Experimental Stress Analysis - An Overview
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Lecture - 2.7
Introduction to Photoelasticity

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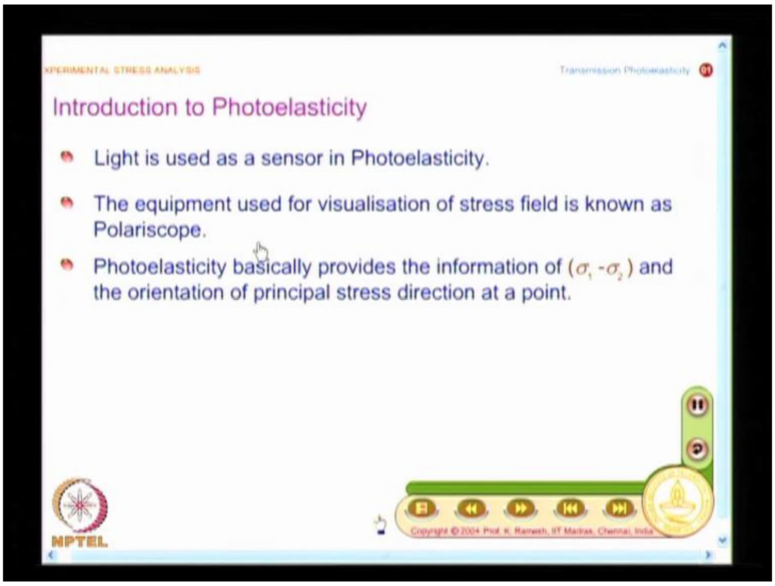

Let us continue our discussion on Overview of Experimental Stress Analysis, look at Introduction to Photoelasticity. Once you come to photoelasticity, the important concept is light is used as a sensor. So when it is used as a sensor, I should know, what is the property of the light, which is impinging on the model completely? The equipment that you use for visualization is called a Polariscope and you essentially use polarization optics to reveal the stress information. In fact, in your earlier courses on physics you have an introduction to what is polarization.

We have also seen very clearly from a solid mechanics point of view, photoelasticity basically provides the information of sigma 1 minus sigma 2 contours. They are called Isochromatics. You also get orientation of principal stress direction at a point and also the entire model. So, at a point you will get sigma 1 minus sigma 2 as well as principal stress direction and being a whole field technique you get this information on the entire model.

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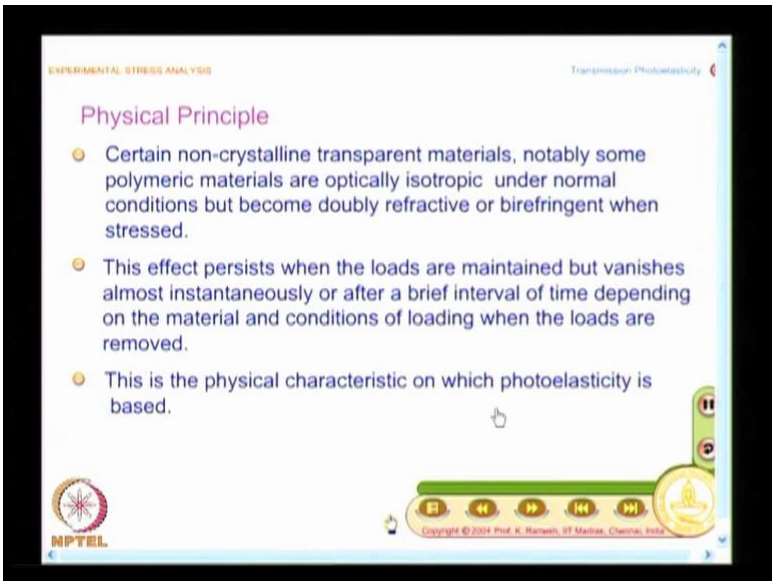

What is the physics behind this? The physics behind this is certain non-crystalline transparent materials, notably some polymeric materials or optically isotropic under normal conditions but become doubly refractive or birefringent when stressed and this is a key concept. So when you go to photoelasticity concept of birefringence is very important, and birefringence you do not have an understanding earlier because even in your earlier courses in physics they might have had only a passing reference and you have to understand what is birefringence for you to appreciate photoelasticity.

How the birefringence is caused? It is caused because of the stresses that you induce on the model. So when you analyze a polarization behavior of this, you will be in a position to go back and find out what cause this change and hence you find out the stresses that has caused this behavior of birefringence. Birefringence in turn alters the polarization behavior of the light that passes through because the model behaves like a crystal.

So, this effect persists when the loads are maintained but vanishes almost instantaneously or after a brief interval of time depending on the material and conditions of loading. So, you see the birefringence under normal conditions they are isotropic, but they become doubly refractive when stressed. How long this effect persists? As long as the loads are maintained but later on we will also see a very special process where you could freeze this stress information by a thermal cycling process that is different, that is very special that has come about with material development. But when you want to do it under live load condition, what you will have to look at is, the effect persist as long as the loads are maintained and after brief interval of time depending on the material and conditions of loading when the loads are removed you do not see this effect. This is a physical characteristic on which photoelasticity is based. And when was this identified?

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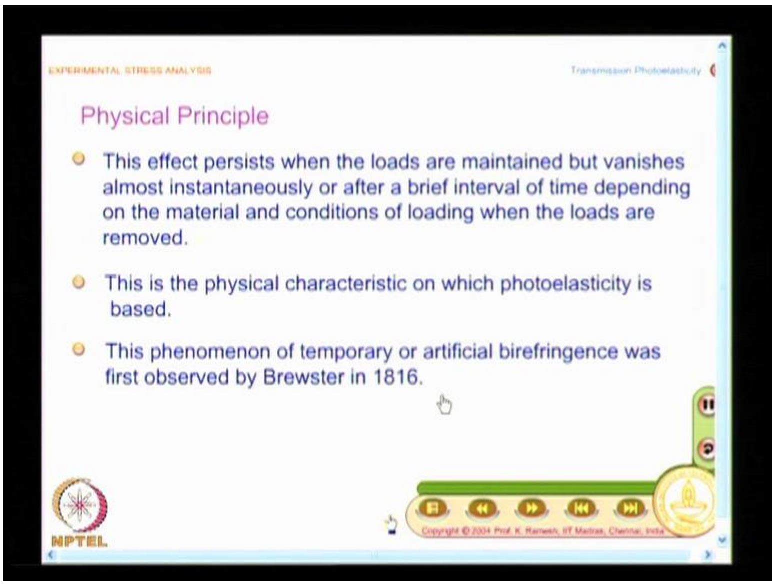

It was identified way back in 1816 by Brewster. As physical phenomena, this was identified by Brewster in 1816, but it took a long time for you to become a mature experimental technique. The moment you come to photoelasticity light is important, polarization optics is important, and you need to know, what is birefringence? So what we will now see is, quickly look at what is birefringence, what does that term means by birefringence, and then come back and then see the development how photoelasticity is being using this concept.

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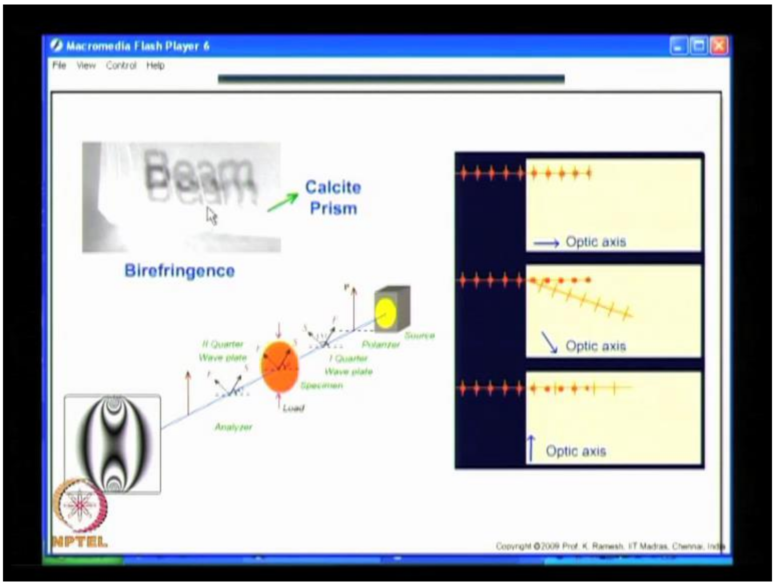

So, what I have here is?

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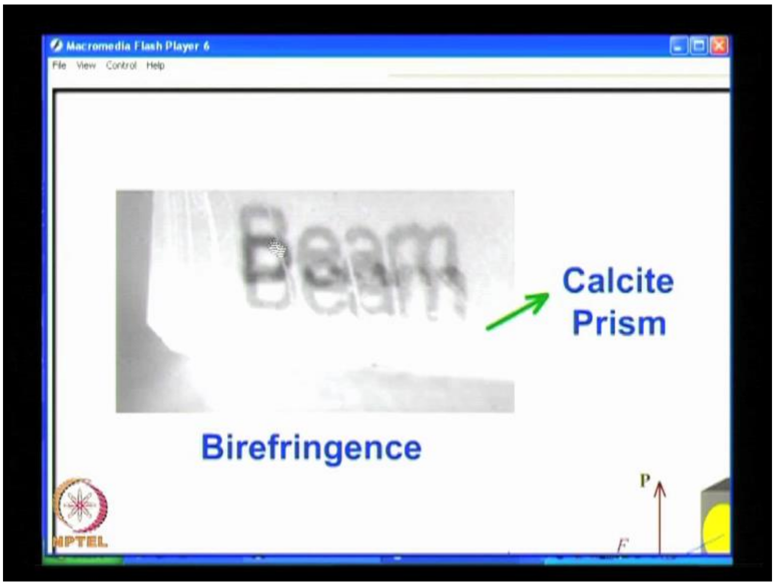

I have a letter beam written.

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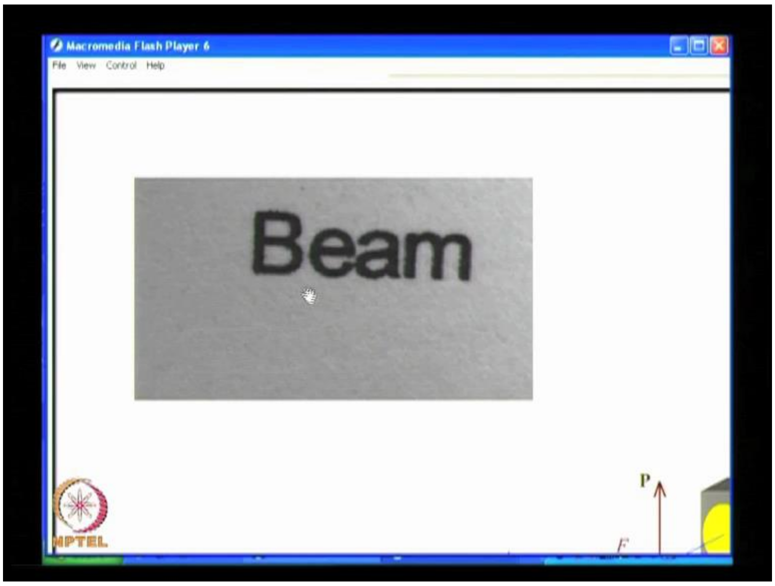

And the moment I put a calcite prism, I see this letters as two, I see a beam, I say a beam on the bottom. Just see this the moment I put a calcite prism, you see 2 images. Normally you are used to see in only one image in your simple lab experiment finding out the refractive index of a glass slab, that you most of you would have done in your physics course. There you would have put pins and then you would have identified the refracted ray by putting another set of pins, and then you find out from your Snell's law, find out the refractive index that is what you would have done.

Here, what you find? I place a crystal; calcite is a crystal when I place a crystal the word beam is seen twice. And this is because the crystal has the property of birefringence even without the application of load. The difference in photoelasticity is the model when it is trust it is starts behaving like a crystal, so if I have to find out from optics point of view how the changes are related to stresses I need to know what happens in a crystal.

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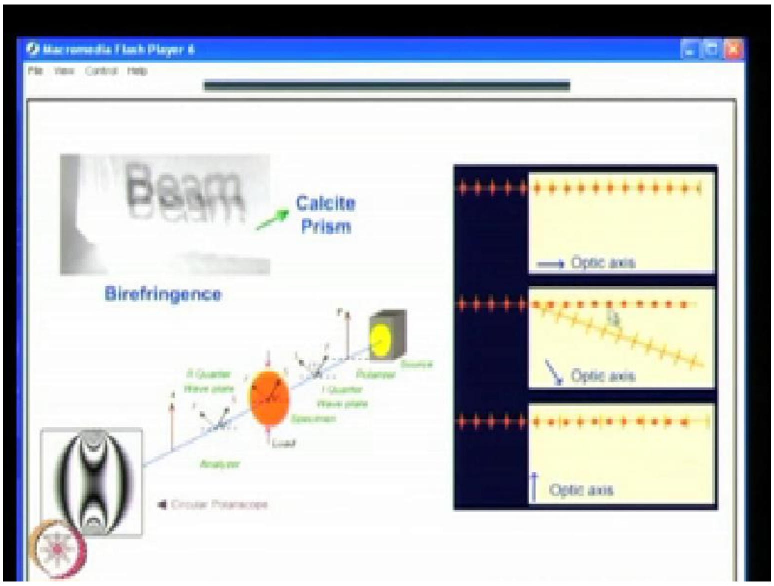

What you have here is the full slide shows something which is very important I have a light impinging on a crystal for different orientation of optic axis. How does this light behave? It is very, very important, if you understand this slide the whole of photoelasticity is understood. This shows a polariscope which is used for measuring the stresses. In this case it shows the circle polariscope where I have a dark field as well as less bright field.

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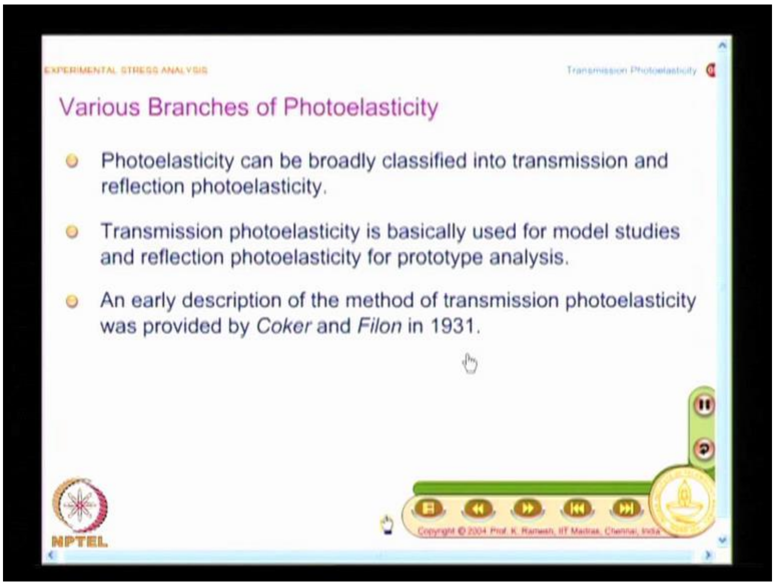

Let us have a brief look at, what are the various branches of photoelasticity? Photoelasticity can be broadly classified into transmission and reflection photoelasticity. This we have seen and we will also see some of the other classifications within it. In any technique you need to know at least briefly what was the history of development, who has contributed what and also some time line also you need to know. And all that we will look at now. What you find is? One of the early descriptions on the method of photoelasticity was provided by Coker and Filon in 1931, they had celebrated book. Imagine 1816 the physics was identified, and as a practice it came up in 1931. We have seen repeatedly the transmission photoelasticity is basically used for model studies, and reflection photoelasticity for prototype analysis. So, it took almost more than 100 years for the technique to develop. It takes that much time, because you need technology also to help you in doing this.

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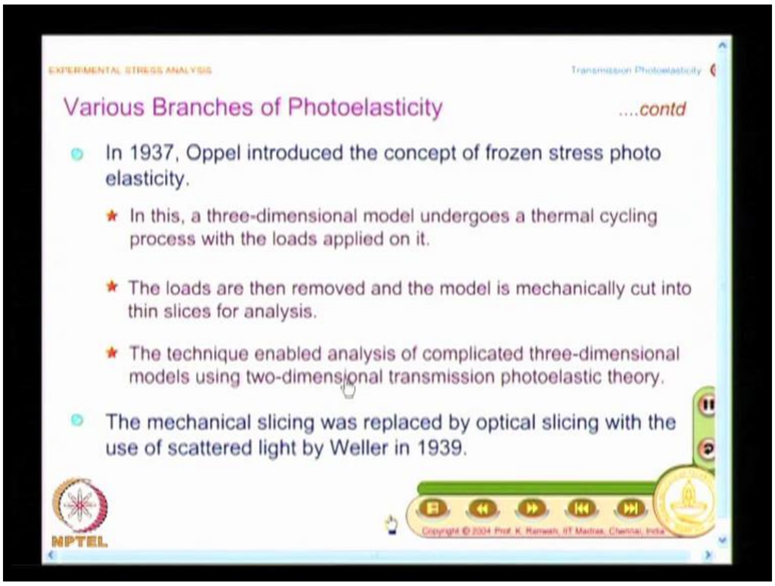

And you have another development which is very significant was introduced in 1937 by Oppel in Germany. What he introduced? He introduced the concept of frozen stress photoelasticity, and this was definitely a boom. See what you find is many of the three-dimensional problems in 1930s when they wanted to establish the design practices they need to find out the stresses developed on three-dimensional components, and the concept of frozen stress photoelasticity has help in analyzing models. And what you have here, the model undergoes a thermal cycling with the loads applied on it.

This thermal cycling helps to freeze the stress within the model that is a first step. You freeze the stresses within the model and it is only a thermal cycling, it is not a freezing operation. The advantage you have in analysis is, the loads are then removed and the model is mechanically cut into thin slices for analysis. Here again, you have to slice it very carefully so that you do not introduce thermal stresses. And whatever the two-dimensional photoelasticity you develop, you can use two-dimensional photo elastic theory for analyzing complicated three-dimensional models. So what you have here is, the model is stress frozen mechanically sliced and analyzed by employing two-dimensional concepts. And that really gave a boost

And what you need to look at is, see whenever you find there is a development there is a parallel criticism about it when you are doing a mechanical slicing in those regions where you slice at you lose some material. So, people thought that why not I improve this process, so this initiated people to come out with what you have is the mechanical slicing was replaced by optical slicing with the use of scattered light by Weller in 1939. So, you have another branch of photoelasticity called scatter light photoelasticity came into existence. This is our research proceeds. You find in the development there is a problem and that issue is researched by people then people find out newer technique for even doing the experiment.

In scatter light photoelasticity you basically use laser elimination; you do not use a normal monochromatic light source in scatter light photoelasticity. You need to go in for laser elimination. Where as normal photoelasticity is done by your mercury or clamp or sodium vapor lamp which are all essentially monochromatic light source, you do not use a laser source for a normal photo elastic experimentation in fact it is not convenient.

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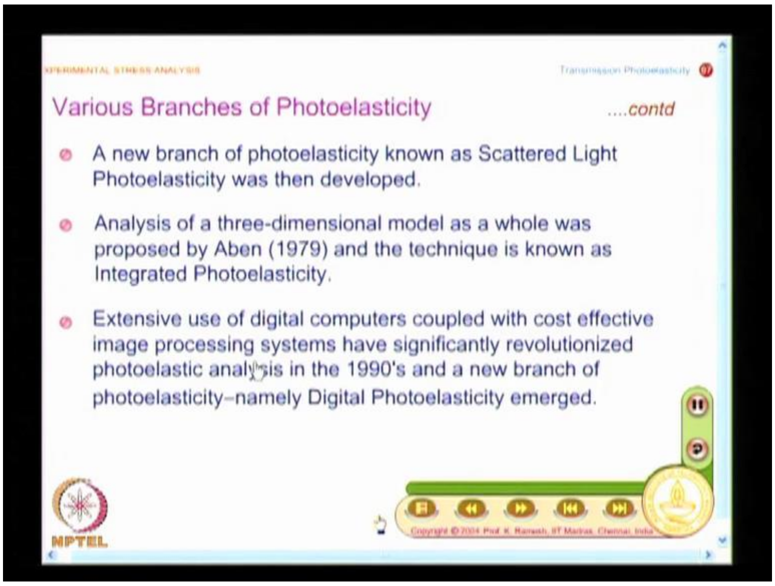

Then what you have, you also have other developments. Three-dimensional model as a whole was proposed by Aben in 1979. See, whatever you do you have to pay a price, the technique is known as integrated photoelasticity. When I want to analyze the model as a whole, I have to pay my price in mathematics. When I do stress freezing and slicing I have to pay a price in terms of more of experimentation, where I have to go a mechanically slice it, but analysis becomes two-dimensional.

When you want to remove that restriction analysis becomes mathematically challenging. So what you have for three dimensional photoelasticity, you can go for Scattered Light Photoelasticity, you can go for Integrated Photoelasticity or the conventional stress freezing and slicing. What happened parallel when all this developments were taking place let us also extensive use of digital computers coupled with cost effective image processing system have also been developed. So this has revolutionized photo elastic analysis in the 1990's and a new branch of photoelasticity name Digital Photoelastacity emerged.

So what you have here is, people have replaced human eye with an electronic eye, newer methods of processing data came into existence, and you have that branch of photoelasticity named as digital photoelasticity. In fact, these concepts could be applied to all branches of photoelasticity. We have seen transmission photoelasticity, reflection photoelasticity, scatter light photoelasticity. There are also other branches you have photo plasticity, you have photo orthotropic elasticity, you have dynamic photoelasticity, too many variants. But, if you understand transmission photoelasticity, the same concepts could be extended and that is why we focus on transmission photoelasticity and reflection photoelasticity. Transmission is meant for model studies and reflection is meant for prototype in general. Whereas, I can apply transmission photoelasticity and glass so it becomes prototype analysis itself, because glass is photo elastically sensitive.

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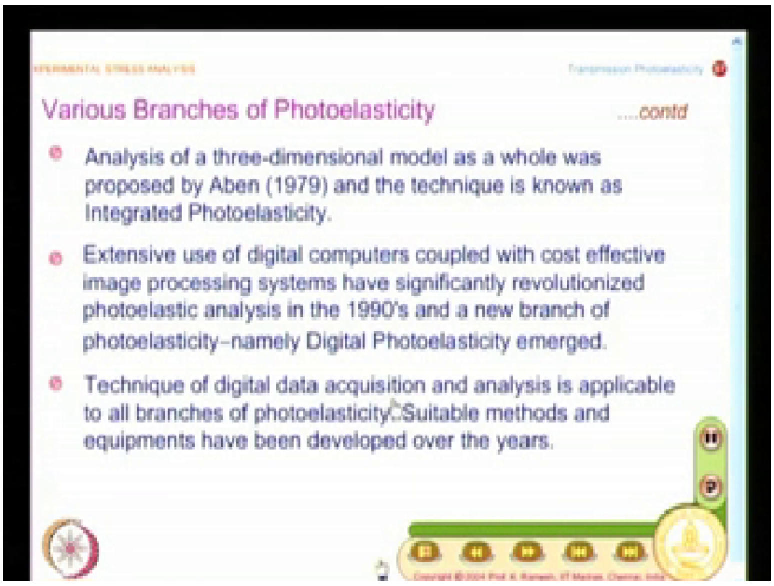

And this is what you have technique of digital data acquisition and analysis is applicable to all branches of photoelasticity. Suitable methods and equipments have been developed over the years. So, digital photoelasticity is a generic term which implies that you use digital computers for data acquisition and processing.. But as such it is applicable to all branches of photoelasticity. Now, let us look at an aluminum disc and also a polyurethane disc.

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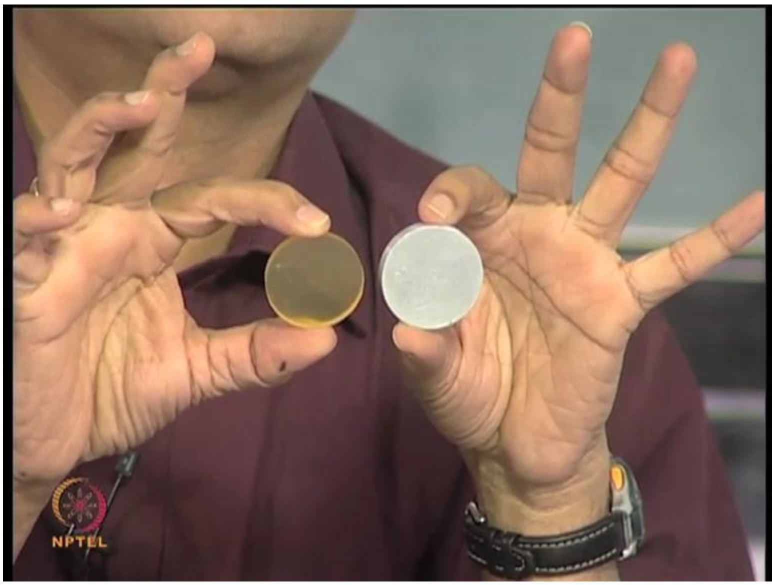

I said polyurethane is a one of the photo elastic model material. Then imagine that I apply a same load; I said what is the nature of the stresses developed. Because polyurethane is a plastic which as low young's modulus, you can visually see the deformation. Aluminum is so strong it has over 70 gpa and this is about a 0.3 gpa, it is very, very small a value. So the deformation is definitely different. There is no two opinions about that. The question I asked was, for the same load and for the same size how the stresses would be? It is a plane problem. Have you brushed your solid mechanics and found out what you anticipate.

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Stress will be same. I am happy to hear that. That is a very key point, without which there cannot be any photoelasticity. In planar problems, the stresses are same; it is very, very advantage. Now let us look at the expression.

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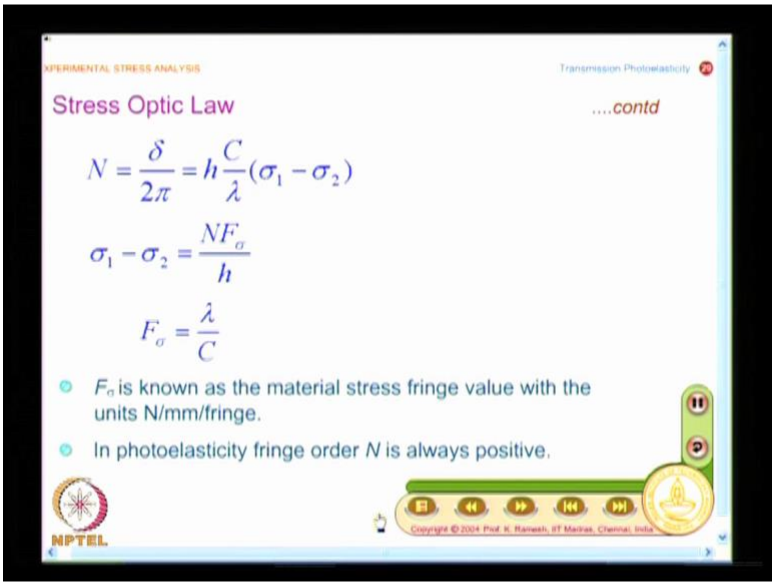

What you have here is a Stress Optic Law. This law relates stress and optics and it is called as Stress Optic Law. See, if I have to use this expression, my interest is to find out sigma 1 minus sigma 2 that is very clear. From the experiment I will have to find out what is the fringe order and depending on the material that I use, if you look at a photoelasticity for class demonstration we bring in polyurethane, and then you have polycarbonate, you have epoxy, you have prospects, you have even glass they are all photo elastic material. And even the recently introduced stereo-lithography resin, they are all photoelastically sensitive material.

We use this for certain purposes, in class it is easy for me to apply the load and then show the generation of fringes very conveniently. When I do an experiment I want certain amount of stability, I do not want model to deform and introduce large deformation, when I introduce large deformation the whole analysis become different. So I want to minimize deformation so that is one reason why I choose different material.

There is also another reason, availability. Then you have what is called time edge effect, we will see all those issues later. The essence here is there will be chances for you to use models of different material for each of this material I need to find out the material stress fringe value. Now the question is, by looking at this expression for a given problem I change the material, what would happen to the fringes? We have just now seen I take aluminum disc or a polyurethane disc for the same load applied, stresses do not vary. Instead of aluminum disc I am going to have (Refer Time: 19:01) disc or a polycarbonate disc or (Refer Time: 19:05) disc and so on. In such a scenario what happens, sigma 1 minus sigma 2 will not change at a point of interest. So this product will change appropriately.

If I have F sigma is small, I will have more fringes. If I have F sigma is high, I will have rest fringes, this product will remain a constant. If you look at the kind of problems that can be coined the arithmetic is very, very simple, if you understand the physics behind it. If you anticipate that this is how it has to choose the left hand side here, it is a left hand side sigma 1 minus sigma 2, it does not change and only the right hand side changes, so they will adjust. So you will see more fringes less fringes. More fringes less fringes is not the indication of the values you need to know the material parameter, only when I know that I can evaluate the stresses. And also this is very important, if I find out this parameter inaccurately then, all my match between experiment, and if I want do the comparison whatever I do from the experiment and analytical methods they will not match if I measure this quantity carelessly. I have to do sufficient care in finding out.

From photoelastic point of view we will have to find out how to get the fringe order N. I caution to even several classes back, that in all optical techniques finding out the fringe order is tricky, you do not get it in the first go, you have to use auxiliary methods, you will have to develop engineering equipment, you have to verify from various methods of finding out and then another question is you find only fringe order and the fringes, you do not find out in between fringes, so you have to use compensation techniques. So finding out fringe order is an issue. If I have to find out the stresses I have to know the fringe order N and material parameter.

Let us have a look at what is it photoelasticity can give. See I said photoelasticity can give you directly only fringe order and the principal stress direction. How it is going to give? How we have to do? We have to look at the optical arrangement understand and then go about it. But even before get in to the details we can now find out from our strength of materials knowledge, can I extract what information if I know these two quantities that could be of interest. Because even before we want to do experiment on photoelasticity you can be assured what I can get as information from stress analysis point of view to an extent possible. So that is what we will see in the next slide.

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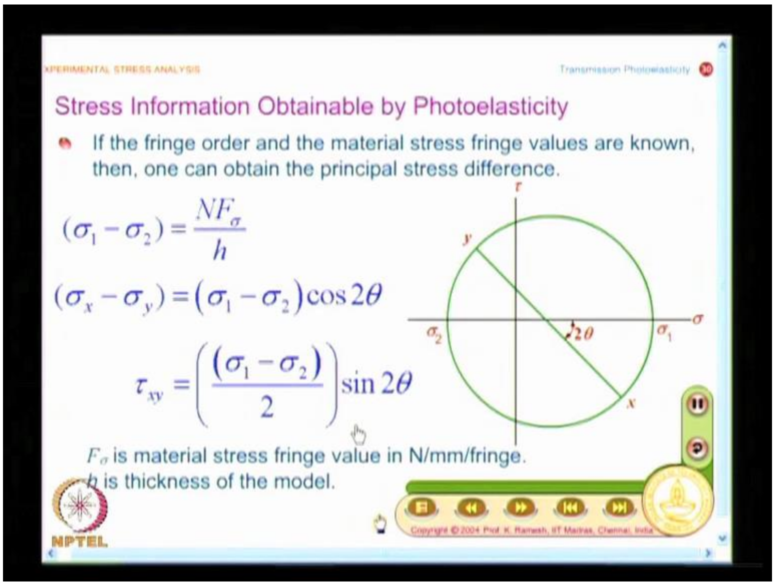

So, what is the stress information obtainable by photoelasticity? Here, for this discussion we assume at a point of interest you know the fringe order, we have not at looked at the fringes how to find out the fringe order, what is the optical arrangement? All that we will take it up later. Suppose, I know the fringe order, I know the material stress fringe value, and I also find out theta what I can do. So, I will go to the more circle and look at what it is, and take an advantage from your knowledge of; it is not new, it is all we build on your understanding of solid mechanics strength of materials.

The foundations have to be strong that is why we had a review on solid mechanics, you should know about more circle, you should know that stresses a tensor, and more circle represents this beautifully. And what I have here? I have sigma 1 minus sigma 2 is given as NF sigma by h, and if I know the more circle I can easily write sigma x minus sigma y equal to sigma 1 minus sigma 2 into cos 2 theta.

Now, you all know more circle you draw in the sigma and tau plane, I draw a circle and each point denotes a plane and here it is a x-plane and this is y-plane, and in more circle all these angles are twice the angles that is why they are at 90 degrees it is shown at 180 degrees. When I have so many points on the boundary it shows all the possible infinite planes, you can find out, what is the normal shear stress? Absolutely no problem, so that is why it is a beautiful presentation. I do not know whether you looked at more circle from this point of view. When I said all the possible state of stress in all the infinite planes when I have a point of interest that is what you understand a stress tensor and a beautiful graphical representation is more circle.

So, on the more circle every point on the circle denotes a particular plane. And using this you can also find out what is the principal stress plane? What is the magnitude of a sigma 1? And what is the magnitude of sigma 2? And simple geometry will help you to find out what is difference in normal stresses and also the shear stress. What is the value of shear stress? You all know it. It is simply sigma 1 minus sigma 2 divide by 2 into sin 2 theta. So what you find is, from photo elastic analysis, a simple normal incidence can give you fringe order again and theta at a point of interest. If I know the material stress fringe value of the model material then I can go use more circle, find out normal stress difference as well as in-plane shear stress.