension test. You try to take maximum out of the test, right from selecting the material and also to understand the failure theories, you try to interpret what happens in a tension test. So, it is a very very important test.

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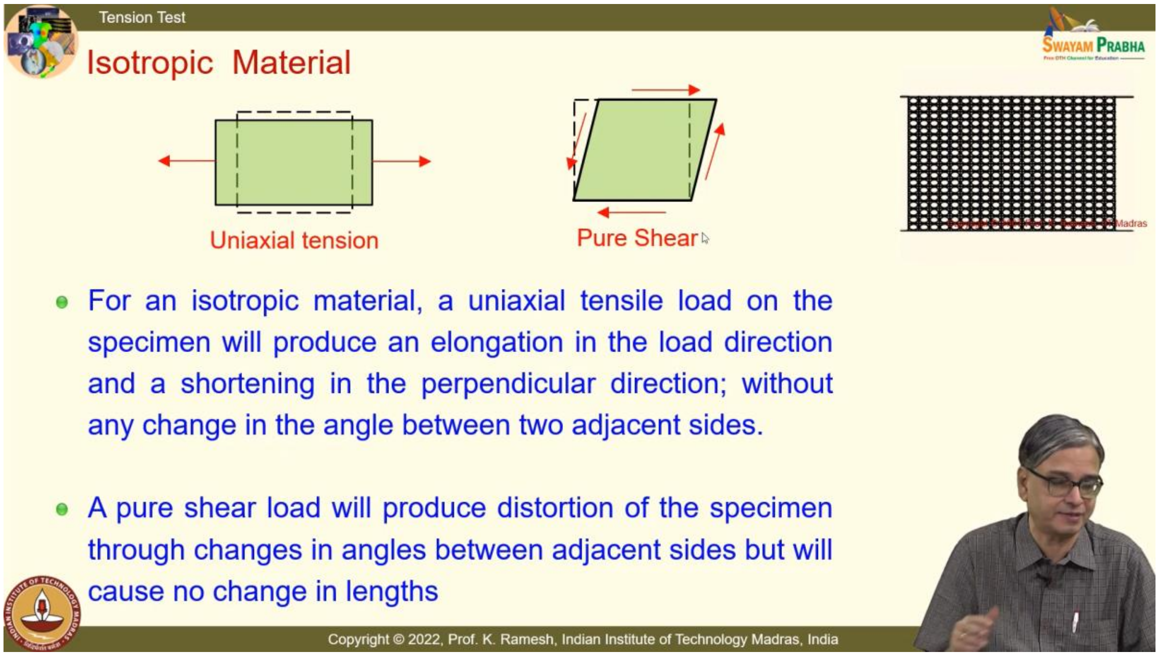

And you know, you should also look at, all the time when we discussed state of stress and state of strain, they were developed independent of the material. For the purpose of discussion, you know, I brought in how a chalk fails. It is a brittle material. For the illustration, how the ductile material behaves differently, so that you appreciate why should I collect the information on all the possible planes passing through the point of interest. To illustrate that, I have taken advantage of failure of some of these materials. Otherwise, the concept of stress stands alone, concept of strain stands alone. If at all I look at what is the material aspect I bring in, we have said that it is an elastic continuum.

That was used because when the $\lim_{\Delta A \to 0}$ or the element shrinks to a point, for that, you need to have that idealization. Otherwise, we have not qualified whether it is an isotropic material or orthotropic material or an anisotropic material, fine? Now, we will look at some of the experimental observations, which is also helping us to formulate the constitutive laws. See, if I have an isotropic material, if I stretch it, it has only axial expansion and a lateral contraction. This is observed from the experiment. Suppose, I apply pure shear for an isotropic material, it distorts like this.

It does not elongate. So, it is a very very important observation. This observation we will also use to formulate the constitutive law. It also makes our life extremely simple. So, this is the peculiarity of an isotropic material.

And you know what is the meaning of isotropy? The elastic properties are identical for any direction of interest. They do not change as a function of direction. And another aspect is, we have studied state of stress at a point. You have determined the principal stresses. You have also determined what are the principal stress orientation.

When we go to state of strain at a point, we have also discussed about the directions of maximum axial strain. These principal directions and principal planes are identical for an isotropic material. That is not the case when you go to an orthotropic material or an anisotropic material. It can, in principle, be different depending on which way you load the system.

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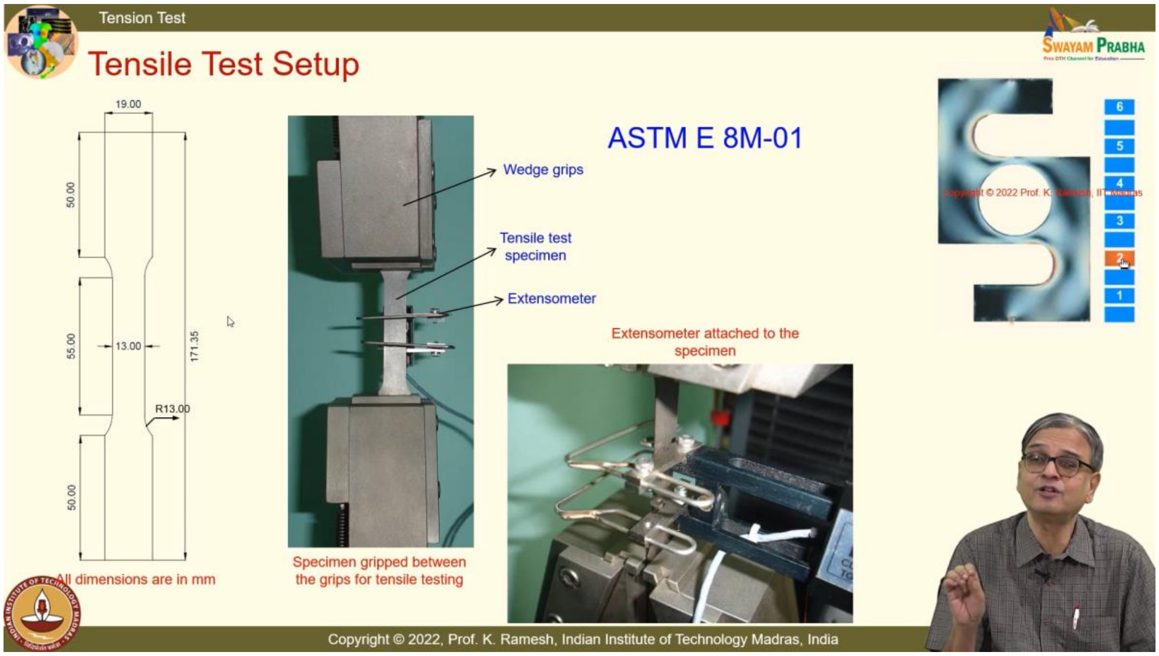

And you know, you have standards available. You have ASTM standards. And they give you what should be the dimensions for a flat specimen like this. And you have a sufficient length for you to grip the specimen. And you also ensure that you provide a generous fillet so that this is a test section and the test section fails in an experiment.

It is not the material fails near the grips. It fails at the test section. And you also have provision to measure the strains. See, you are all now exposed to strain gauges. Many of these transducers for measurement of force or measurement of strain, these are all essentially strain gauge based.

So, when I conduct a test, obviously you cannot pull it with your hand because it is made of steel. It is very very strong. And when you have sufficient thickness, you need a testing machine which has maybe 10 kN capacity for you to do the tests. And you have a system to measure the force which is not shown here. That would have a spring element like this.

See, do not think spring means you have seen only coiled spring. Am I right? I do not know whether some of you have noticed in your, the big lorries, you have at the back, you have layers of material put. It is in the shape like this. That is a leaf spring that bends. And what I said here was, you can have an element shaped like this.

When it is subjected to loading, if you perform a test because these are all not coming under your strength of materials and it is difficult to analyze what is the stress state in this. And they put four strain gauges 1, 2, 3, 4 on the inner boundary of this. And you know, because we have discussed, we want to amplify signal in the case of transducers. So, if I put four strain gauges, I can get four times a signal when the load is applied. So, in many of these axial force transducers, you have an element like this which deforms, which is instrumented with strain gauge and you are in a position to estimate the force accurately.

See, accuracy is very important. And you have an extensometer connected here. What you have is, essentially you have a cantilever beam and you have a strain gauge pasted on this. And when it is attached to this specimen, it can measure the axial strain with little more accuracy than the movement of the cross-heads. You need accuracy for this.

So, when you have a tensile testing machine, you have a provision to measure the axial strain as well as the force applied. And you have ASTM standards, this is called E8. And these standards also develop at a particular year and they keep modifying it. And all over the globe, they follow these standards. Only on the basis of standards, people report the results.

Suppose you are an automobile manufacturer and you want components to be supplied by some of the ancillary units, ask them - what are the material properties? Only if it meets your requirement, you accept the component. You understand? So, it also involves legal aspects. You know, you cannot supply a component with poor quality material. So, you have standards for this and standards are very elaborate.

It is also given in your laboratory manual. Few pages I have it, even in my web page, I have loaded that strength of materials laboratory manual. So, you can have a look at it. That gives only extracts of it. It also says what should be the surface finish and then what should be the fillet radii. All the details, only if you stick to the standards and also the machine is calibrated, then your values will be respected. And it should also have repeatability. Is the idea clear?

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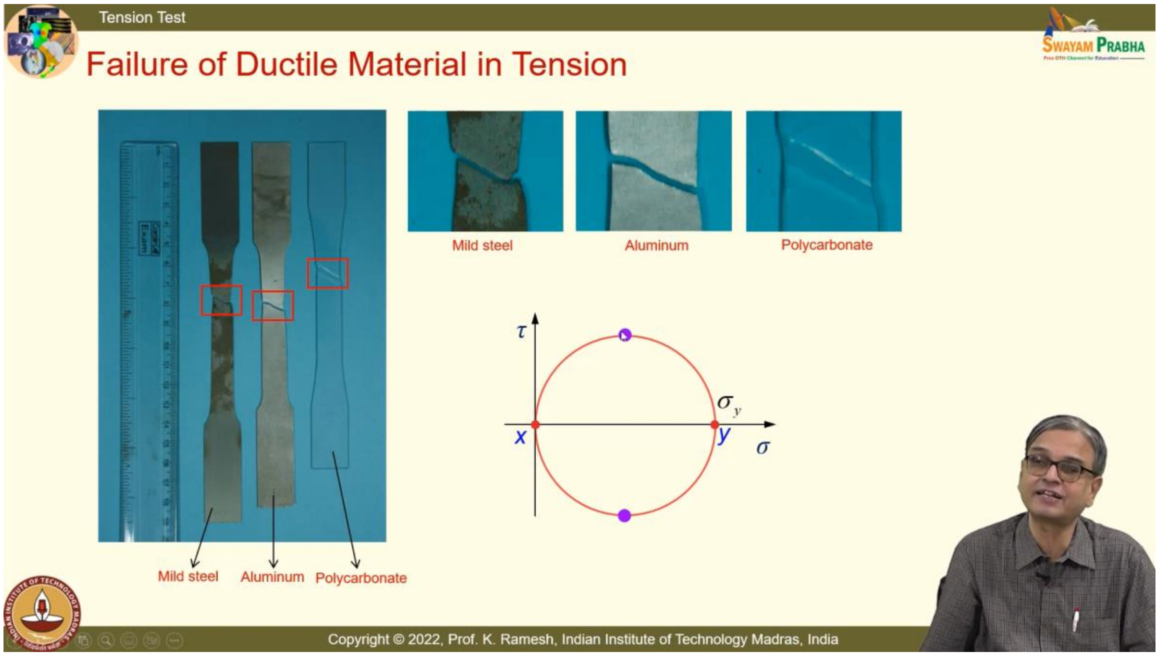

And when you have a ductile specimen like this, you know, this also shows. Now, you have fairly a decent idea why it fails like this. I have a mild steel specimen; I have an aluminum specimen and I also have a polycarbonate.

Polycarbonate can become plastic, ok? It has the property to be ductile and mild steel has broken. Can you guess what should be this angle? Because you have been exposed to failure also. What should be that angle? 45°. You know, all know very well because you can go to Mohr's circle and then you can say it fails by shear and you see that in aluminum also. And when you go to polycarbonate, you know, it has not failed.

It has had a long stretch. The material has not failed in the experiment, fine? And to support your observation that it fails at 45°, I have also drawn the Mohr's circle. And you know very well that maximum planes of shear is at 45° to the axial loading. So, that has precipitated failure in the case of a ductile material, fine?

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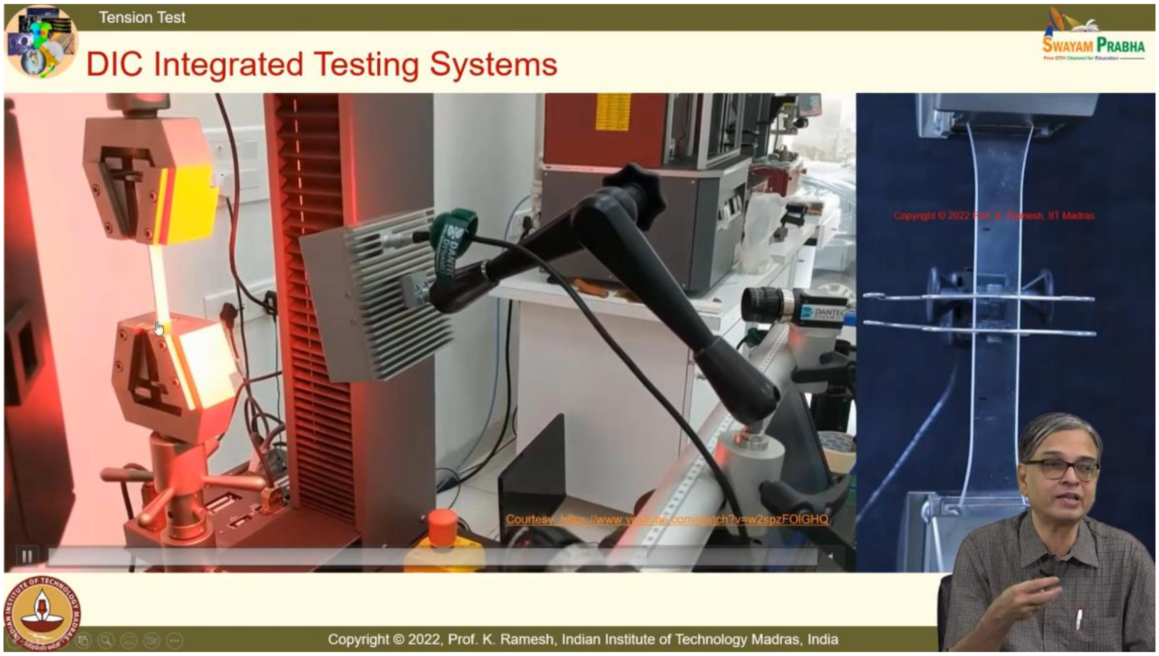

And if you look at modern instrumentation that comes with what is known as DIC integrated system, the expansion is Digital Image Correlation. So, you have a calibration of the measurement system here and then I would like you to notice the specimen is loaded and it is illuminated by a monochromatic light and you have two cameras that simultaneously record. So, you do not have a clip-on gauge or any such attached to the specimen and you directly get large value of strain.

So, this is the way the modern equipments are coming out. It is a very big business, ok? You have Instron and MTS and also there are companies in India. You have many such systems available and people have to test the material. And here, you have, how a brittle material fails. See, if I have photoelastic material that we have used as epoxy and if you have epoxy, epoxy fails in a brittle fashion. It depends on the hardener that I impose, ok? And you can see how the failure, how do you anticipate the failure? It is a brittle material, ok? Let us see how it, ok, we will also see the failure towards the end. So, you have a fairly good idea even before we take the theories of failure that a brittle material fails in a particular fashion and a ductile material fails in another fashion.

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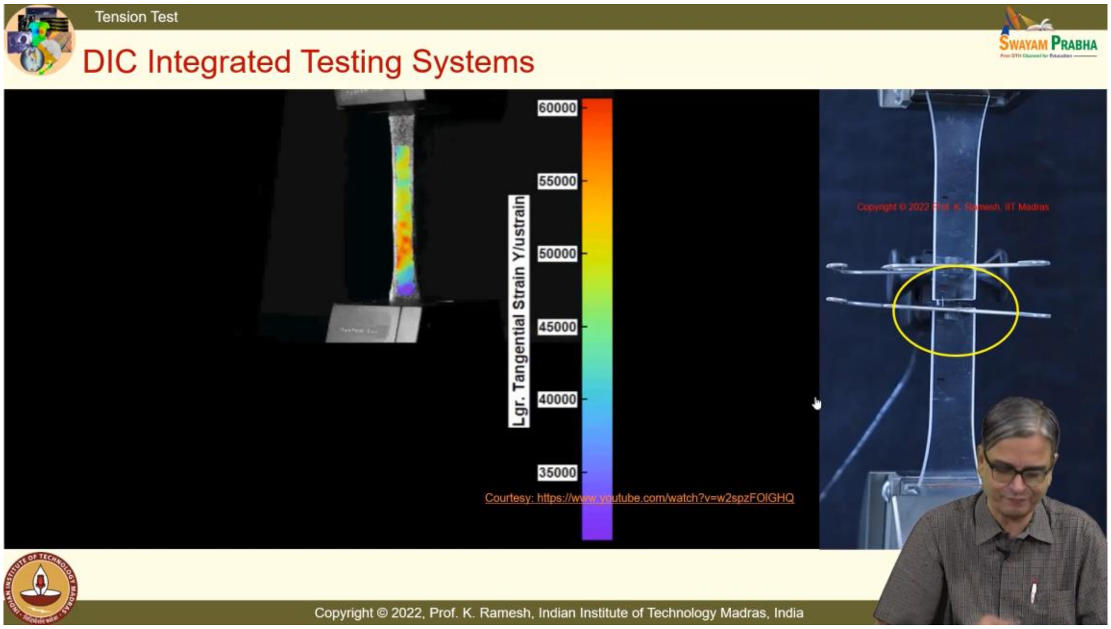

You watch this zone and you will find that, you know, it will take some time for it to break, fine? It has to reach the peak load. So, you find that it is horizontal. See the idea of me showing the experiment in full is to feel that when you perform the experiment, failure occurs like this.

In the earlier case, I showed the failed specimen. This case, I am in a position to show you that material actually fails. So, a brittle material fails by maximum normal stress, that is a reasonable approximation and then a ductile material fails by shear stress reaching a maximum as we have discussed till now. We will see that further.

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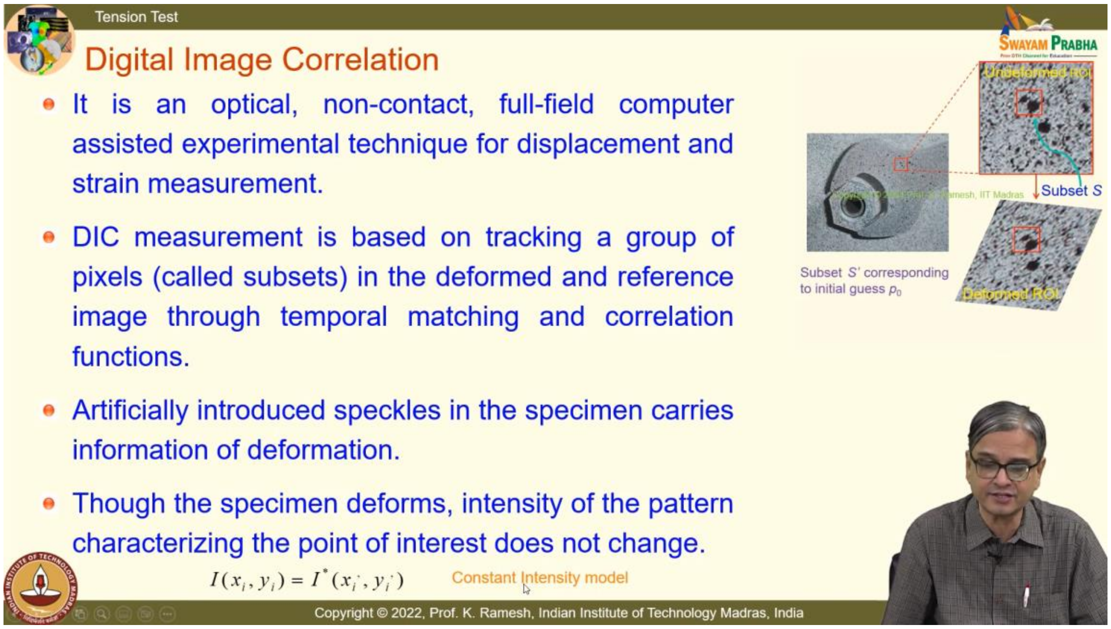

And before we get into looking at the tension test very closely, let me also introduce to you, what is digital image correlation because when you are learning it now, at least you should have a rough idea what is it all about. It is an optical, non-contact, full-field, computer assisted experimental technique. The emphasis is that. More than the experimental measurement, a lot of number crunching is done from your computer 3D imaging, ok? So, that is very important. And what you have is, you have to spray the specimen with speckles. You actually have a white background, on that, you spray black dots; that requires skill.

See, the measurement accuracy depends on how well you have generated the speckle. They should be sufficiently random. The size should be controlled and if you change the size, you can also work on different length scales. These are all the advantages. Particularly for very large deformation, the image correlation is very good.

So, like I said, artificially introduced speckles on the specimen carries information of deformation. And what is done here is, what is the basis? I have a deformation that takes place and then I have to locate where the deformation is actually. This location is done by an assumption, intensity of the pattern characterizing the point of interest does not change. Initially, it is called as white light speckle. People use white light. White light means I have all the wavelengths. And in the DIC integrated system, we have seen that they have used a monochromatic light. And one of the claims is, if you use monochromatic light, the accuracy of the system is better, ok? And this is the basic assumption with which the technology started in this. Now, you also have systems that accommodate intensity variation, higher order terms and so on and so forth. This is one of the basic methodologies that assumes that you have a constant intensity.

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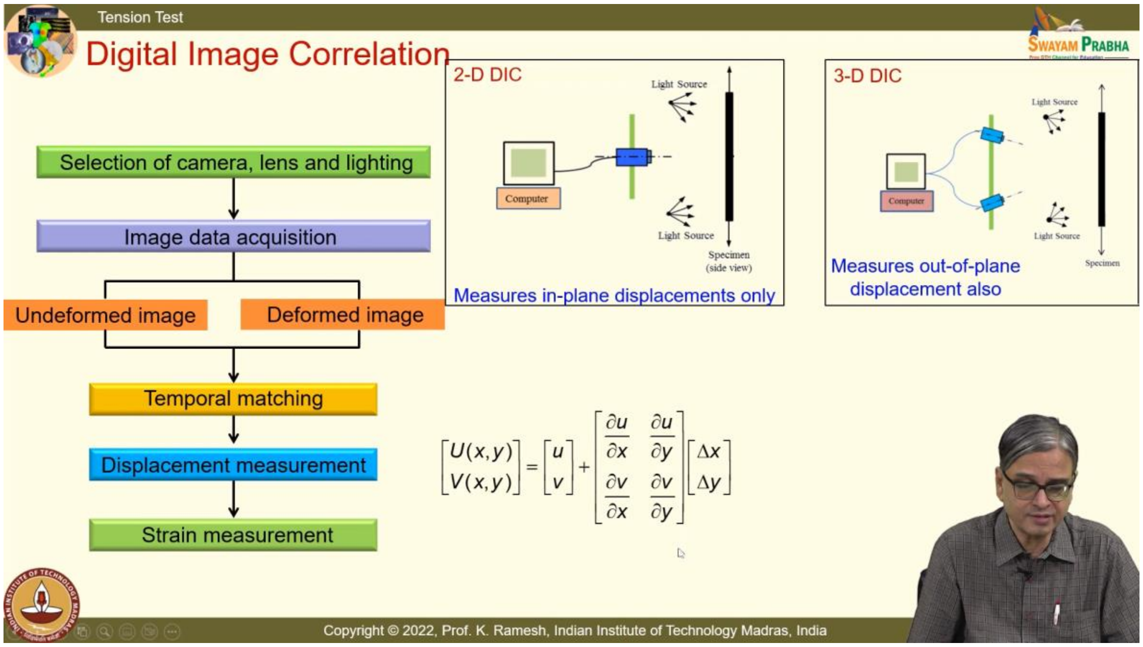

And what is that you do? You have to select the camera, lens and lighting. See, your lighting should be cool. It should not heat the specimen. You understand? Because, now you know, even for recording, they have come to a cool lamp. Earlier, people will be sweating, fine? Earlier days if you talk of 20-25 years back, if you see how videos were recorded, they had such illumination, they used to sweat.

I would like you to make a sketch of this, ok? You have a specimen loaded. I have a light source and I have a two-dimensional digital image correlation which is cost effective and the software is also very simple. You use only a single camera. On the other hand, if I use two cameras, that is the only difference. If I use two cameras, then I have what is known as three-dimensional DIC.

So, in a two-dimensional DIC, you will not be in a position to accommodate the thickness change of the specimen in the three-dimensional direction, the z-direction. The direction in which you are looking at it, if there is a thickness change, you will not be able to measure it. And people have shown later when you want to make strain measurement, only if you make the depth measurement, it improves the accuracy when there are stress raisers, ok? And what you do is, you record an undeformed image, you record a deformed image. So, you need two images for analysis. So, it is called, I would also like you to draw this flow chart that gives you a summary of what are the important components.

Then I do temporal matching. Temporal means time dependent matching. So, I look at an undeformed image and a deformed image. And primarily, I get displacement information, fine? While I find out the displacement, I not only find out u and v components, but I also try to find out $\frac{\partial u}{\partial x}$, $\frac{\partial u}{\partial y}$, $\frac{\partial v}{\partial x}$ and $\frac{\partial v}{\partial y}$. I also try to measure the gradients. Why do I try to measure the gradients? With these gradients, I can find out the strain components later, fine?

So, I have the displacement measurement. From this information, I post-process, I get the strain measurement. And in every stage, there are many, many approximations involved and it is a very involved technique from number crunching also and also from the point of view of the capacity of the hard disk that you require because these images are occupying large memory, ok? So, you need to have a good system which also responds very fast.

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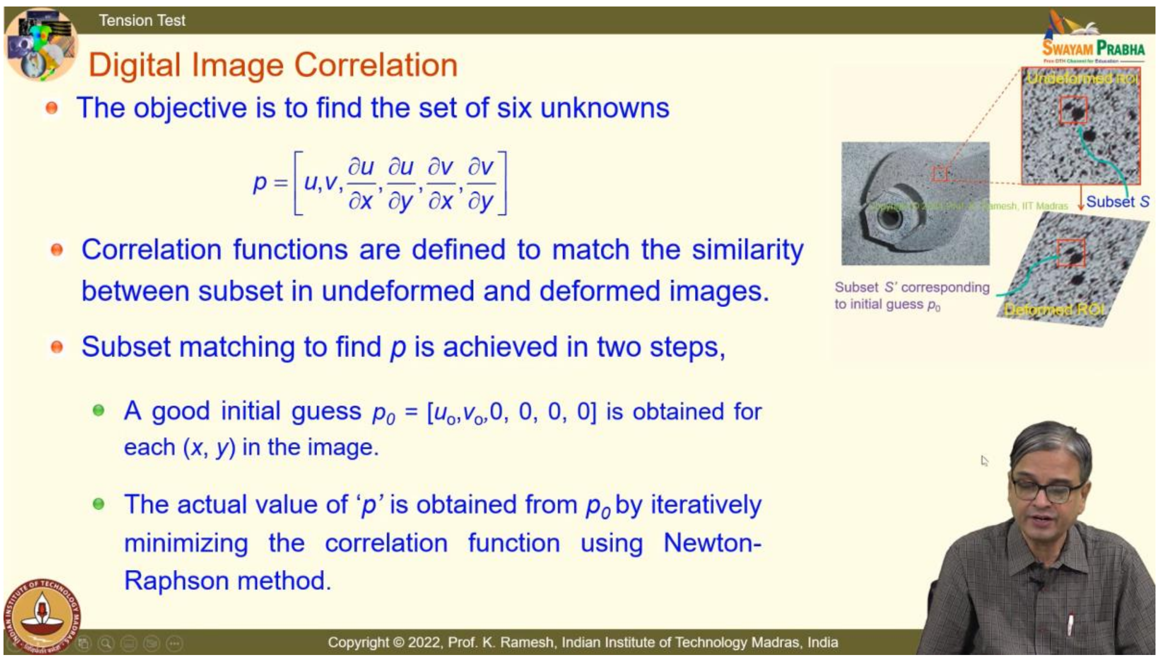

And the objective is to find the set of six unknowns. I have already listed them earlier. So, I call that as unknown P. When I say P, I have six unknowns listed here u, v, $\frac{\partial u}{\partial x}$, $\frac{\partial u}{\partial y}$, $\frac{\partial v}{\partial x}$ and $\frac{\partial v}{\partial y}$. So, what I do is, I have a small subset and then this subset is moved on the deformed speckles, and you first locate where it has moved by intensity measurement. There is a correlation coefficient that you develop. And then, you improve by an iterative methodology. The correlation functions are defined to match the similarity between subsets in undeformed and deformed images.

And subset matching to find P is achieved in two steps. You start with an initial guess where these gradients you put that as 0, you have some assumption of u_0 and v_0. See, whenever you do the iterative methodology, initial guess is also very important, fine?

There are thumb rules available and the thumb rule is, you need to have u_0, v_0, but you can have these quantities as zero. The actual value of P is obtained from P by iteratively minimizing the correlation function using the Newton-Raphson method.

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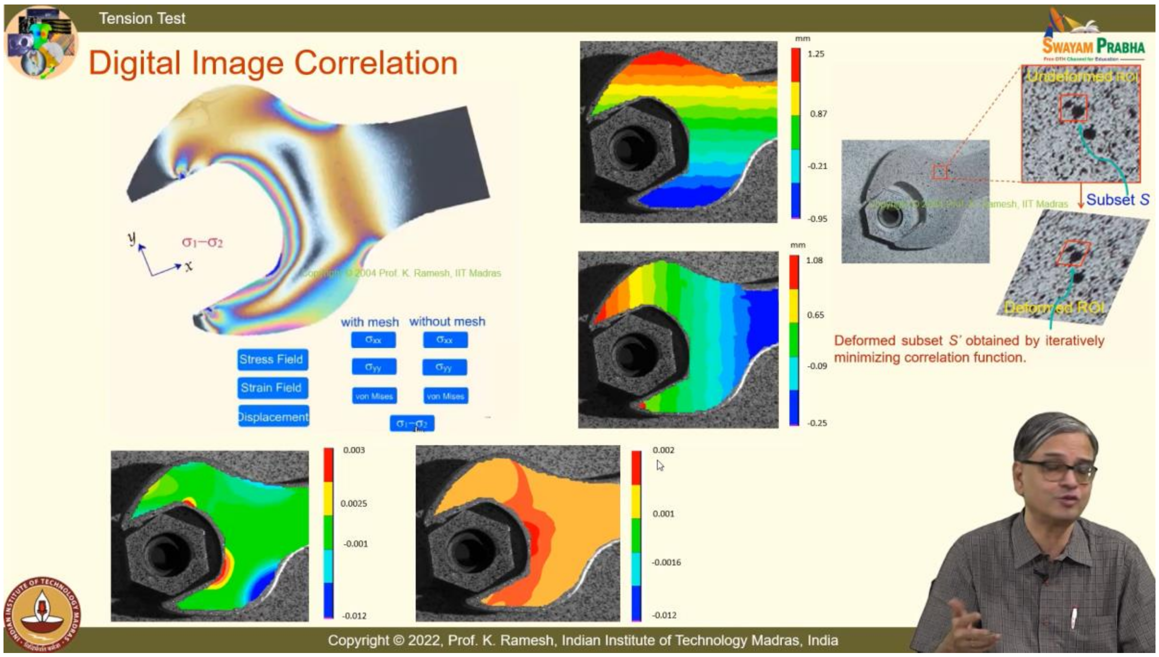

So, this summarizes. So, I have a speckled image. So, I take one photograph in the undeformed configuration. It is again an exaggerated picture. See, the spanner does not go through large deformation. So, the accuracy what you can anticipate in strain measurement is going to be poorer. It is not going to be as high as what you get under large deformation.

So, initially, you identify the subset and then do the iteration and you finally get what is the distorted shape. So, deformed subset S is obtained by iteratively minimizing the correlation function. And this also compares, you know, what is the result I get from finite element and what is the result I get from image correlation. See, finite element, I have used different reference axis. So, these things have to be rotated; that is not done here, but the idea is, you see similar patterns and displacement.

Displacement measurement is reasonably good, fine? But when I compare the strain, the accuracy is not very high, ok? And because we are talking about very small value of strain. See, strain, we have seen in different ways. I have expressed it as a percentage. I have also expressed it as number like 0.002, and then, we have also expressed it as in micro-strain. So, you should be able to comfortably move from one representation to another representation, fine?

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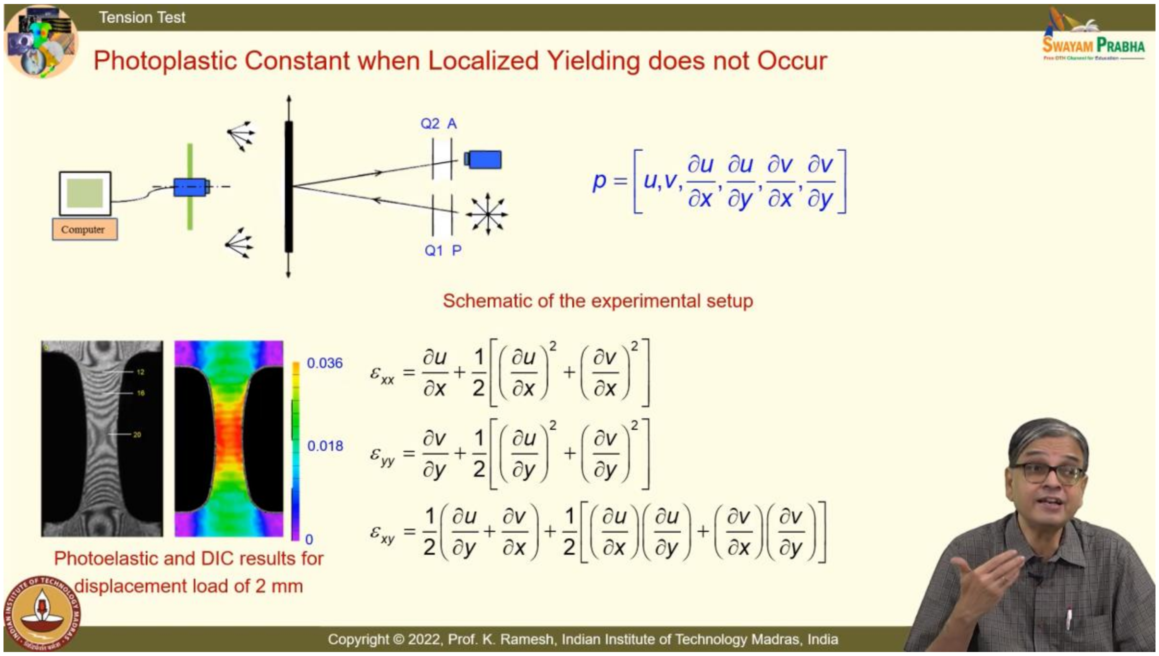

And we have also seen, I can use reflection photoelasticity for strain measurement. And this is a very innovative experimental setup where on the same specimen, on one side, you apply a DIC measurement, on another side you apply a reflection photoelasticity. And the specimen is made of polycarbonate and I said polycarbonate has ability to deform plastically. And we also have what is known as photoplasticity. So, you have beautiful reflection photoelasticity fringes and the corresponding strains are measured by image correlation.

And this is about 4%. When I have 0.036, it is about 4%. 4% strain is reasonably good, reasonably high value. We are crossing the yield, ok? So, here the image correlation is more accurate. Not only that, you will also have to use finite strain measurement. So, I can also calculate the finite strain values from my image correlation. Is the idea clear? Because the current day equipments for tension testing comes integrated with DIC. So, it is better that you have a basic idea what a DIC system is capable of.

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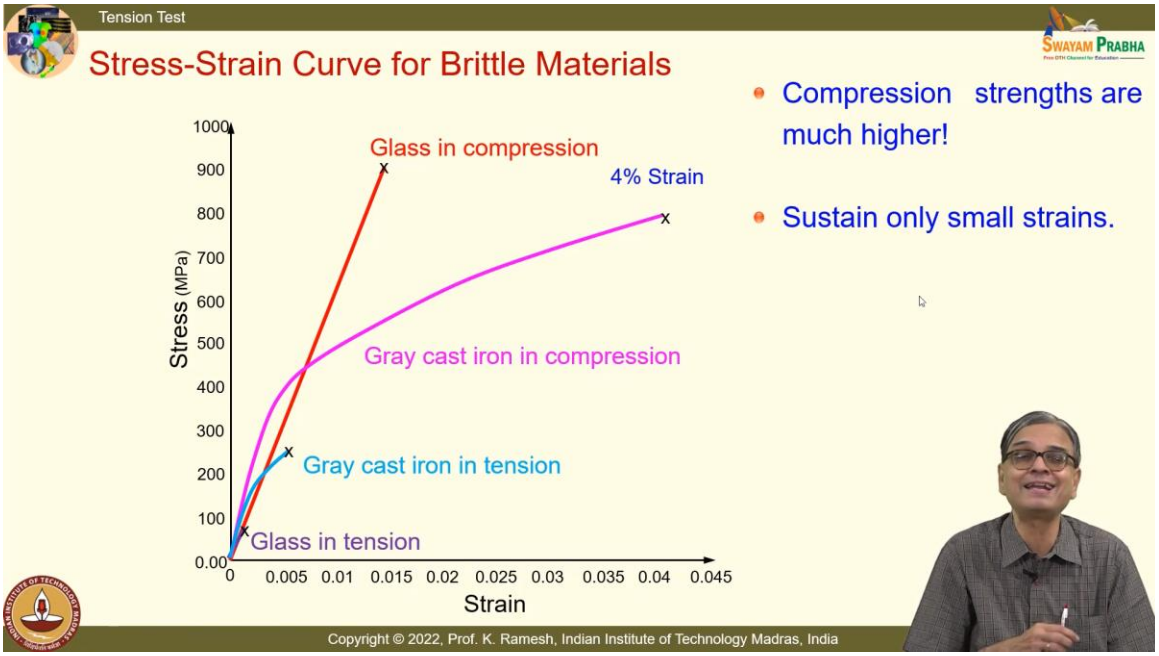

And I have also shown that this is about 4% strain. And you observe this and then find out; I want you to draw the graph. Draw the graph with the axis labeled. It is very important because I would like you to be sensitized on the numbers. When I have a brittle material, you know the maximum strain is within 4%, which is listed as 0.005 in numbers. So, 4% means 4/100, ok? So, I have this something like 0.04. And what you see strikingly? I have a glass and it shows that glass in compression is about 900 MPa. Is the idea clear? Whereas, glass in tension fails below 100 MPa. Is the idea clear? It is strikingly different when you take a brittle material. First observation is, the strain levels are also very small. In the case of glass, it is extremely small. Second observation is, it is not having a same failure strength in compression and in tension. And if you look at the ratio in the case of glass, it is almost 10, 10 or 11.

And I also look at grey cast iron. Glass is almost linear whereas grey cast iron has a slight curvature. And you find that this is about 250 MPa in tension. And the same grey cast iron, when you put it in compression, this is about 770 MPa or so. It is below 800 MPa. So, the striking observation is, when you perform a test, the test tells you brittle materials are very strong in compression. They are very weak in tension. And the level of strain that they can withstand is much smaller when you compare it with a ductile material.

The next one, we will see the ductile material. Have you drawn the axis with numbers? Because I would like you to be sensitized on the numbers. It is very important. You should feel. We have seen glass is about 900 MPa in compression.

Let us see what happens to mild steel. So, what I have said is summarized here. Compression strengths are much higher. Sustains only small strain. These are all the important observation when you handle a brittle material.

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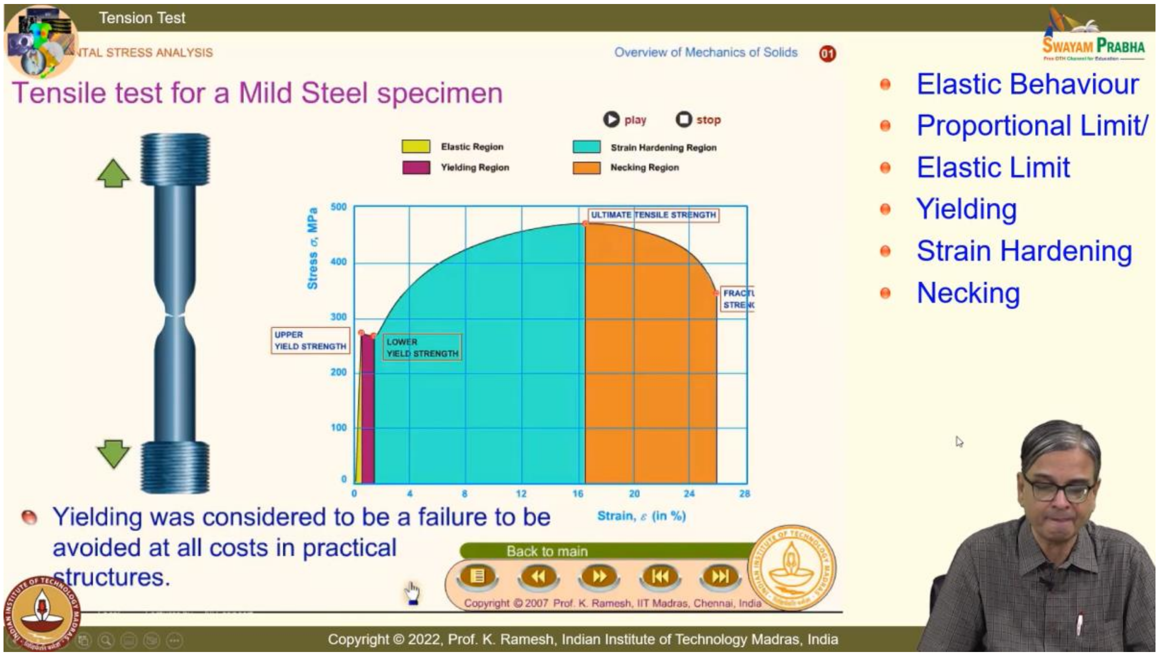

Now, we move on to a ductile material. You have seen this graph many times in the course, but today you are going to see it minutely. We are not going to be in a hurry. I have a ductile specimen which is pulled in a tensile testing machine because you cannot pull it by your hand. You need large amount of energy to do that. And you have various regions. I have elastic region, I have a yielding region, I have a strain hardening region, I have a necking region. And I would like you to draw this graph and demarcate these regions and also put, what is the strain measure which is put in the horizontal axis.

So, we are talking about 26% of strain, the fracture has occurred, and this is a mild steel specimen. This has a peculiarity. You know, it has a very sharp definition of what is the yield strength. So, we have to recognize in a tension test what is an elastic behavior, what is a proportional limit or an elastic limit, what is yielding, what is strain hardening and what is necking.

All these aspects that we will have to learn from this simple graph. And you find the elastic region is extremely small. You know, in order to drive home that we deal with extremely small deformation, I have used this graph even much earlier. See, the stress analysis, whatever the concept, they are interrelated. The difficulty is which concept you should say first, which concept you should say later, it becomes difficult. Even before you understand stress or strain, I have shown this graph particularly to show you that this is basically a non-linear graph. If you confine your attention to a small region, you can idealize it as linear. It also gives you host of other benefits in your mathematical manipulation. And in the case of mild steel, it has a peculiarity here. We will see that. Then you find, as the strain increases, the stress also increases, ok? It reaches ultimate tensile strength.

Then it starts necking and then necking eventually transfers to fracture. That is what you see. It has fractured here. So, we will see this one by one, fine? Have you drawn the graph? Have you been able to identify these regions roughly? Because you should have a feel of it. You should know how to interpret a graph. Subsequent graphs, I would like you to look at the graph and tell me, what are the salient things that you are looking at. Is the idea clear? Because you should also learn how to read the data. Just presenting the data is not sufficient. Interpretation of data, what the experiment tells you is also equally important. In this case, I have a very sharp demarcation when the material yields. And you all right now know, yielding was considered to be a failure to be avoided at all costs in practical structures.

See, you have seen material separation. What happens to a ductile material? What happens to a brittle material? Suppose you are coming in your bicycle, you do not want your bicycle components to fracture while you travel. It should withstand your load, whatever the bumps it has to go up and down, the component should stay safe. So, you design it so that it never goes to either large deformation or failure. Is the idea clear? And the moment you have yielding, the material has not failed. Material has failed far away. It has failed only when the strain has reached to this extent. But if you define what is failure as functional loss, when you have mating members, when I have a shaft in a bearing, if it starts yielding, you are going to have large deformation, the shaft will get stuck in the bearing. Is the idea clear? So, from the design perspective, you do not want to reach yielding. You want to work much below yielding. That is the idea.

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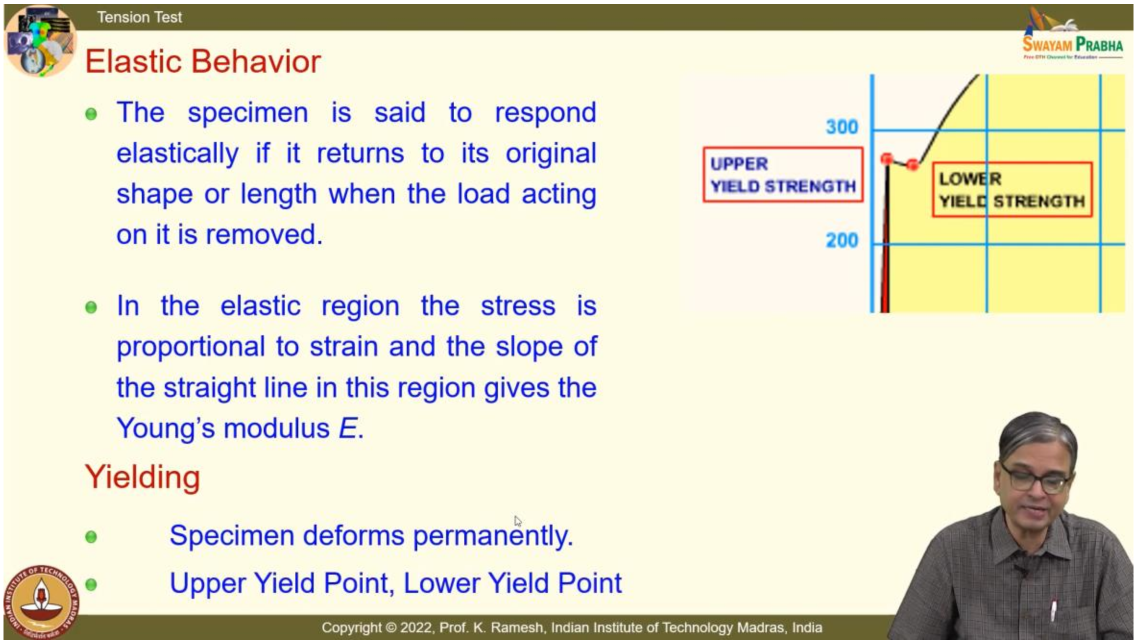

So, what is an elastic behavior? Suppose I apply the load and then release it. When I release it, it will come back in the same loaded path and it will come back to its original position. What was happening in the case of a rubber? When I had taken the rubber band and I stretched it, I could go up to 250% very very comfortably and release my hand, it was coming back.

In the case of metals, this is about 0.2% of the strain. We will also get that number. And what you say is, in the elastic region, the stress is proportional to strain, obvious, because I have a straight line. And the slope of the straight line in this region gives the Young's modulus *E*, which is also taught in your high schools. Am I right? And in the case of mild steel specially, there is a dip when you increase the strain, when you increase the load and then it starts increasing, ok? Stress starts increasing. So, this is called the upper yield strength and you have a lower yield strength. That is something peculiar to mild steel.

And the moment you have yielding, the specimen deforms permanently. So, when I unload, it will still retain some value of strain that it has got stretched, which is undesirable from functional point of view and you have components that are assembled together. You do not want any one of the components to go to yielding. So, I have an upper yield point and lower yield point in the case of mild steel.

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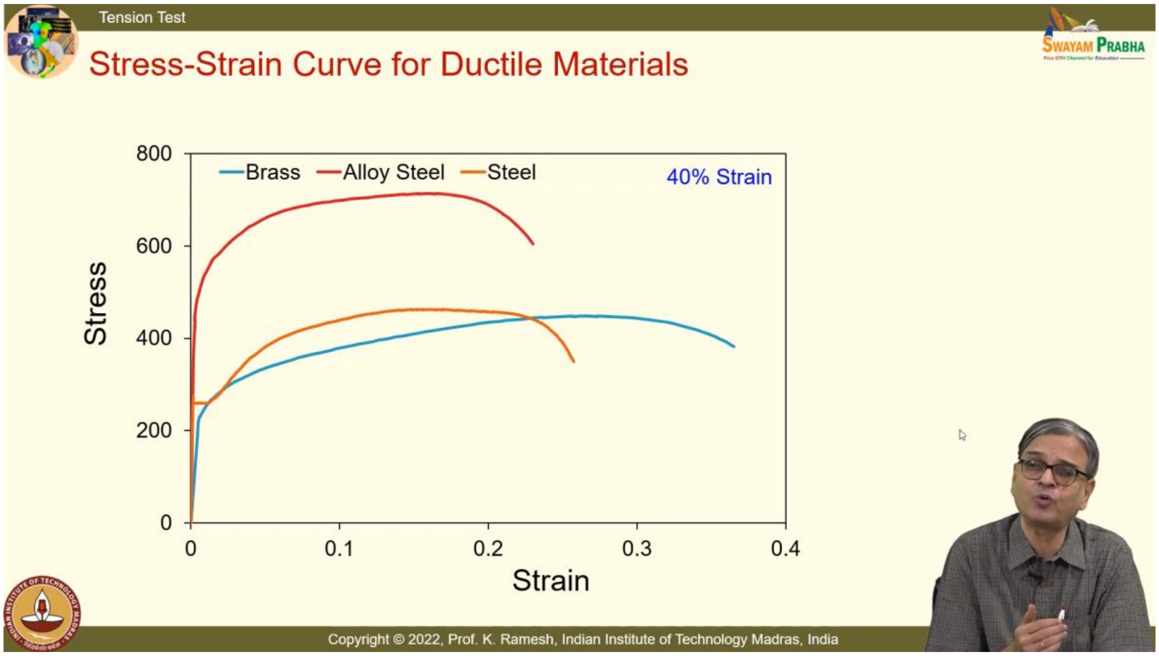

Hence, you look at the graph and I would like you to draw these graphs as it is drawn. While you draw, please apply your mind. I am going to ask certain questions and I would like to get answers from you.

You should improve your observational skills. I have drawn it for three materials. I have drawn it for brass. That is the blue curve that you have and I have drawn it for alloy steel. And when I say steel without any adjective, it is understood as mild steel. And you have the mild steel which is shown. I have this. I have a sharp demarcation of the yield point and it then dips and then it increases and then it is drawn like this.

And this graph is drawn up to 40% of strain. So, I have 0.1, 0.2, 0.3 and 0.4. And what is the first observation you see from alloy steel to mild steel? What is the first observation, striking observation? See, mild steel has lower yield point. He has looked at it that this has a lower yield point. And this apparently has capacity to withstand large stresses.

And you have a difficulty. Can you locate where it demarcates from elastic to plastic? There is no demarcation. There is a clear demarcation in the case of a mild steel which is absent in the case of an alloy steel. And if you look at the maximum strain, they are similar. There is a small dip in this. But there is another important observation. Let me see whether anybody makes it, which is important from your strength of materials point of view.

Because you know, why do you do alloying? You want to improve the material characteristics. By alloying, you have been able to improve what? You have been able to improve the yield strength. Can you do anything with the Young's modulus? What does the graph say? Does the graph give you some clue on what happens to Young's modulus by alloying? How do you say it increases? I got the answer I wanted, because first you should make a mistake. Only if you make a mistake, you understand the concept better.

See, you look at brass, you look at steel. I see this region distinct for a brass. I do not see from this graph; we will also see subsequent graphs. There is no distinction in this initial slope between alloy steel and mild steel. It is very very important. It is extremely difficult to change the Young's modulus of a material. Your heat treatment or alloying does not change the Young's modulus, which you will see elaborately in your material science course.

It is a very important observation. Because when you look at a graph, when you have the data appearing before you, you should also know how to interpret them. Now, what I am going to do is, I am going to draw this graph for different strain values.

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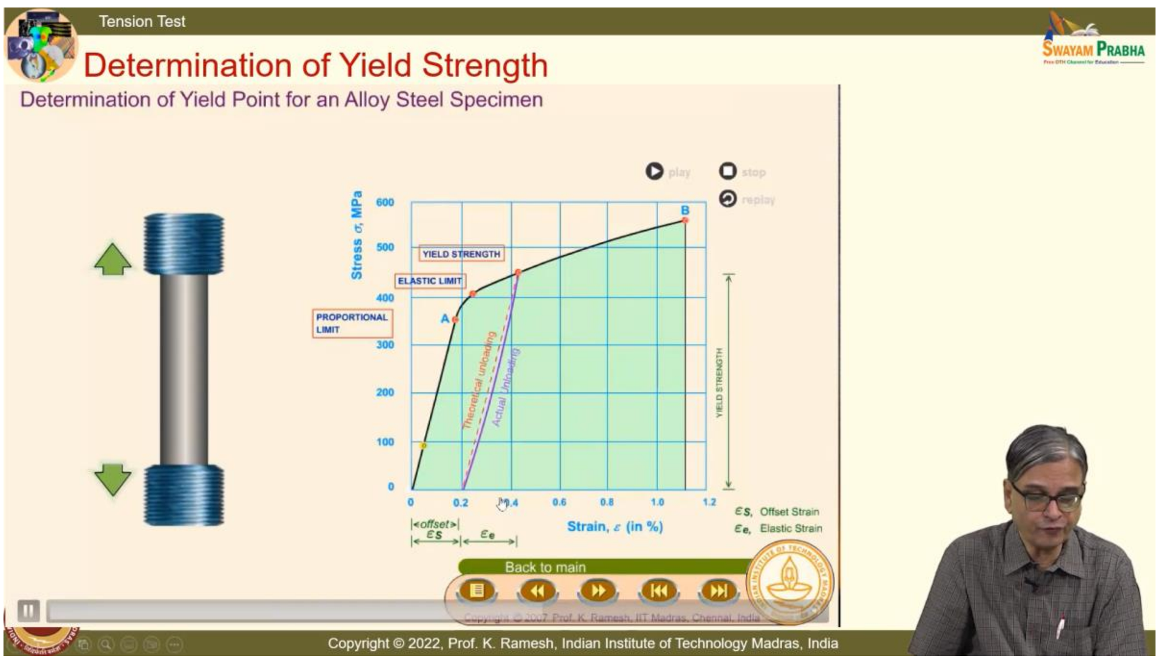

Before that, I have an important aspect, which tells me what is the way I have to locate in the case of an alloy steel; How to locate the point of yielding? So, these are again governed by standards. You do not have a demarcation; it is varying smoothly. Please draw the graph. I am giving you time for you to draw the graph. These are all very, very important concepts. You have excellent animation here. And what is shown here is, I have a proportional limit, which is linear. I have shown the elastic limit slightly away and, in this zone, this is non-linear. So, that is what is observed in alloy steel. What is the meaning of an elastic limit? Until this point, when I load the specimen, if I release it, it will come back in the same loaded path. Loading and unloading paths are identical. Please write down this. I will also show it in an animation. These are all very very important concepts. Now, what I do is, I want to find out what is the yield strength. The standards say, you draw a line at 0.2% of strain, which is parallel to this initial curve and you draw the line. You draw the line and this dotted line hits the curve here. You take this as the yield strength. Is the idea clear? I have also mentioned 0.2% is very important. 0.2% means, it is 2000 micro strain. Is the idea clear? You should know, it can be expressed in terms of micro strain, it can be expressed in terms of percentage or it can also be expressed as just a number. At 0.2% strain, the material yields.

And I want you to observe the graph after you have drawn this, I have an offset strain here. And when I unload, it does not take this route. That is the way it was loaded. When I unload, it unloads in this fashion. Is the idea clear? It is very important. The loading and unloading paths are different. The material has yielded plastically. Even though you call yield strength, in the case of mild steel, we could get even before it has some permanent deformation, we have been able to identify the yield strength.

Here, you permit a small permanent deformation and that is given as 0.2%. And you have the offset and you have an elastic strain recovery. The elastic strain gets recovered, but you will have some amount of plasticity embedded in the material. The material has become different. That is where the plasticity theories are struggling.

If the material has gone through multiple loading and unloading, how to predict its behavior? It is very difficult. The history of loading is also very important in plasticity theories. That is where the mathematics gets stuck. It is also very sophisticated, ok? And what this shows is, till the elastic limit, not restricted to straight line, but also the curved line, the loading and unloading paths are identical. Is the idea clear? Loading and unloading paths are identical in the elastic region and there is a difference between proportional limit and elastic limit, which is very distinct in the case of alloy steel or any material. Even aluminum will have a curve like this. So, you have a via media, how do you find out the yield strength? Is the idea clear? Ok.

So, this is emphasized again. Failure in ductile material is specified by the initiation of yielding. You do not want to have yielding in your running component with assembled parts, ok? You do not want yielding. You want to operate much below that.

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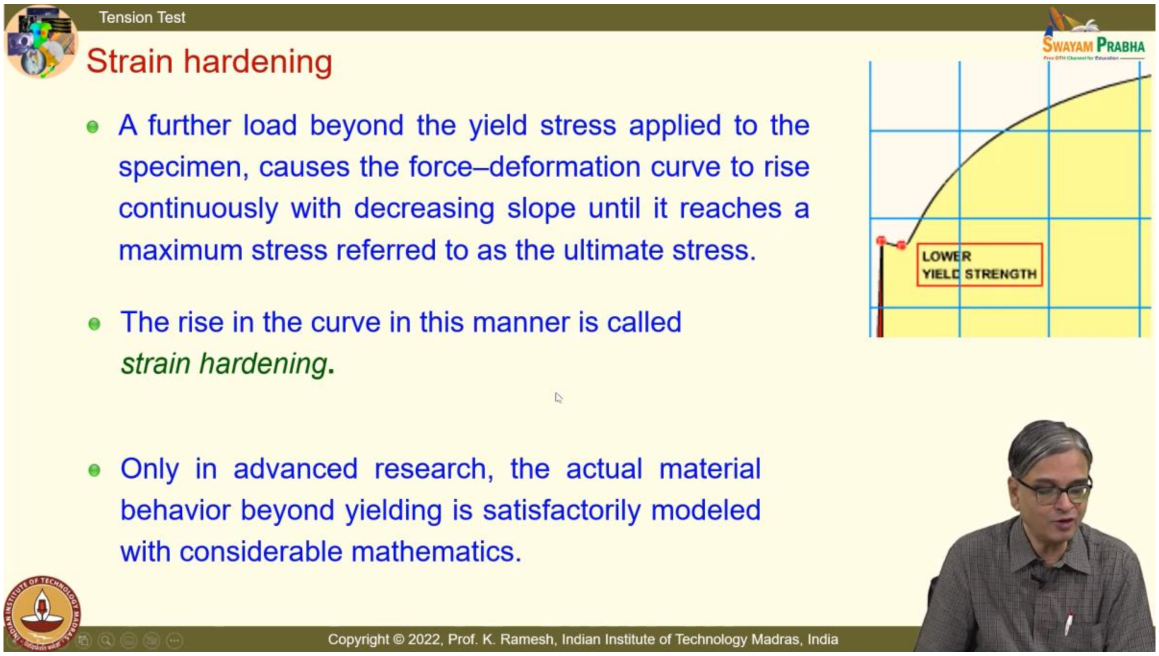

And you have a region; see, scientists always want to coin new terminologies, ok? So, they have come out with a bombastic term like *strain hardening*. As if as a strain is increasing, the stress is also increasing. That is the meaning here, fine? Because you know you want to escape; suppose I want to model the complete curve, strength of material would not have developed. It is just because we have modeled only the linear portion, strength of material has developed. So, we want to keep this out and say that this bombastic name that is strain hardening. As if strain is increasing the strength of the material, it is not to be interpreted like that, but that term implies this, ok? You have the slope; it changes and then it becomes horizontal when you go to the ultimate strength. When I plot engineering strain, there is a definition of engineering strain, there is also a definition of true strain which we saw, which will also see what way it is different.

The rise in the curve in this manner is called strain hardening. That is what is mentioned. And that is the only way to say that we are not considering strain hardening, we will confine only to the elastic or proportional limit. And only in advance research, actual material behavior beyond yielding is satisfactorily modeled with considerable mathematics. If you look at the mathematics, the amount of effort that you put in mathematically modeling, you have Rombert Osgood law, it is very difficult to handle. And it also for slightly above plasticity, I mean above yielding, it is not for the complete range either. So, you have to appreciate that as you go and want to model the material behavior beyond yielding, it is mathematically demanding, it is not that simple to do.

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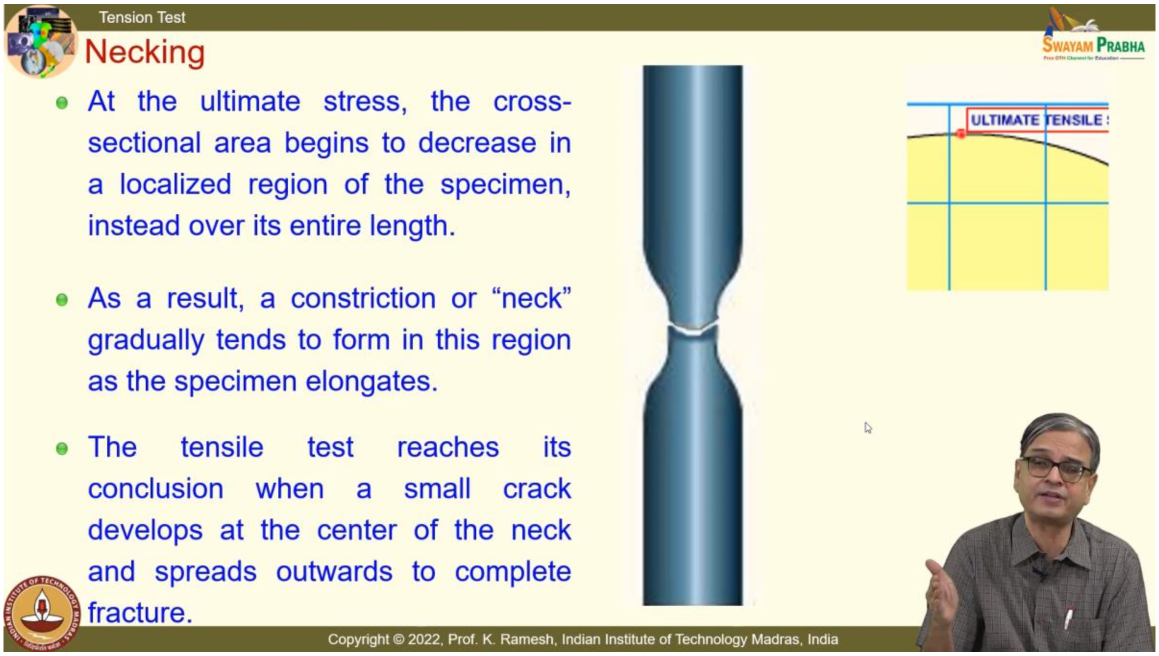

And we have also seen, once it has reached the ultimate tensile strength, I have necking that has started. And then you look at the animation. And you have localized yielding that takes place. And what you have is, ultimately the material separates and you have cracks developed and that propagate and separate the material. And analysis of necking is very very difficult from a mathematical perspective, fine? So, when you do the tension test, you go up to breaking of the specimen. So, you completely record the stress strain behavior up to that. And you know, we have looked at necking, does this necking happen exactly at the center of the specimen? What do you anticipate? Please make a guess.

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See, we have said it is an elastic continuum. That is an assumption or reality? It is an assumption. Reality is different, the material has some kind of defects, inherent defects. So, when you do the test, here I have shown it for a round specimen, in this specimen, it is more or less at the center. I have another specimen, it is not at the center, there is another specimen, the location is totally different. So, necking is precipitated by inherent defects, it can happen at any other point.

You are all given jump clip, fine? You know you have seen; I have a tension testing machine with 10 kN capacity for you to pull this specimen and then do it. I want to give you a challenge, ok? See, you open it up like this. And obviously, you know, you and I do not have the strength to separate it by pulling. Can you find out what is the way that you can separate it with your hands alone, any type of loading you can apply, can anybody guess? Do that! You are much stronger than me, I am not stronger than like you.

Can you just show, you focus on the students and let me see who gets it first, I will also try to do. Yeah, now I separated it, I am faster than you because I know the mechanics. Idea what I have done is, I have applied only small load, but I have repeatedly done that. I have actually done bending. So, one observation from this is, I need much less load if the loads are repeated. Is the idea clear? And, suppose we are in the third floor, I ask you to go down and come up once, you will not mind. I ask you to do it ten times. At the end of ten times, what you will say? I am fatigued; will you say that or not? Same thing they have coined it for the material. So, when I apply repeated loading, it fails by fatigue and I will operate at much lower load than what we have discussed till now about monotonic loading. So, we are justified in looking at a linear elastic theory, that is where we have to come out. See, for our day-to-day life, the strains that you can permit are so small, our small deformation assumption is good enough and reasonably accurate for all that. It is not an arbitrary assumption, that you have to keep in mind.

So, in this class, we have looked at tension test much more closely and I have also sensitised you on the numbers; they are very important. The important take is, a brittle material is very strong in compression, but very weak in tension and the difference in yield strength can be of the order of ten to twelve times; it can even be higher, ok? And in the case of a ductile material, we have also looked at; in the case of mild steel, you have a clear demarcation of where the yielding occurs. And you also have a methodology, if the curve does not show a sharp demarcation, how to locate the point of yielding by using the offset strain. Thank you.