Experimental Stress Analysis
Prof. K. Ramesh
Department of Applied Mechanics
Indian Institute of Technology – Madras

Lecture – 23
Introduction to Photoelastic Coatings

See, we have looked at transmission photo elasticity elaborately, then we also had an idea of how photoelasticity can be applied for 3 dimensional problems, then we moved on and looked at what way we can use digital image processing techniques to automate photoelastic analysis. Now, we take up the industrial application of photoelasticity that has become a success with the advancements in photo elastic coatings.

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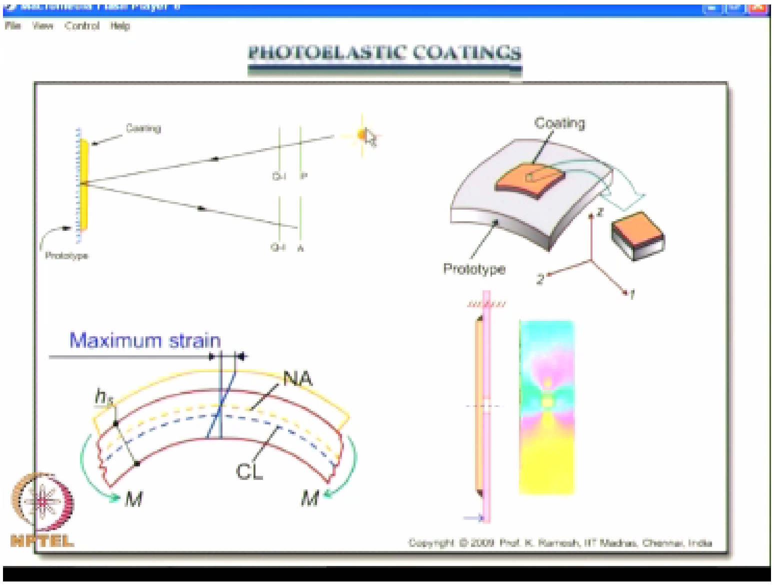

And what you have here is; I have the basic optical arrangement that is used and once you come to photo elastic coatings, you know you need to make idealizations on how do you translate the results seen on a coating to the specimen and one of the important factors there is to consider what are known as correction factors, which will improve your prediction of the results and this shows an example of how the fringe patterns appear in photo elastic coating.

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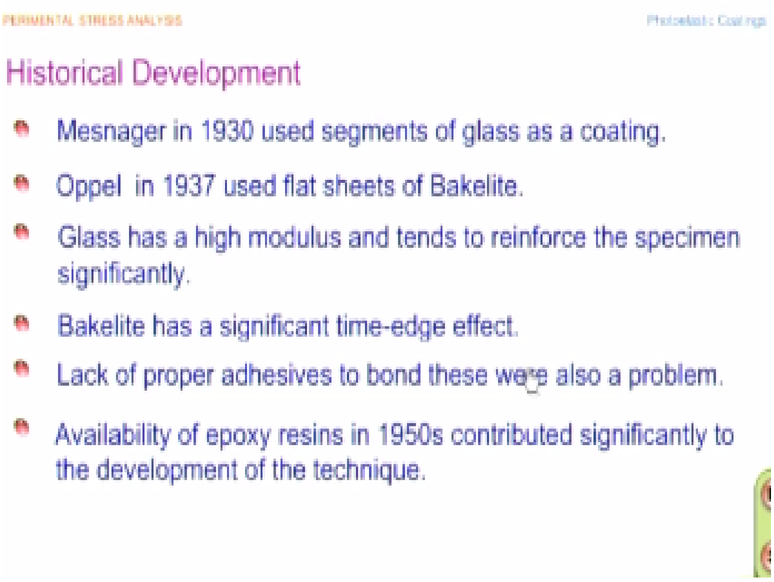

And this also shows on a specimen I have a birefringent coating pasted onto it and if you look at any of the techniques, we need to look at history behind it and what you have as historical development, we have Mesnager in 1930 used segments of glass as a coating, it is very surprising, you know we have looked at in photo elastic materials that glass is also a photo elastic material.

And it has a Young's modulus of 70 GPA equivalent to aluminium, whereas all other plastics we had only 3 GPA and because this has a very high value of Young's; modulus one of the problems with glass was that it reinforces the specimen significantly and after glass, what they tried? Oppel in 1937 used flash sheets of Bakelite, so when we graduate from transmission photoelasticity to photo elastic coating, initially people concentrated only on flat surfaces.

So, they initially use glass, which was found to reinforce the specimen significantly. The problem with Bakelite was, it has a significant time edge effect and we have already seen in transmission photoelasticity because of time edge effect, you have spurious fringes that are formed. So, you do not want spurious fringes, so Bakelite was also not a suitable material when you want to go in for photo elastic coatings.

And I said, any development in science on engineering was always tagged on to developments in material science. So, what you find was availability of epoxy resins in 1950s contributed significantly to the development of the technique, so it is a material research which has helped in advancement of photo elastic coatings. This has multiple names; you can call it as photo elastic coating, you can call it as a birefringent coating based on what is the kind of material that you use.

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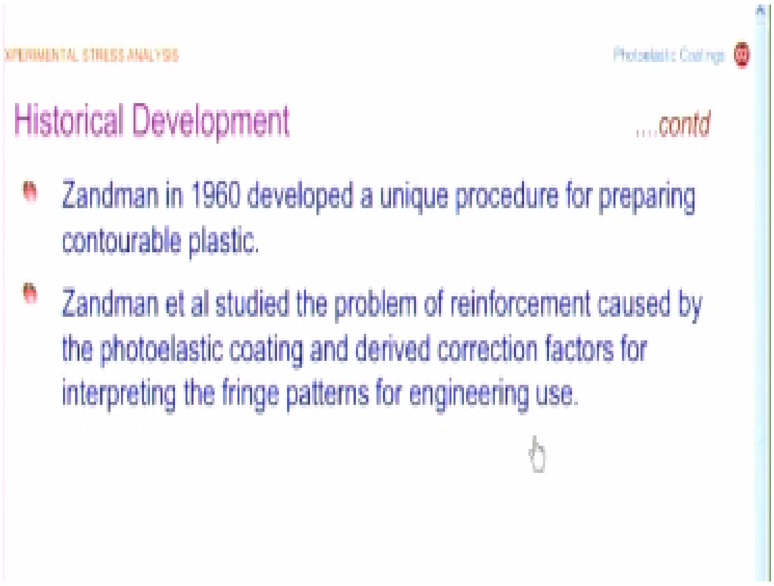

And because you see the reflected light, this is also termed as reflection photoelasticity and the other difficulty was lack of proper adhesives to bond these coating were also a problem. So, the development of the technique hinges on development of proper adhesives and also development of epoxy resins. Initially, many of these applications were confined to flat surfaces, later it was shown by Zandman, who developed in 1960.

A unique procedure for preparing contourable plastic; see, if you look at any of the industrial component, you have a very complicated surface and if I have to put a coating on top of it, I must be able to make the contour of the actual object. So, in a contourable plastic, the technology is; you cast a sheet and when it is in a gel state, you take it out from the casting pan and then put it on the actual prototype.

And then, allow it to take the shape of the actual object and in this process, no stresses are introduced because the plastic; whatever the polymer that we use is in a gel state, it easily forms the contour of the actual object. After it is cured about 24 hours, you get as a shell and the shells are pasted on the actual object and do the experiment. So, this was a very significant development, whatever Zandman has introduced.

And this is a very famous contourable plastic and now you have whatever, the sheet in gel state is put with proper icing and then you have such gel sheets available, you directly buy the sheet from them, take it off from the cold storage and contour it, you do not even have to cast it and then wait for whether it has reach a gel set or not, all that your steps are simplify, you have those sheets available but it is expensive.

In abroad it is available, in India still not come, so if you want to take photoelasticity to solve industrial problems, photoelastic coating paved the way and particularly contourable plastic has made this technique very attractive and the moment you come to any of the coating techniques, you will also have to study the problem of reinforcement, whether it is significant or not, we will have to find it out; caused by the; in this case photoelastic coating.

And Zandman provided correction factors for interpreting the fringe patterns for engineering use and this applies to all the coating techniques. Suppose, even if you look at a strain gauge, it can reinforce when the specimen size is comparable to the size of the strain gauge. I said in the case of electronic packaging, I cannot go and paste a strain gauge on the leg of those IC chips because the sizes are comparable.

On the other hand, an optical technique would definitely help in such situations. In the case of photo elastic coating, if I use glass, it has a very high Young's modulus and it is definitely going to reinforce, so people dropped glass and now moved on to epoxy. Nevertheless, you know when you are having a coating; if the coating is thin enough, then we do not have to worry about. In photoelastic coatings, coating thickness of 3 milli meters are not uncommon.

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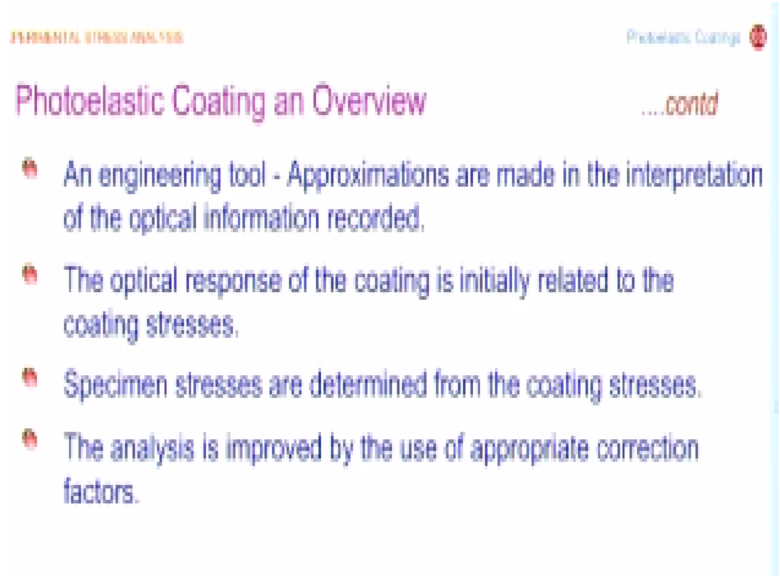

So, you are really talking about sufficient thickness, so that you have to keep in mind and you have to appreciate that this is an engineering tool and I have said engineering means approximations and approximations are made in the interpretation of the optical information recorded. We say that we want normal incidence in photoelasticity and you would find because of industrial application even that is compromised to some extent.

And what do you do? First, you get the optical information; the optical response of the coating is initially related to the coating stresses, so that is what you find out. Well, all the theory that we have developed in transmission photoelasticity are equally applicable in photo elastic coating with slight modifications and those modification, you can easily figure it out. So, the focus what we are going to do is you will not spend much time on the optical aspect.

We will spend much time on the mechanic's aspect, we will initially look at how the optics information is translated but we will essentially look at; how do you find out the coating stresses. From coating stresses, how do you find out the specimen stresses, what kind of approximations are needed in this kind of analysis that is would be the focus and in engineering, when you are actually making certain approximations, you always bring in a correction factor.

So, that is why it is an engineering tool that is why he said, Zandman contributed contourable plastic as well as a methodology to develop correction factors, which take into account the thickness of the coating and also it is possible reinforcement effect. Then, what you have? The specimen stresses are determined from the coating stresses and as I mentioned earlier, the analysis is improved by the use of appropriate correction factors.

See in transmission photoelasticity, we never even talked about correction factors, the marriage between physics and engineering so good in transmission photoelasticity, there is no need for correction factors but in reflection photoelasticity even for calibration, you need to bring in the correction factor. If you do not bring in the correction factor, your evaluation of the calibration constant itself can be erroneous.

So, right from the optical arrangement even to calibration and even if you want to find out the stress concentration factor, you have to do it very carefully in reflection photoelasticity. In transmission photoelasticity, you just find out the maximum fringe order on the horizontal diameter and find out the average fringe order, you take the ratio, your job is done and I have said in all the coating techniques, Poisson's ratio place its spoil sport.

So, you have to accommodate the role of mismatch of Poisson ratio in photoelastic coating systematically, so that you will see even in the evaluation of the stress concentration factor. So, you will always have to look at, it is an engineering tool, you make approximations because you make approximations, you improve your results by employing appropriate correction factors. This is engineering you know, engineering always we do like that.

We do not give up say, if I am unable to solve the problem in all its totality, I do not give up, I at least bring in correction factors and make my result as acceptable as possible because in design, people want results with 50% accuracy that is good enough because they always have a factor of safety, they have such factors which accounts for deficiency in the analysis. Only, when people develop some finite element code, they really talk of 0.1% accuracy, 0.01 % accuracy.

Experimentalist do not operate that way; + or – 2% most cases people accept 5%, 10%, and even 50% are alone at least, we know I am closer 50% to the result because the problem is what you handle are very complex, even a very little information which is available with certain level of confidence can always go into your design calculations and we will see what kind of approximations are made in photoelastic coatings.

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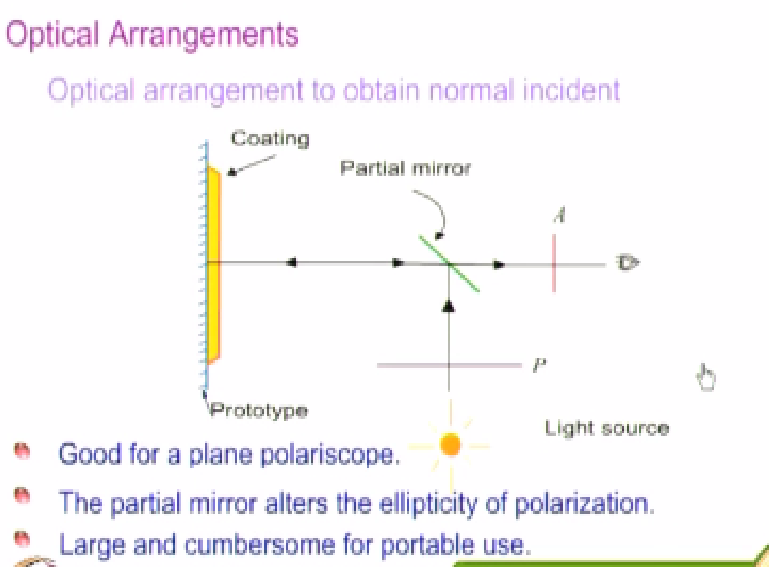

We will also look at the basic optical arrangements and just observe the animation. So, what I have here is I have the prototype here that is shown with a hash the line; hatched line and I have the coating that is pasted onto this and in transmission photoelasticity, we always wanted a normal incidence. Suppose, I want to have a normal incidence, the possible optical arrangement could have a partial mirror here.

So, that the light passes through the polarizer and then part of it goes and hits on the model and whatever the light reflected that comes out and reaches your eye through the analyser and what strikes you first? See, we will look at in the case of transmission photoelasticity, thickness of the model is a key parameter, then we modified it when we moved on to 3 dimensional photoelasticity, we looked at as length of the light paths.

Because depending on the size of the 3 dimensional models and the angle of incidence, I may have different lengths; the length is the one, which is going to determine the retardation seen in that light path. So, if you look at what can immediately guess, when I have a reflection arrangement like this, very simple. Suppose, I have thickness of the coating as HC because light goes in and comes out all those equations are equally valid if I replace thickness by 2HC.

Because the light actually travels twice the thickness of the coating, so you get how transmission photoelastic equations could be translated into reflection photoelasticity. Though this optical arrangement is good enough for a plane polariscope, the use of a partial mirror affects the ellipticity of polarization, when I use it for a circular polariscope and not only this, an arrangement of this nature is large and cumbersome for portable use.

If you really want to have normal incidence in reflection arrangement, you cannot avoid a partial mirror and partial mirror is good enough for a plane polarized light but in a general elliptical polarization, it interferes to some extent on the state of polarization, this is one defect. The other defect is an arrangement like this is bulky; it is not efficient for you to carry it around and set it up in an industry environment.

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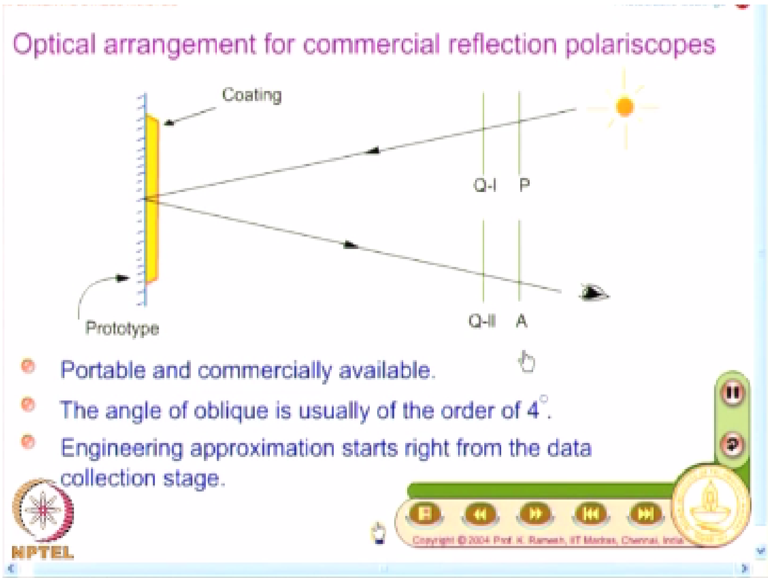

So, what is the kind of arrangement that they have in a commercial reflection polariscope. Observe the animation again, so what i have here is; I have to send the ray of light to the model and I have to analyse only the reflected light and what I can do this is; I have to do this at an angle for me, this is a reflected light. The way, I can improve my technique is keep this light source and your observation far away from the model.

So, it is about at least 2 meters is what is recommended, when you have that kind of distance, you know this angle of oblique can be as small as possible, you do not want to have compromised fully on normal incidence, you do not want to impinge the light at 45 degrees, you do not want to do it that way, you want to have a shallow angle of oblique and in order to achieve that you view the model from a distance.

So, in the case of reflection photoelasticity, now you know people replays human eye with a camera, so they use telephoto lens, which will focus objects at a distance very conveniently and by keeping the optical elements away from the model, you reduce the angle of oblique and this is of the order of about 4 degrees. The angle of oblique is usually of the order of 4 degrees and what you find here?

Engineering approximations starts right from the data collection stage and this set of optical elements can be put in a very convenient form and you can even hold it on the hand and you just need the light source and view the model and you already know this P denotes polarizer, when I say Q1, it denotes the quarter wave plate 1 and you have the quarter wave plate 2 and you have the analyser.

So, in order to maintain the angle of oblique as small as possible, you keep your optical elements at least about 2 meters from the specimen surface because if I get it very close, then the angle of oblique will increase. So, I would like to have it as small as possible and this is the optical arrangement of commercial reflection polariscopes, many reflection polariscopes are available and there again, you can employ digital photoelastic analysis.

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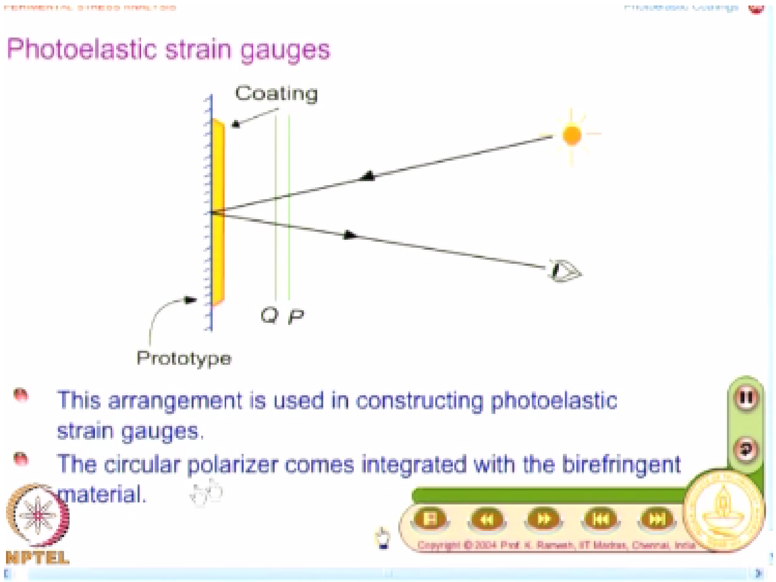

And one of the outcome of this kind of approach is also what are known as photo elastic strain gauges. What they have done is along with the coating, you will have the quarter wave plate and polarizer integrated with it, you know these were developed in Germany, like you have electrical resistance strain gauges; you will have a small strip of plastic with its own quarter wave plate and polarizer embedded.

And pasted it on the model and do it in normal white light, you will see fringes, when the model is loaded you will see fringes on the optical, it is an optical strain gauge and it was popular for some time. So, the philosophy there is they just put a quarter wave plate and polarizer integrated with the coating and you would see and you will see the isochromatics, you will not see isoclinics in this arrangement. You know, in those days when you have a uniaxial stress or biaxial stress, even that knowledge was considered important.

And people had strain gauges, photo elastic strain gauge with the hole on it and then they will find out whether it is uniaxial state of stress, biaxial state of stress, it gives you quick information because in a strain gauge, you have to connect it to an instrumentation and read the strain. Here, if there is any load applied, you will see movement of fringes, so it was very attractive.

So, the circular polarizer comes integrated with the birefringement material, so what you look at now is; you have looked at, if I want normal incidence what is the kind of optical arrangement, I should think of in deflection photoelasticity. We saw that it requires a partial mirror, we said that it is bulky and also it interferes an elliptical; ellipticity of polarization, so it is not desirable to have that.

So, we moved on to a commercial polariscope where we allowed certain angle of oblique without which you cannot see the reflected light, so you have to live with that and but what you will have to look at is what is the advantage of photo elastic coatings? The coating material is isotropic, the base material can be anything; it can be composite, it can be ceramic, it can be rubber, it can be borne, it can be aluminium, it can be steel, it can be concrete.

So, what you find here is all the so called engineering materials, you could have one technique which provided you the necessary information. So, if you look at composites, they are anisotropic in nature and if you look at that material equations are very complex to handle. On the other hand, if you have to interpret only what happens on a isotropic coating, it makes your life simple on finding out at least the surface strains on composites.

And I said in any technique, material advancement has contributed to the development, so people have developed coating from rubber to human bone because the base material controls what should be the nature of the coating because you know, if you look at composites, they actually reinforce it with fibers and one of the thumb rules as if you look at the base material, the reinforcement material should have Young's modulus ten times that of the base material.

This is a thumb rule, only then the fibers really reinforce the primary material and here we have seen when I use a glass, it is 70 GPA, which is comparable to the metal, so it is going to reinforce. On the other hand, if I have a photoelastic coating, which is just 3 milli meters, even though it is 3 milli meters, the Young's modulus is only 3 GPA, whereas the metallic this one, if aluminium at a 70 GPA and then steel, it is 200 GPA.

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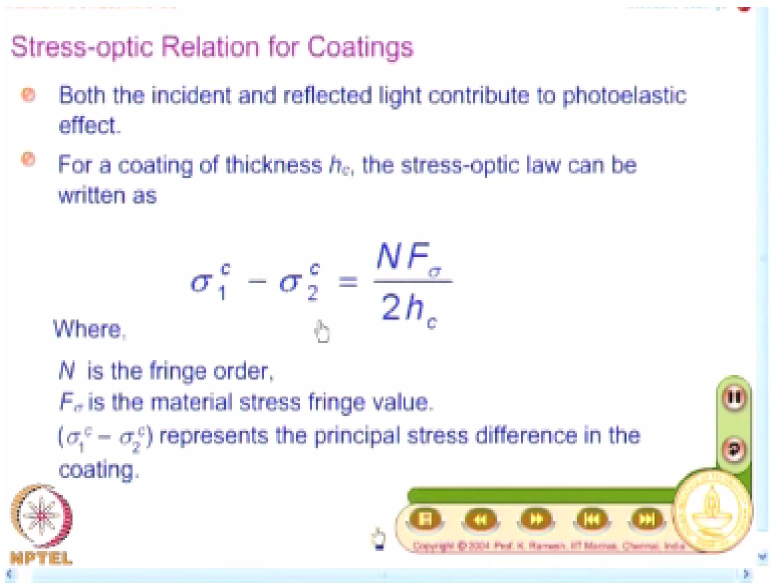

Hardly, this coating will affect but even then we have developed correction factors for other reasons. So, what you will have to look at is the greatest advantage of a coating technique, you can apply to a variety of base materials provided you have appropriate coating properties and now let us look at extrapolation of whatever we have learnt in transmission photoelasticity analysis and we look at stress optic relations for coatings.

And I have already drawn up your attention that both the incident and reflected light contribute to photo elastic effect because you are seeing the light reflected and I said for a coating of thickness hc because the material, what I use is birefringence, it behaves like a crystal when it is loaded, I can also write the stress optic law, wherein I get the coating stresses. Since, we are going to have specimen as well as coating; the symbolism used is a symbol c either at a superscript or a subscript indicates that I am dealing with the coating.

And when I want to have sigma 1 c - sigma 2 c, if I know the F Sigma of the material, then I can write this as NF sigma/ 2hc, you know for developing this equation, we took about 6 to 7 classes in transmission photoelasticity because you need to know what is retardation, how it optics related, how the refractive index is looked at as ratios of velocities, how the refractive index can be compared to stress tensor, all that we developed.

Now, we take that advantage; we take the advantage of that knowledge and we only look at both incident and reflected light contribute to the fringe formation and what you have, instead of hc, I had to put 2 hc but even this representation is not very convenient. See in the case of photo elastic coating, one of the assumptions I make is; I put a coating on the specimen, when I load the specimen, I want to perceive the adhesive is so well bonded at whatever the strain developed on the base specimen is transmitted faithfully to the coating.

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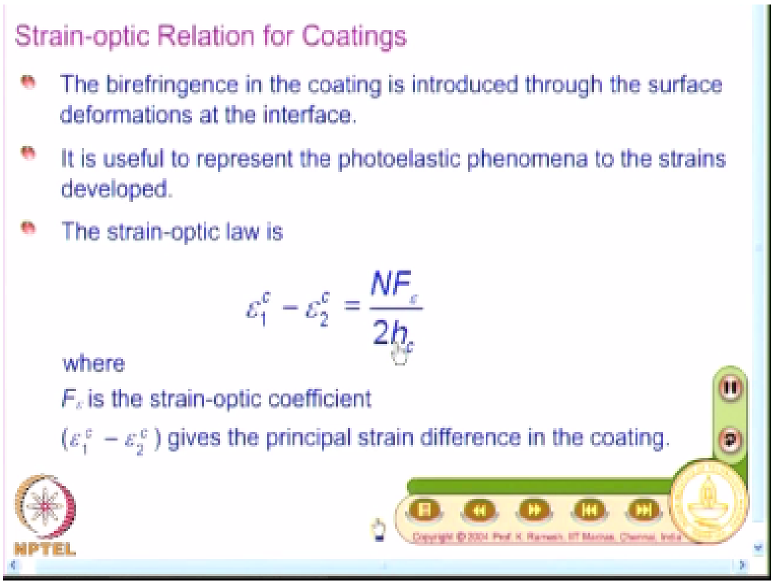

So, instead of looking at stress optic law, I should essentially look at strain optically that is more appropriate because the way the model is loaded, the way the coating is loaded is different. So, we will have to look at what is strain optic law? So, what I have here is the birefringence in the coating is introduced through the surface deformations of the interface because we said that the coating becomes temporarily birefringence, when loaded.

How the loading comes? The loading comes; it is introduced through the surface deformations of the interface. So, in view of this, it is useful to represent the photo elastic phenomena to the strains developed and you know strain is also a tensor of rank 2, so instead of having sigma 1 c - sigma 2 c, I could also think of writing it as epsilon 1c - epsilon 2c and I will also bring in a material parameter.

There we have said; you must be wondering why I was calling that as F sigma, at the time, you would not have noticed why a suffix Sigma should be attached to F, I said it is a material stress fringe value, so following the similar logic, we will have this equation with F epsilon. We will say, material strain fringe value but you have to find out what is F epsilon, that is a different story but writing the equation is now much simpler.

We follow the same logic and I write this epsilon 1c - epsilon 2c as NF epsilon/ 2 hc, the factor 2 comes because both the incident and reflected light contribute to photo elastic effect. So, we call F epsilon is a strain optic coefficient and epsilon 1c - epsilon 2c, gives the principal strain difference in the coating. See the real utility of photo elastic coating; you will see only when this equation is recast comfortably.

Because ultimately, what is it that I want. My interest is not to worry about what are the coating stresses, my interest is to find out the stresses developed on the specimen, so that is where I have to bring in mechanics of solids. How do I find out the stresses on the specimen based on coating stresses; the coating is birefringence that is why I call this as the birefringence coating. When the loads are applied, it acquires properties or the crystal behaves like a crystal.

And you have the phenomenon of birefringents and fringes get formed and there are also many other subtle issues. See if you look at transmission photoelasticity, we have never discussed how many fringes I will observe in an experiment, we never even talked about it. Depending on the load applied, you will get so many fringes, if the fringes are less, increase the load, only when we discussed 3 dimensional photoelasticity, I said I have to calculate the load very carefully.

So, that at stress freezing temperature, the model should be strong enough to withstand and also how many fringes you have to see on the slices and you have to do some calculation, as far as 2 dimensional photoelasticity is concerned, there was no discussion on how many fringes I will see but the moment you come to photo elastic coatings, we will also have to worry about how many fringes I would normally see in a photo elastic coating test.

This becomes an issue because what do you want? Many of your engineering components you do not want them to become plastic at service load conditions, you want them to remain only as elastic for various reasons because if there is a moving parts involved, it has to remain elastic for it to do its function and another important aspect what you have noticed here is, it is the strains that developed on the specimen gets translated to the coating.

So, coating is not loaded directly. See, in the case of plastic, you know if you directly load; apply the load, you are really applying because of low Young’s modulus, you will also have large strain developed and you will have many fringes seen but here only the surface strain is transmitted and surface strain in a service load condition, you want to operate much below 2000 micro strain.

Even, if you said reaches 2000 micro strain, normally the number of fringes observed in a photoelastic coating test are minimal and we are also looked at in transmission photoelasticity, most of the time we worry about monochrome light source and we have looked at the colour white light only from the point of finding out the gradient direction and white light was used as an exception in transmission photoelasticity, in conventional transmission photoelasticity.

But with the digital photoelasticity, you have 3 fringe photoelasticity, where we use colour for quantitative evaluation of data that is different. In reflection photoelasticity, because the fringes that you see normally are much less, you generally use white light very occasionally; you look at a monochrome light source you look at white light, only. So, this is one difference and we will also have a specific discussion, what is the maximum fringe order you can see for a given coating and base material combination?

It is dictated by the base material because when it yields, what way it is going to the properties; elastic properties will influence. So, the number of fringes you see are very small, so one of the caution, which I used to normally mention is I have been saying, if I have good colours, it is very interesting and motivating for you to work, photoelasticity offers that benefit but in reflection photoelasticity, if you see colours, it is a warning signal.

The specimen is heavily loaded, so you should not; you should not get enamoured by the colours, you should really take corrective measures and then improve your design, these are all like thumb rule type of thing okay, depends on various factors but you will have to keep in mind, if you do not see colours, be happy about it. If you see colours, you have to worry about it but if you do not see colours, the problem may be the coating may have got peeled off.

If you do not bond it, you know all the coating techniques you have to follow the supplier's recommendation, whoever is supplying you adhesive, he will give you a recommendation what is the surface preparation, what is the curing cycle, what is the kind of pressure applied all that you should follow faithfully. If you do not follow that faithfully, the strains of the specimen would not be transmitted to the coating.

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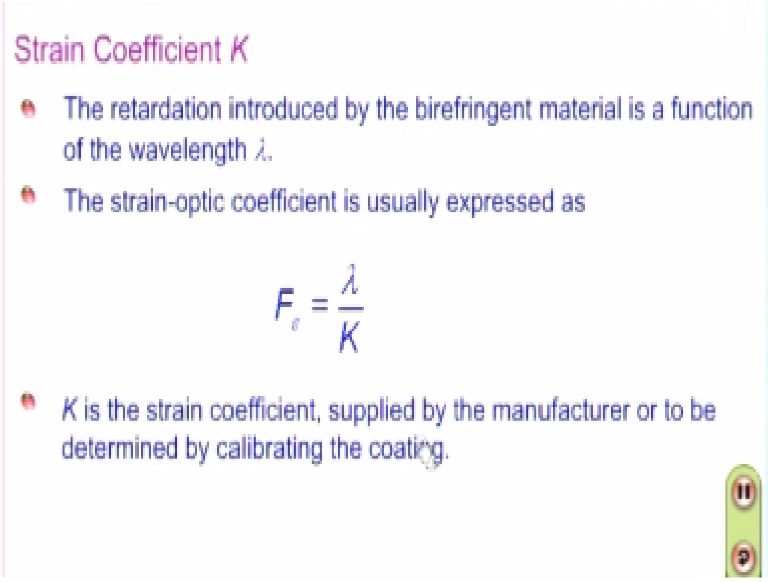

So, this is one issue, even if the strain is transmitted faithfully. the number of fringes normally observed in a photoelastic coating test are generally smaller and we also define a factor called a strain coefficient K. This is very similar to what we have seen in transmission photoelasticity. In transmission photoelasticity, you had defined F sigma as lambda/ capital C. Here it is defined as; F epsilon is defined as lambda/ K.

And you have to recognize the retardation introduced is a function of wavelength lambda, so now you have the definition of F epsilon. F epsilon is related to lambda/ K; K is a strain coefficient; it is supplied by the manufacturer or to be determined by calibrating the coating. There is also a subtle difference; in normal transmission photoelastic analysis, you do not handle capital C, you only evaluate F Sigma.

And many of your calculations, you do with F Sigma and you know I have already said that arithmetic in transmission photoelasticity is very simple, only the conceptual understanding is little involved. The same applies to refraction photoelasticity also, arithmetic is very very simple. Instead of finding out F Sigma or F epsilon, we would find out, what is K? By calibrating the coating material, you essentially find out K.

And I also said photo elastic coating can be applied from a range of material from rubber to high strength steel; rubber has a very low Young's modulus and if I have a coating material that should have much lower young's modulus, so that it does not reinforce the surface of the rubber. So, in those applications, it may be prudent to directly take a tension specimen and pull it, which is made of the coating material and find out F Sigma.

From there, you find out K ultimately, you want to have K, finally we are going to develop an expression involving sigma 1s – sigma 2s as a function of the fringe order observed and also the thickness of the coating and elastic properties of the base material will come that is will be the final expression and what you need to see here is K is much more fundamental, in the case of photo elastic coating.

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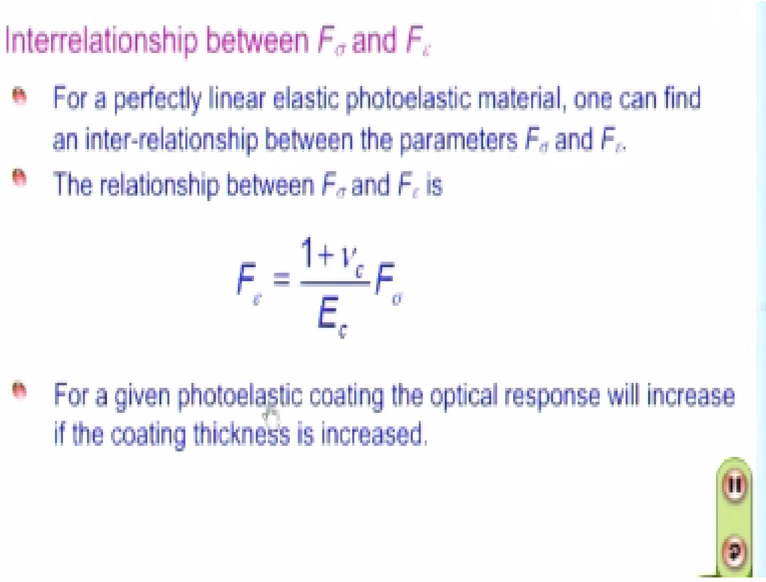

And what is the interrelationship because we all deal with isotropic material for a perfectly linear elastic, photo elastic material, one can find an interrelationship between the parameters F sigma and F epsilon, which is straightforward, it does not require any great mathematical skills. I can find out F epsilon as 1 + Nu c/ Ec * F sigma, so what it shows is; if I find out F sigma, I can find out F Epsilon, if I find out F epsilon I can find out F Sigma from this interrelationship.

And that is what I said, when I have to go and find out the calibration constant for a coating that is to be applied on rubber, finding out F epsilon may not be practical, finding out F Sigma is more practical, you take the coating material make a tension specimen and pull it, find out F sigma, find out what is the F epsilon from this interrelationship. Once I know, F epsilon, I can also reported, what is the value of K.

Because I know F epsilon = lambda / K and another basic observation is why do you want to have a thick photoelastic coating. See, I said number of fringes you generally see in a photo elastic coating test is small and if you want apply any coating, it should be as thin as possible is desirable from analysis point of view but from practical consideration point of view, I must see some fringes.

If I do not see some fringes, how do I make measurement and there are also development, see the digital imaging hardware has also influenced photoelastic coating test, what I could not perceive with human eye; I could do a very refined analysis with digital photo elastic technique, so that also says I can go for a thinner coating. If I go for thinner coating is always advantageous, my mathematics becomes very simple.

If I go for a thicker coating, I do not give up but I bring in correction factors that is how engineers operate; correction factors are part and parcel of reflection photoelasticity, even for simple calculations, you have to bring in correction factors but it is an engineering tool and has been solved for a variety of problems, assembly stresses. See, you must have seen in several towns, they now put this central lighting.

You have a huge pole that is put and you have a lamp on top of it and if you go and look at how this lamp post is clamped to the ground, you have thick bolts and that had assembly stresses problem and this was sorted out by performing a photoelastic coating test. Now, it is a well proven design but when the initial design was developed by tightening those bolts, you had developed assembly stresses.

And eventually, the failure of that pole was because of stresses introduced during assembly. See, assembly stresses how do you model analytically, you cannot model it easily, it is so difficult and photoelastic coating came to the rescue and another instance, where photo elastic came to the rescue was in the analysis of rudder of a conquered aircraft. The rudder was failing repeatedly and what they found was they had done a finite element analysis.

They had also done a strain gauge analysis, the design was based on strain gauge analysis but still the rudder kept failing and strain gauge is a point by point technique, then people decided why not apply a photoelastic coating on the rudder, when they took the measurement, they found the location of the strain gauge was slightly away from the maximum stresses zone. So, it was only reporting 75% of the stresses.

So, you had an error in strain gauge value because it is shifted away from the main point of interest with photoelastic coating being a whole field technique, they could use that information and redesign the rudder, then it had a fairly a good life. So, if you look at photo elastic coating, it is a very industry friendly technique, like I said it is only a tool you should know how to employ the tool correctly.

So, for those assembly stress problem, what you have as light poles, photoelastic coating help and many engineering applications you find, so you want to have sufficient optical response in a photoelastic coating test. If the coating thickness is increased, you get sufficient optical response but when the coating thickness increases, interpretation becomes difficult, so you have to have a trade-off, you have to have a compromise.

So, that is part and parcel of engineering and you will see in the correction factors, what we will find out is they will say that you put a coating of reasonable thickness or the material or the specimen, find out pockets of stress concentration, then peel of this coating and put a thinnest coating possible because in a stress concentration, I already have sufficient stresses to develop, sufficient number of fringes.

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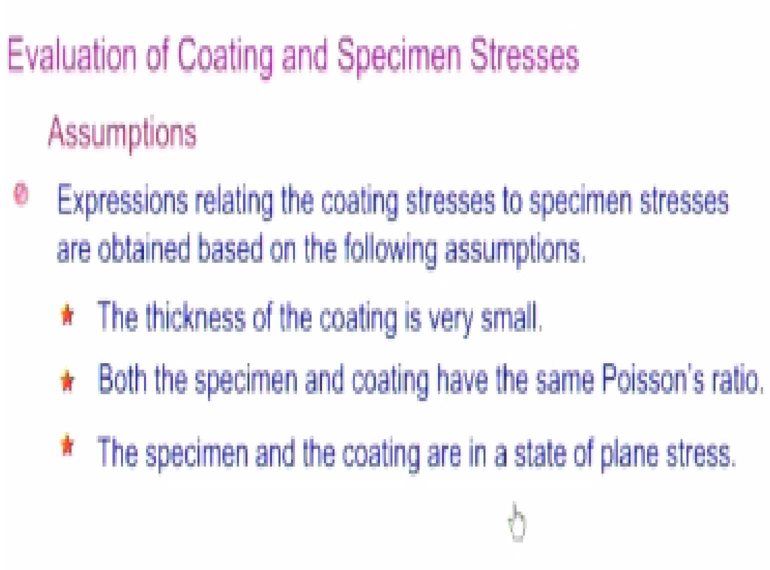

So, this is how they have handled the problem from engineering sense; coating thickness is a nuisance but without coating thickness, I cannot see the fringes, so identify pockets of high stress concentration then redo the analysis with a thinner coating. Now, we look at what is the mathematics behind it because the focus is evaluation of coating and specimen stresses and we have to make an assumption, without assumption we cannot proceed.

Are we satisfying all the assumptions in the coating testing is what we have to examine and just now, I said that thickness should be sufficient for me to see fringes but when I do the analysis, I want to claim the thickness of the coating is very small, so this is the assumption that I make and I said do not think when I make assumption, we are making a crime, it is not so. I have pointed out that when the Young's modulus of the coating material is much smaller than the base material.

Even though, the thickness appears considerable, it really does not reinforce. In certain class of problems, it affects; in certain class of problem it is not a very serious mistake, so the thickness of the coating is very small and I said in all the experimental methods Poisson ratio will be a nuisance and here you assume both the specimen and coating have the same Poisson's ratio and you know polycarbonate we have seen.

Polycarbonate from material property we saw, it has a Poisson ratio of 0.28, many materials have 0.25, 0.26, all these metallic materials and this is much closer and polycarbonate is a very popular coating material in photo elastic coating also. So, second assumption also can be reasonably satisfied. The third assumption is the specimen and the coating are in a state of plane stress that also can be easily satisfied, it is not a difficulty.

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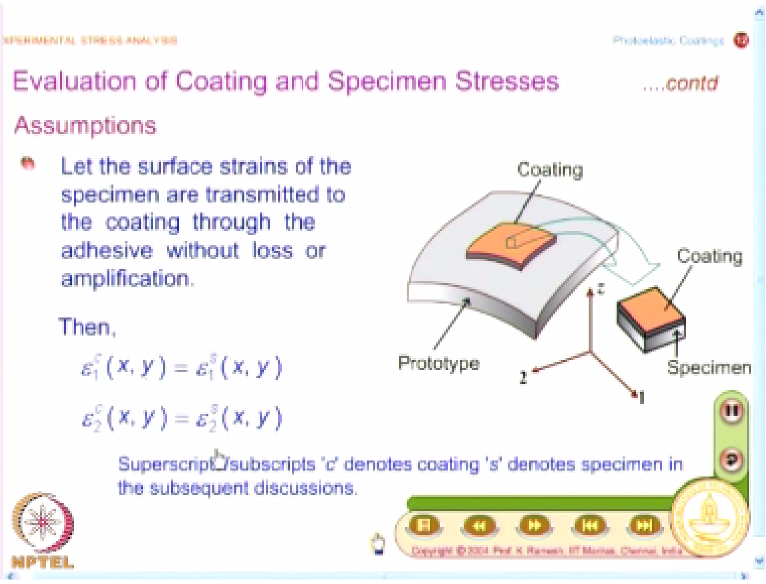

And what do we see and we also have a very nice way of looking at it, I have this as a prototype that is given in grey shape. On the prototype, I put a coating at a place of interest, which is large enough and I take a small element, which is shown here and I have a full freedom to select my axis at the point of interest. So, to minimize our mathematics, I take an axis along the principal stress direction 1 and 2.

And they also in isotropic material coincides with principal strain directions and I take the thickness as a direction z and imagine this coating is very large enough, this is not, you know because it is a small place, it is represented; the representation is I have a prototype of some thickness on which a coating is put, I am looking at a small elemental area, where I have a coating as well as the specimen.

And what is the important assumption that I make, which I have already mentioned it, I have adhesives, which is good enough such that the surface strains of the specimen are transmitted to the coating through the adhesive without loss or amplification and what I have? On the coating, I will have a strain epsilon 1c, which is a function of x, y. I will also have the strain epsilon 2c because I have taken my axis of reference along the principal strain directions.

And if I have to say, the surface strains are faithfully transmitted, what do I mean physically? I physically anticipate the strains in the coating and the strains in the specimen are identical. For a moment, we close our eyes on mismatch a Poisson ratio but we have started the assumption both have the same Poisson ratio, so that does not; whatever happens to this specimen happens to the coating also.

If there is a mismatch in Poisson ratio, I have to bring in a correction factor, this is what I said. While developing the basic equations, we make certain assumptions but when we actually put the methodology in practice, I violate some of these assumptions because of exigencies in the experiments but I improve upon my results by bringing in correction factor. So, what I am going to have is I assume epsilon 1c = epsilon 1s and epsilon 2c = epsilon 2s.

This is what I am going to have and what I have here; I have already mentioned when I have a superscript or subscript with c denotes coating and s denotes specimen in all our subsequent discussions, we will have that symbolism followed and what is my ultimate goal? My ultimate goal is I have to find out the coating stresses and specimen stresses. How do I go about? I am just going to make a beginning of it and the later you do the development at home and come back for the next class.

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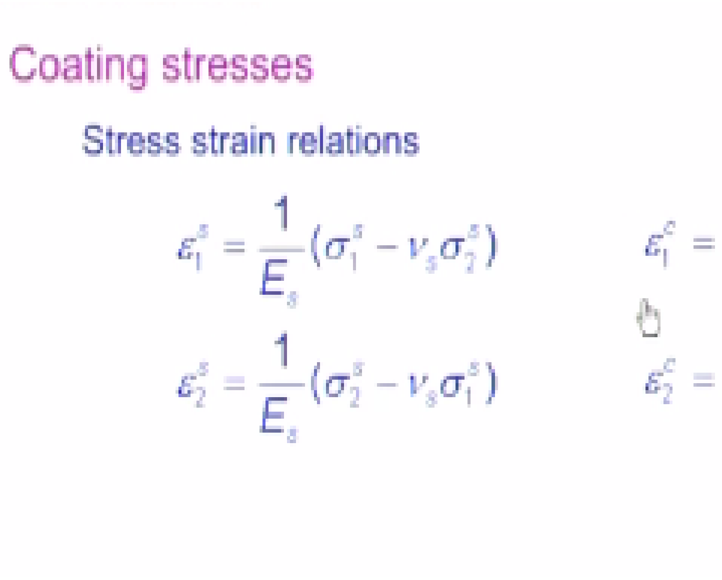

So, I can look at the stress strain relations and which you know very well, when I am also looking at the plane stress situation, I can write epsilon 1 as simply as 1/ Es sigma 1s - Nu s sigma 2s, these are all very well-known equations; epsilon 2s as 1/Es * sigma 2s - Nu s sigma 1s. On similar lines, I can also write, epsilon 1c, epsilon 2c in terms of coating stresses and now we have the basic assumption epsilon 1c = epsilon 1s; epsilon 2c = epsilon 2s.

Now, you have strain stress relations, what is the next step? You can find out the coating stresses as well as specimen stresses from all these quantities. I have this epsilon 1c like this and what I want you to go to the room and then work on this is; what is the expression for sigma 1c and sigma 2c. It is fairly simple and straightforward, take it as a home exercise, when you come for the next class, give me the expression for sigma 1c and sigma 2c, in terms of the Poisson ratio of the coating, specimen.

And also the specimen stresses and this expression will be same, when I go and see brittle coatings. In brittle coating, we will handle them individually, in photoelasticity what do we get; we always going to get only principal stress difference or principal strain difference that is where the whole thing changes. So, in this class what we have looked at is; I said photo elastic coating has made application of photo elasticity to industrial problems very attractive.

And I said it is a very nice engineering tool, an approximations start right from data recording because in transmission photoelasticity, we wanted normal incidence, we maintained that even in 3 dimensional photoelasticity, even if I analyse a 3 dimensional model, though I have not mentioned it explicitly, I may immerse it in a liquid which has the same refractive index and then when I put the ray of light, it will still retain a normal incidence.

Though the model is complicated shaped; the moment I come to reflection photoelasticity because I have looked at reflected light, I compromise on normal instance and in order to simplify that or minimize that whatever, the error introduced, one of the requirement is I keep the polariscope far away from the model, so that I reduce the angle of oblique. Then, we looked at; what is strain optic relations?

And I said what is the interrelationship between F sigma and F epsilon, then we moved on to look at how to find out the specimen stresses and specimen stresses; you have to find out first from coating stresses, determine the coating stresses, from coating stresses go on to specimen stresses and what is the basic assumption? The strains are faithfully transmitted and you will have to go and get me the expression for sigma c and sigma 2c.

It is very simple arithmetic, if you do it at your rooms, your preparation for examination becomes very simple and this is fundamental for any of the coating techniques.