Experimental Stress Analysis

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Module No. # 04

Lecture No. # 30

Analysis of Brittle Coatings

Let us continue our discussion on brittle coatings. We saw one of the earliest brittle coatings was naturally formed scales on hot role steels, then we also saw even the oxides that were formed on surfaces, they were also used as a brittle coating and primarily those coating failed to indicate the presence of plastic deformation in the component.

Only latter with advancement in material research, people developed sensitive coatings, which fail at strains much below the yield strain, that is about 2 thousand micro strains is when the yielding take place. So, people developed coatings, which can fail even at three hundred micro strains and in all the coating techniques, you need to follow a specific procedure for bonding the coating over the specimen surface.

So, in the last class, we saw what are the steps in performing a brittle coating test. We saw the first step was to select a suitable coating; the second step was how to clean the specimen surface and now we will see the third step.

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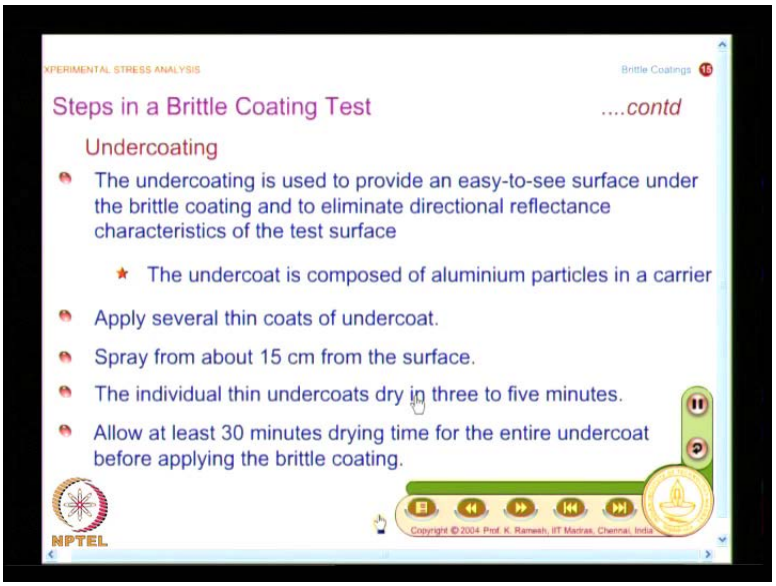

The third step is to provide an undercoat and what is the use of this undercoat? Undercoating is used to provide an easy- to- see surface under the brittle coating and to eliminate directional reflectance characteristics the test surface; it is very important, because you have to go and identify the cracks and you must have a convenient detecting the cracks.

And what are the types of undercoat that they have? The undercoat is composed of aluminum particles in a carrier and you know, in order to make some of these procedures systematic, you know, the manufacturer give you detailed set of instructions, because it solve skill development and after trial and error, they find out typical values for each of the operations.

So, what we will have do is, you have to apply several thin coats of undercoat and the recommendation is spray from about 15 centimeter from the surface so that you will have a uniform layer of coating being formed and you must allow after each spray, the individual thin undercoats to dry and they take about three to five minutes. So, you have a recommendation what kind of a cycle that you need to follow.

And after you made the several thin coats of undercoat, allow at least 30 minutes drying time for the entire undercoat before applying the brittle coating. You know, what will have to keep in mind is, though this procedure look very detailed, this has come out by

several iterations operated by the manufacturer and it is better that you follow this recommendation.

And what will have do also keep in mind is, when you prepare the undercoat of the model, you must also keep a number of calibration specimens; spray them with undercoat and allow them to try in the same environment. Because in all these techniques, calibration is equally important; unless I find out the failure strain of the coating for each test, my data interpretation becomes difficult and this you have to keep in mind.

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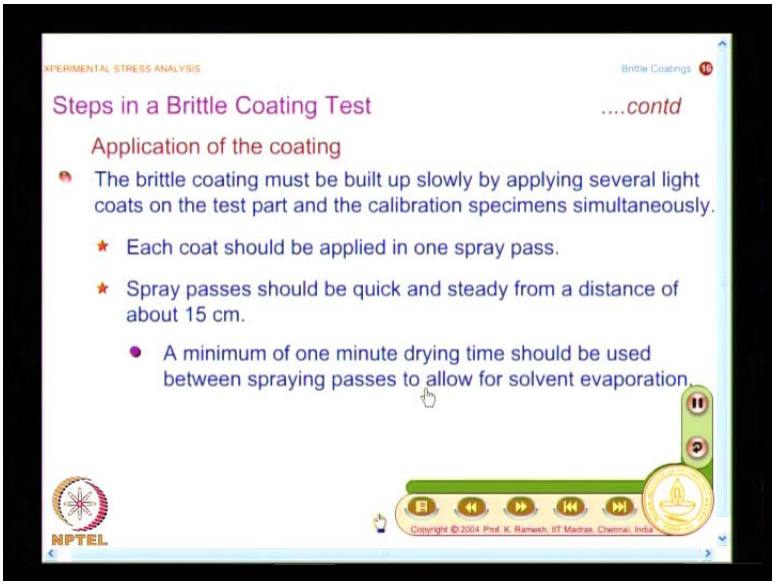

And after undercoat, now you get on to application of the coating and how do you apply the coating? You have to build up the brittle coating slowly by applying several light coats on the test part and the calibration specimens simultaneously.

So, you are also taking care of preparing good calibration specimen, which are identical to the way that we have prepared the model and like the undercoat, each coat should be applied in one spray pass and you should also do this quickly and do it with steady hand from a distance of about 15 centimeter.

So, the spraying technique is very similar as undercoat and what you have is, after each spray, you must allow one minute drying time to allow for solvent evaporation; the reason is also given. You know, after every coat, you must allow sufficient time fall,

whatever that you are apply to dry and what you find is, undercoat require little more time for drying, whereas the actual brittle coating takes much less, it takes just 1 minute; there you had about 2 to 3 minutes.

And all these information is very important to follow, because unless you allow the solvent to evaporate, the next coating that you apply may not strict properly; smudges may take place. So, that is the reason why you have to observe these types of procedures.

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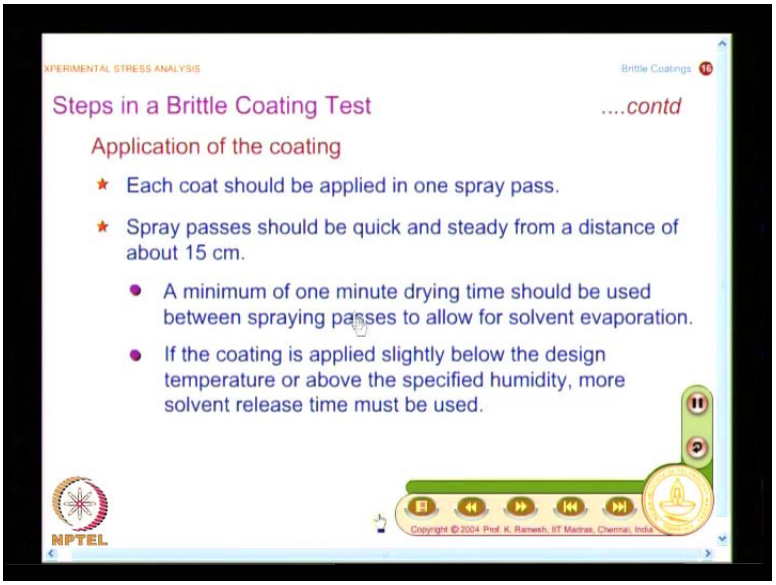

And you know, you will have to be careful when I say one minute for each of the coating, the environment is also very important. Suppose you apply the coating slightly below the design temperature or above the specified humidity, more solvent release time must be used. So, you must access for the given environment, are you in a position to establish that you have provided sufficient time for solvent evaporation. So, it is more like an art; you know, you have to develop this; be sensitive to what is happening and then apply the coat uniformly.

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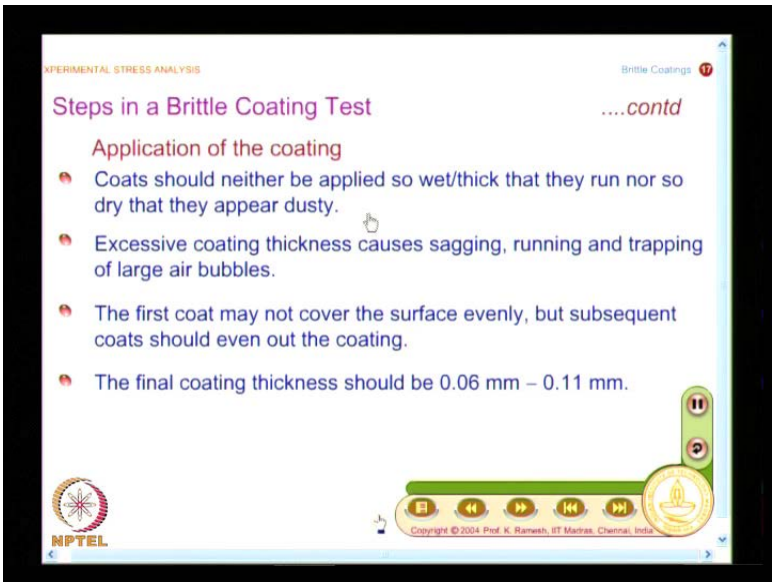

And what are all the problems that you can come across? So, you want the coats should neither be applied so wet or thick, that they run nor so dry that they appear dusty; so it has to be in between totally wet and totally dry.

And what will happen if we have excessive coating thickness? The excessive coating thickness may cause sagging, running and trapping of large air bubbles. See, this is very important; when you are applying a coating, you also ensure that the coating is uniformly applied and there are no air bubbles in trap so that, whatever the strain of the prototype is faithfully transmitted to the coating, that you have to ensure. So, I want a uniform thickness; only if I have uniform thickness, my quantitative estimation will became meaningful.

And what will happen? When you are putting a coat, the first coat may not cover the surface evenly; so you do not have worry about it, because you are going to apply the coating by several processes of spray.

So, the subsequent coats should even out the coating. So, what you need to look at is, when you do the first coat, just follow the procedure; keep it at 15 centimeter away from this specimen, and then, make one pass like this, allow it to dry and after you make several passes, the coating will form more or less uniform on the surface and what is the typical coating thickness you are talking about? This is about 0.06 milli meter to 0.11 milli meter; so here you have the comparison.

The moment you go to photo-elastic coating, I said coating of 3 milli meters are not uncommon; people use less than that, but very often you come across 3 milli meter coating so that you have sufficient optical response.

So, compared to whatever the thickness effects what we discussed in photo-elastic coating, those effects are not significant in brittle coating and also you are not doing a very careful quantitative evaluation of stresses; you are only using this for finding out the principal stress direction; from that point of view, the technique is very robust and industry friendly that is what you have to keep in mind.

It is industry friendly technique, because I can use it for a large structure simply sprays. So, the final coating thickness is very small, so the assumption that you have a thin coating is reasonably satisfied in brittle coating technique.

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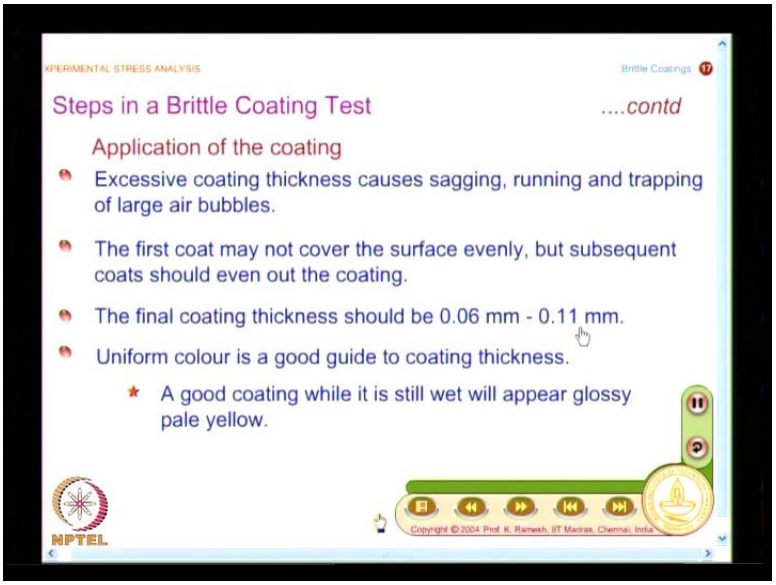

And how do I access, I have reached the final thickness? You know, color is very important; you know human brain is very sensitive to observing the color. So, if I have a uniform color, it is a good guide to coating thickness.

And what is stated is - a good coating while it is still wet appears glossy pale yellow. Because you are now talking of huge structure; you are not talking of a simple cantilever beam that is used for calibration. When you are having a huge structure, we must also have a mechanism by which you quickly check. So, visual inspection is the first

operation that you can do. So, you can visually appreciate, whether the coating is uniformly applied on the specimen surface.

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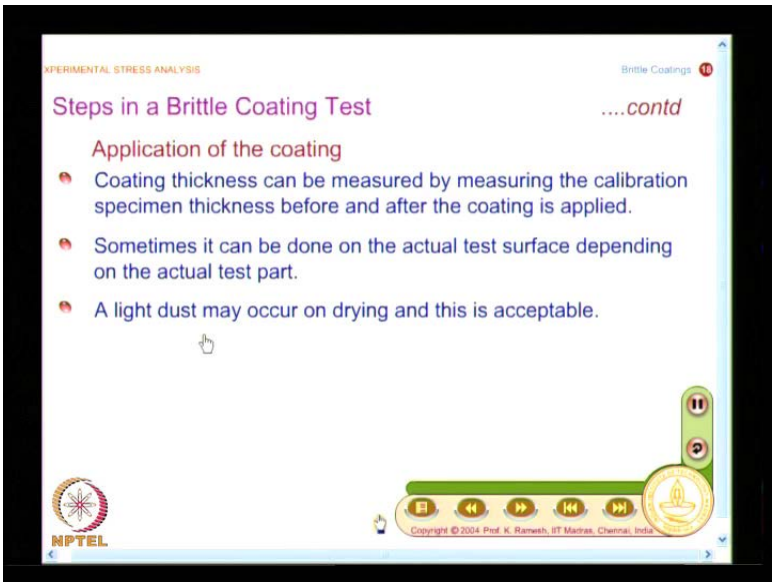

And the next question is how you find out the thickness of the coating? So, one way of looking at thickness is to measure the calibration specimen thickness before and after the coating is applied. So, this is straight forward, because you are keeping the calibration specimen as part of your specimen preparation. So, whatever the operation that you do for the specimen is evenly done for the calibration specimen; if I have done five passes on the actual specimen, you also do five passes on the calibration specimen.

So, that ensures that, if I five measure the calibration specimen thickness before and after the coating, I can find out what is the thickness of the coating on the actual specimen. And in critical applications, it can be done on the actual test surface depending on the actual test part; you also have methodologies that help you to find out the thickness.

And I said, it is an industry friendly technique, not necessarily you apply the coating in your controlled laboratory environment. So, you may have a light dust because of the environment and this is the acceptable; you do not have to be annoyed that I have a dry a light dust what I do; I do not have to get annoyed. Suppose I have a heavy dust, you also have a methodology to handle the situations.

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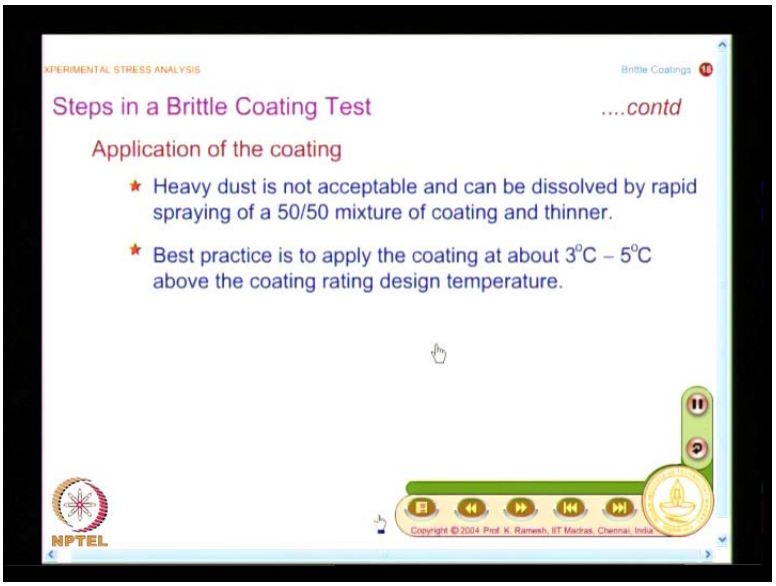

So, when you face a problem, you also have a solution. Heavy dust is not acceptable and you can dissolve it by rapid spraying of a 50 by 50 mixture of coating and thinner; so, this is the beauty. When you look at the procedure, you know, the manufacture has looked at all aspects of applying the coating, because in all coating techniques only the coating is properly formed, data interpretation is meaningful; this you cannot ignore it.

You know if it require skills, then you need a skilled technician who helps you to do this or you have agencies which provides you such specialty. So, you must pay attention on forming the coatings very carefully and there are also other minor recommendations that, best practice is to apply the coating at about 3 to 5 degrees above the coating rating design temperature, this helps in curing.

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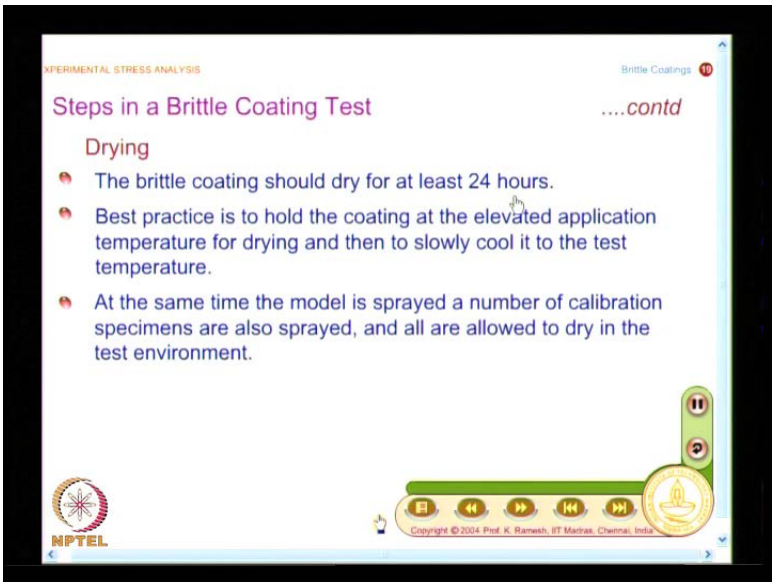

And the final process is how you do the drying. And you should note that brittle coating takes 24 hours for drying it is not immediate; whereas the undercoat took about half an hour, whereas the actual coating, you must allow 24 hours.

And you also have a suggested practice - best practice is to hold the coating at the elevated application temperature for drying, and then, to slowly cool it to the test temperature. And like what we have seen earlier, at the same time the model is sprayed, a number of calibration specimens are also sprayed, and all are allowed to dry in the test environment.

So, what you need to ensure is, you mimic a very similar processes like the actual specimen to the calibration specimen also. So, now, after this processes, both the calibration specimen and the actual model or prototype are ready for your test and now the data interpretation comes. And I said, when we are discussing photoelastic coating, we saw that for all coating techniques the basic equations are similar. So, I am going to just show this equation for your refreshing; they are same set of equation, there is no difference.

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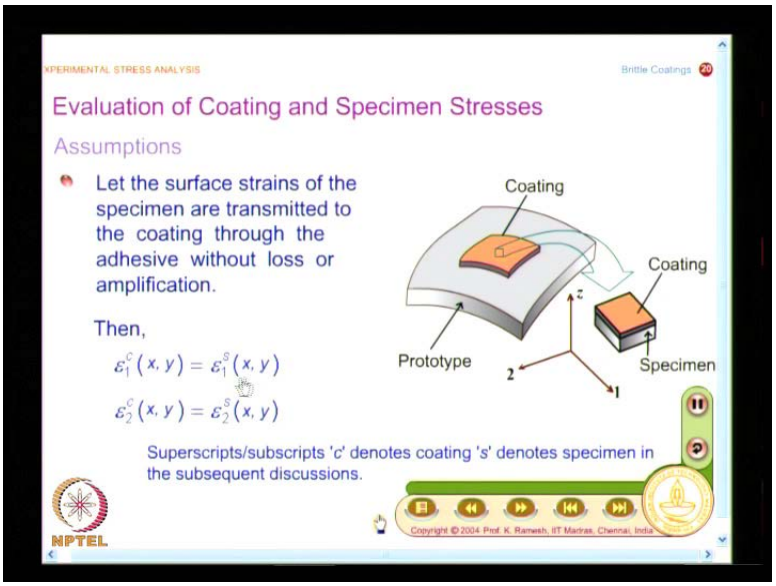

And the assumptions are also similar. So, I have a prototype, I have a coating and on the coating, I select appropriately an axis, for convince I take axis 1 and 2; they correspond to the principal strain direction at the point of interest. And what we assume is, the coating strain is equal to the specimen strain at the point of interest. The adhesive is properly used to transfer the strain without loss or amplification, that is what is important; you should neither it should be amplified nor it should be a loss.

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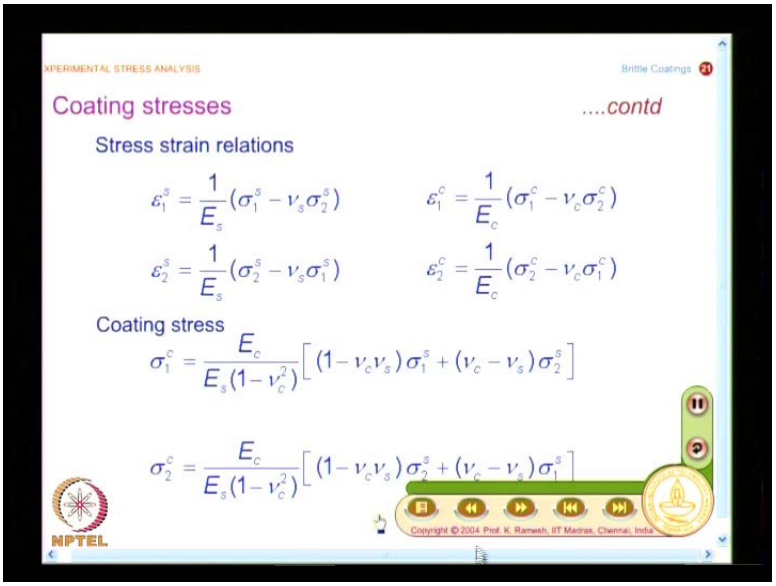

And then, we also looked at how to get the coating stresses; we have looked at stress strain relations for the specimen; we have also seen this for the coating and you have also got the expression for coating stress.

Now, look at these expressions very carefully. You know, I have always been saying Poisson's ratio place it spoils ports in all experimental techniques and in this case a very special thing happens.

Suppose I have a specimen is subjected to only a uniaxial state of stress, what do these expressions indicate? The specimen stress is only uniaxial; sigma 2 s is 0, but what happens to the coating? By looking at this expression, what you infer?

Suppose I have mu c is not equal to mu s, when you have uniaxial specimen stress, I will have biaxial coating stress, very interesting. You know, I have always cautioned uniaxial stress is simpler, whereas uniaxial strain is difficult to achieve in experiments and I also cautioned, when I apply a uniaxial stress on the specimen, the strain would be either biaxial or triaxial depending on the specific geometry of the specimen under consideration.

And now, what you see here is, because I have a coating applied on this specimen and the Poisson's ratio of the coating and this specimen are different, which is usually the case you find, I will have sigma 1 c as well as sigma 2 c for a uniaxial specimen stress.

So, this makes your data interpretation complex. See, my interest is to bring out and also discourage you from using brittle coating for quantitative evaluations. Because left to myself, I will use it only for finding out the principal stress direction and reduce the channel and you have to know what are the difficulties.

So, you find for a uniaxial specimen stress, I have a biaxial coating stress in general. Suppose I make the Poisson's ratio equal, then I do not have this problem, but you have to appreciate this.

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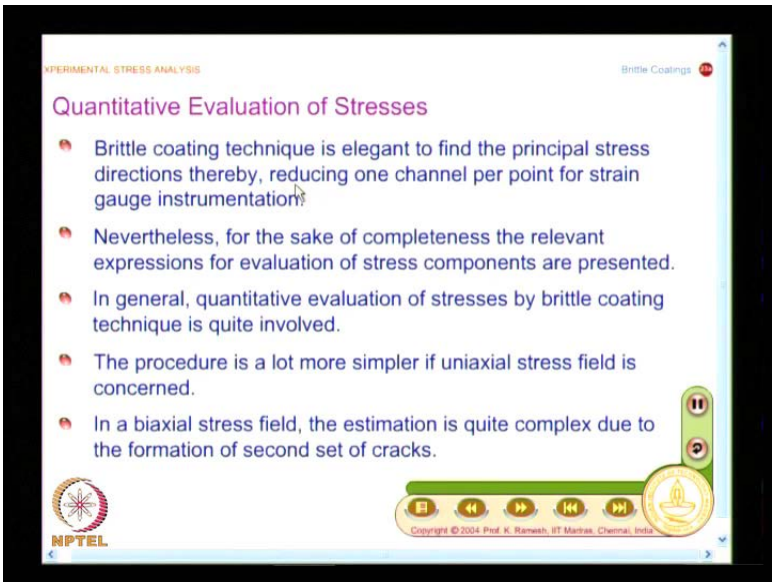

Now, let us look at how I do quantitative evaluation of stresses and this is what I emphasis again and again. Brittle coating technique is elegant to find the principal stress direction thereby, reducing one channel per point for strain gauge instrumentation.

And I have already indicated, to some extent the quantitative evaluation of stresses by brittle coating is quite involved. On the other hand, suppose I have only a uniaxial stress field on the specimen, the procedure is a lot more simpler and you have enough examples, where uniaxial stress need to be evaluated.

On the other hand, if the specimen has a biaxial stress field, the estimation is quite complex. See, we have seen in some of the examples, that you saw one sets of cracks and you saw another set of cracks form perpendicular to it and when you want to find out the governing equations, what causes the formation of second set of cracks, you have to bring in lot of approximations and also information from the actual experimental situation, that makes the quantitative evaluation involved; not only involved, but doubtful in accuracy.

And I have already said brittle coating provides you plus or minus 20 percent; you are not guaranteeing plus or minus 1 percent. So, you have to consider that it is an industrial friendly technique, where the problem is very complex, even small information will go a long way in improving your design. So, in a biaxial stress field, the estimation is quite complex mainly because of the formation of second set of cracks.

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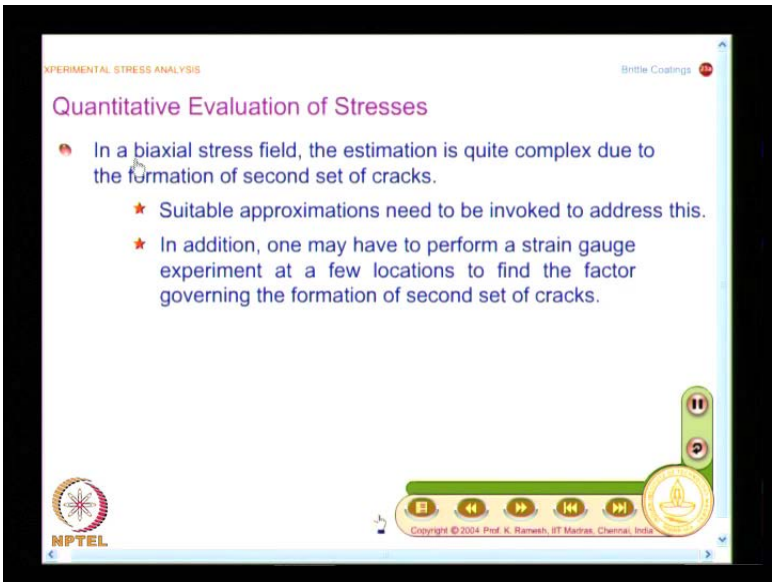

And what kind of information you need from the experiment? First is, you need to make suitable approximations. In addition, one may have to perform a strain gauge experiment at a few locations to find the factor governing the formation of second set of cracks. Because in the initial case what we say is, the coating is unperfurated you know, I have a uniform coating and you can say that coating being a brittle material, it may fail by maximum stress theory or maximum strain theory, whatever the theory that you want to have, then the cracks form.

But if you want to analyze the formation of second set of cracks, you do not have a uniform coating; you have a coating with cracks. So, that is why you need to bring in additional approximation and you have to say there must be some kind of factor which governs, which may not happen at the actual failure strain of the coating; there will be a factor, and that factor has to be determined experimentally; you need to make additional experiment using strain gauges otherwise, you will not be in a position to do it.

See, my interest is, I am not going to get in to the mathematical details; I am going to skip that. But I want to give you an idea that, when I get into a biaxial stress field, what kind of complexities are involve in quantitative estimation of stress magnitudes, that is where the focus is.

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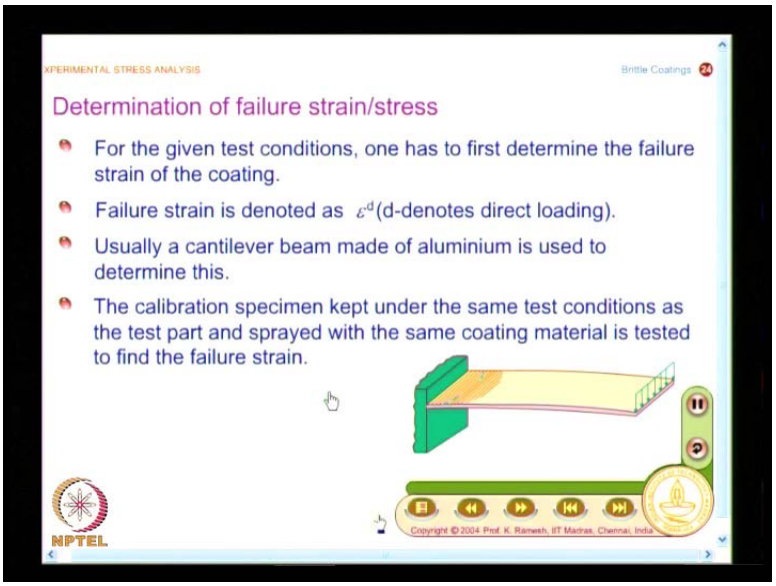

And what is the first step in the case of brittle coating? See, we have all along looking at in any of the experimental techniques, you have to find out what is known as calibration constant. In transmission photo-elasticity, you had sigma as the calibration constant that you need to find out; in photoelastic coating, you need to find out k.

Once you come to brittle coating, I need to find out what is failure strain of the coating for the given test conditions. This is the basic information that helps you to get the quantitative data and you need to find out the failure strain and for our discussion, we will look at the direct loading.

So, in order to indicate that we are finding out for direct loading, the failure strain is indicated with the super script d, the d denotes that it is the direct loading. And I have said cantilever beam is the best choice of the specimen configuration that is used for calibrating the failure strain; whatever the coating that you have, you find out the failure strain by coating a cantilever beam made of aluminum and then estimate it.

And we have already seen, the calibration specimen has to be kept under the same test conditions as the test part and sprayed with the same coating material and you apply the load and find out when do the cracks form. And now, we have to bring in several cases; you know, you have to bring in… I may do a calibration on an aluminium specimen so that becomes a specimen for calibration.

So, I will have Poisson's ratio of the aluminium; so I will have mu a as a Poisson's ratio of aluminium, then I have a Poisson's ratio of the coating, then I have a Poisson's ratio of the specimen.

So, I am going to handle three different Poisson's ratios; so that is how the expression will come. And if you actually look at sigma 1 c and sigma 2 c expression which was seen earlier, it is a play of that only. But what you need to keep in mind here is, because I use a calibration specimen, which is made of aluminium and I have to do it on actual test path, which material may be different and I said Poisson's ratio mismatch is nuisance and lets us see how. This is interplay of all these values that is what you are going to see.

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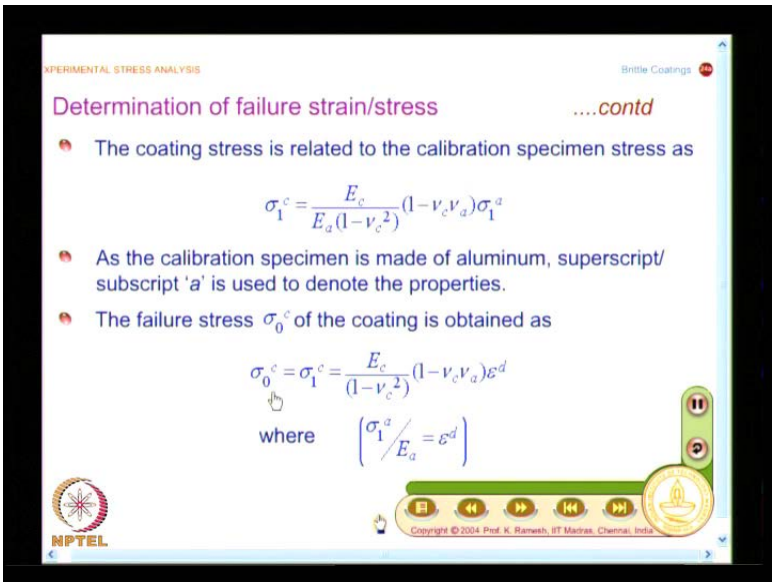

And from whatever the expression that you have seen earlier, it is possible for you to write an expression for coating stress sigma 1 c and I am having only a uniaxial specimen stress; the same coating stress expression have two terms, one with sigma 1 x and sigma 2 x; since I am using aluminium as the calibration specimen, instead of using s as your sub script or super script I use a.

So, what I have here is, the coating failure strain can be determined from this expression; the coating stress is expressed as e c by e a 1 minus v c square multiplied by 1 minus mu c mu a into sigma 1 a.

We will modify this expression until we get the failure strain or failure stress and the corresponding stress in the specimen; it can expressed in three different ways, all the different ways we will look at.

Now, I put 0, and then, say that this is the failure stress of the coating and from this expression, I rate sigma naught c equal to E c by I minus v c square into 1 minus mu c mu a into epsilon d, because I have a uniaxial stress applied, sigma 1 a divided by Young's modulus of the aluminium gives you the strain.

So, this is the strain for the formation of first set of crack and I have already cautioned in the brittle coating test, the first set of cracks of the most critical one. So, you should not take the incremental loading casually; you have to estimate fairly, accurately what would be the desirable increment for a particular component on hand and you are going to find out the failure strain and you roughly know it will fail around 300 to 350 micro strain. So you can also estimate.

So, you can do your experiment very carefully and not miss out this; this is what is important. So, I have what is the failure stress. See, my interest is to go, and then, show how these Poisson's ratio mismatch can effect. What I am go to do is, I will also find out what is the corresponding specimen stress; when the coating fails, there must be some specimen stress for which the coating has failed.

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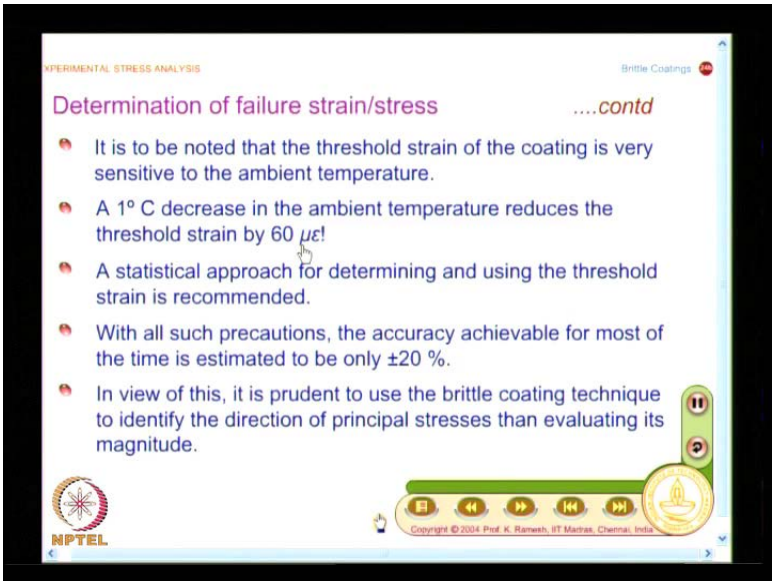

And I can bring in the Poisson's ratio of the specimen and look at what way this affects. And you must also keep in mind, the environment place a very important role and what is reported is even a 1 degree centigrade decrease in the ambient temperature reduces the threshold strain by 60 micro strains, it is very large.

See, what you need to keep in mind is, you know when the temperature is lower the coatings behaves more brittle. So, you have to be very careful, the temperature and identifying the humidity relative humidity, this is the very important; you must maintain that and you must also look at the charge supplied by the manufacturer that you have used the appropriate coating for a given application.

And also ensure that you follow the recommendations and what is recommend is, a statistical approach for determining and using the threshold strain is recommended. Because I may have to do several test and find out from a statistical approach what is the failure strain of the coating.

Even with all such precautions, the accuracy achievable for most of the time is estimated to be only plus or minus 20 percent. See, this more of a caution; you have to keep in mind that with all the precautions you do, you cannot get accuracy better than plus or minus 20 percent.

So that is the reason why I have always been saying when you are asked to use a brittle coating test, use it more for finding out the principal stress direction thereby, reduce 1 strain gauge for point. So, in order to establish that also, I am showing you all this; so, now, after you see all this, even a 1 degree centigrade can affect the failure strain by 60 micro strain, so the quantitative evaluation becomes involved as well as not very accurate when you have this.

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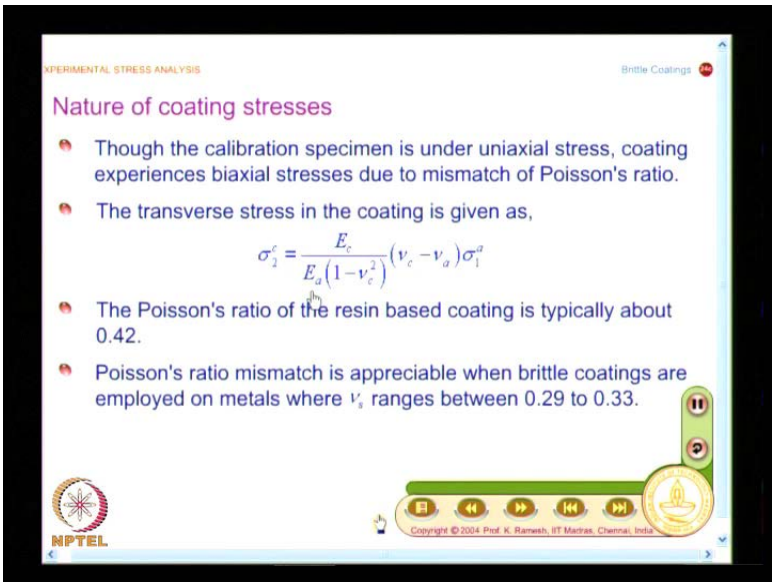

And I had already mentioned to you that even for a uniaxial specimen stress, the coating in general will have a biaxial stress that is why I am going to look at it. And from whatever the expression that we have seen for the coating stresses, you readily get, because the specimen now used is aluminium, you get sigma 2 c equal to E c by E a into 1 minus mu c square and you have mu c minus mu a into sigma 1 a.

So, the Poisson's ratio mismatch becomes important in brittle coating analysis and what is the Poisson's ratio of resin based coating? It is typically about 0.42 that is of how they have. And Poisson's ratio mismatch is appreciable when brittle coatings are employed on metals, where mu s ranges between 0.29 to 0.33. So, this is what you have to keep in mind.

Poisson's ratio mismatch has a role to play and what we do here is, what way the Poisson's ratio mismatch shows up in your equations. So, one way of circumventing this is what, at least in calibration, do not do it on aluminium; do it on the specimen on which you do the test.

So, in that case what will happen is, whatever I do it on the calibration specimen can be easily related to the actual prototype. Now, we have not looked at; we have only looked at the calibration specimen; we have only looked at the coating; we are not brought in the actual specimen. Now, I am going to show you the Poisson's ratio because of the actual specimen, then you realize if I use the calibration specimen same as the actual material

on which I am go to the test, I have one problem less that is why we are talking about; is not that you are eliminating all problems, you have one problem less; so that is what we are going to look at it. Now, what we have emphasized is, for a uniaxial specimen stress, the coating experiences biaxial stresses; so that is very important to keep in mind.

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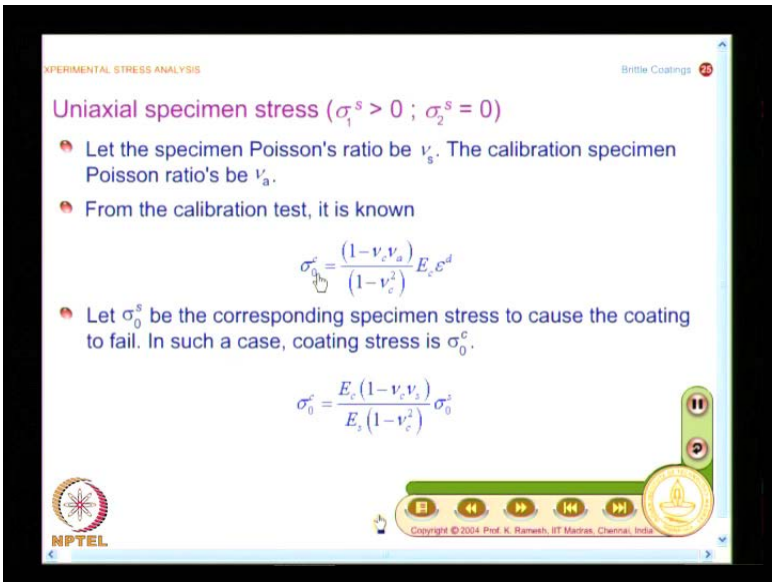

Now, I have an actual prototype also fails only with one specimen stress acting on it, the other specimen stress is 0. Now, let us look at how the interpretation can be done. And we have done a calibration test, from the calibration test what we have found out? We have find out the failure stress of the coating.

And that is written as 1 minus mu c mu a divided by 1 minus mu c square Young's modules of the coating into failure strain epsilon d. And I can also go back to my original set of expressions like what we have written for the calibration specimen, I can recast the same expression with specimen Poisson's ratio and the specimen stress.

So, when I have a coating stress sigma naught c, I can also find out when the coating fails what is this specimen stress that has caused, that is given as sigma naught x and what you have here is, sigma naught c equal to E c by e x into 1 minus mu c mu x divided by 1 minus mu c square multiplied by sigma naught x.

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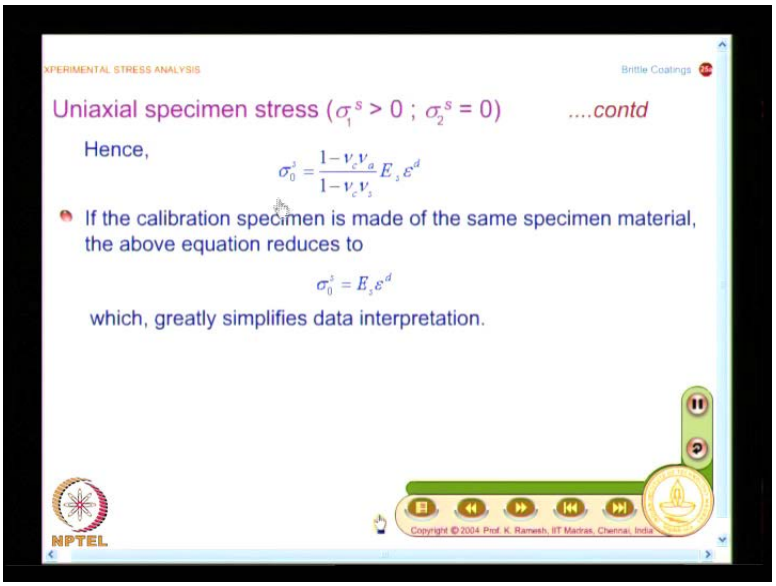

Now, I can bring in; I can express sigma naught x and a different way, where I will find out that if I use a specimen for calibration same as the actual prototype material, then my problem is less and that is what is shown in the slide.

So, what you have here is sigma naught s is equal to 1 minus mu c mu a divided by 1 minus mu c mu x into Young's modulus of the specimen into failure strain epsilon d. This is simple to derive; I am skipping the mathematical steps, it is not difficult; you can go back and work it out. And this brings out the role of Poisson's ratio mismatch; in this expression you have Poisson ratio of the coating, Poisson ratio of the specimen as well as Poisson ratio of the calibration specimen.

And I said you can reduce the problem by having a calibration specimen same as the specimen material, then this equation reduces to sigma naught x equal to Young's modules of the specimen into epsilon d.

So, this gives you a via media that if you want to have less mathematical calculation, if you have very important problem where in you want to do this repeatedly, it is better to use a calibration specimen same as the actual specimen material.

You know, I have expression for what happens in uniaxial specimen stress, biaxial specimen stress, I will not get into those detail; those equations are very complex. Now,

what we look at is, we will look at, for revealing the crack patterns under different type of practical situations that we may come across.

See, when you are looking at design, you want to optimize; you also want to prevent failure. If you want to develop the design to prevent failure, I am interested in finding out maximum stresses, stress concentration zone and so on, because there I would like to reinforce until I am satisfied that it will withstand the operational loads and also any un-force in exigencies.

On the other hand when I want to go for optimization, I must also look for low stress regions; you cannot ignore them, because I put in unnecessary weight over it, so I may have to identify and scoop out material out of it.

So, now, we will look at how brittle coating technique can be modified to reveal crack patterns in zones, where you are not seen cracks; fine this is the one situation we look at. The other situation is, suppose I apply a compressive loading, can brittle coating be employed? You can also employ brittle coating in compressive loading if you restart to a different technique, that is why we call as direct loading and other type of approach will be called relaxation loading.

So, you can handle for situations, where you do not see cracks, how to generate cracks and in situations like compressive loading, how to revel the cracks; so these two aspects we will see now.

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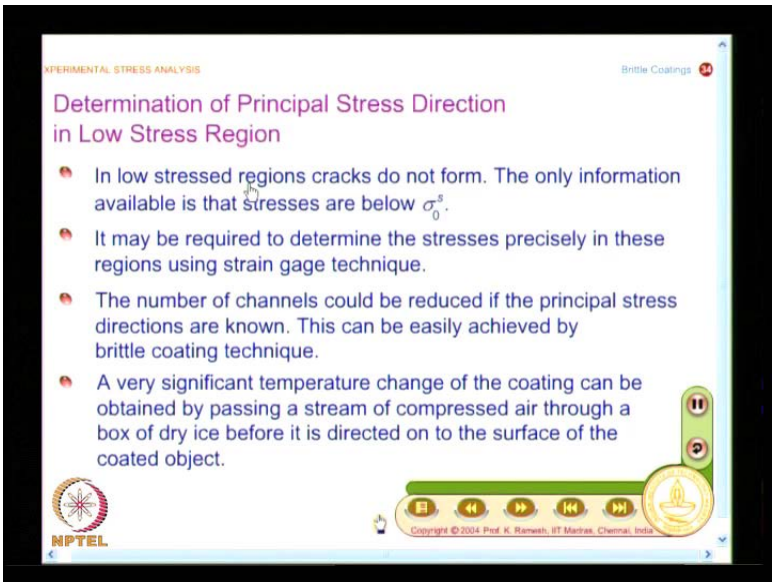

So, we are going to find out the principal stress direction in low stress region that is my interest. Because when I want to do optimization, I need to scoop out material from low stress region and what you have is, the cracks do not form in the low stress region and only the information that you have in those regions is that stresses are below sigma naught x. Because we have already seen, there is something called a failure strain of the coating; we also looked at what is the failures stress of the coating corresponding to the failure strain and we also looked at what is specimen stress has caused the failure of the coating, we called that a sigma naught s.

So, now, we know from the appearance of no cracks that the stresses are below sigma naught s and what we can do is, the next two point say why we need this. What you actually do this, is a very significant temperature change of the coating can be obtained by the passing a stream of compressed air through a box of dry ice before it is directed on to the surface of the coated object.

So, what you do is, you generate a cool air and then put it, so you generate a temperature field which is isotropic in nature and that precipitates cracks formation.

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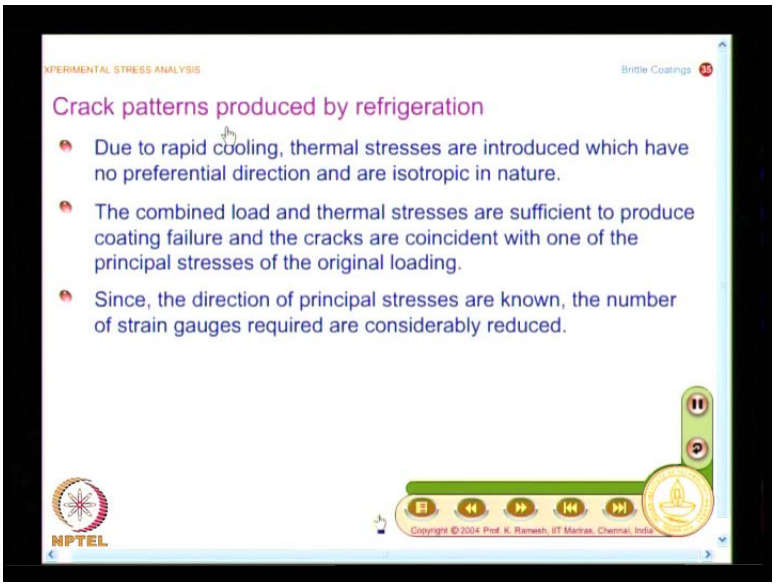

The general level of stress increase that is what you have. Due to rapid cooling, thermal stresses are introduced which have no preferential direction and are isotropic in nature. And what you have is, the combined load and thermal stresses are sufficient to produce coating failure.

So, you are able to reveal crack patterns in region which are not appeared earlier and this approach is known as crack patterns produced by refrigeration. And once you have got the cracks, you have the direction of principle stresses are known and I can reduce the number of strain gauges. So, it is a very simple extension of basic methodology of brittle coating and what I will do for compressive stresses? You apply the coating differently.

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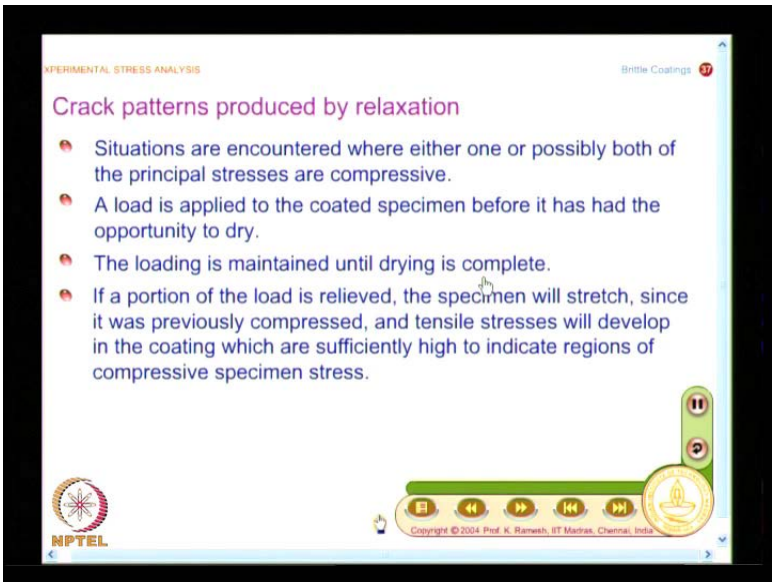

What you do is, when I go for compressive stresses which is known as crack patterns produced by relaxation, you load the specimen first; a load is applied to the coated specimen before it has had the opportunity to dry; the loading is maintained until drying is complete.

So, what will happen? When you release the load, whatever the stresses that were compressive, they will behave like tension, so you will have cracks formed. So, you have crack formation very similar to what you saw in direct loading, and then, you can mark those. But these are very difficult experiments, you know (( )) and his coworkers have very carefully demonstrated all these techniques and they are also very successful in recording crack patterns in problem like ring and diametric compression.

It is essentially a compressive load apply and they have also shown that whatever the isostatics that you get for these two cases, because when I have formation of second set of cracks, what it indicates is, you get contours corresponding to the first set of crack as well as contours corresponding to second set of crack and they showed experimentally the principal stress direction are mutually perpendicular.

See, you have only heard from mathematics that the principal stress direction is orthogonal, you have not visually seen it. Even when I do photoelastic analysis, I only get contours of isoclinic; I do not get contours corresponding to sigma 1 contour corresponding to sigma 2 and see whether they are mutually perpendicular; whereas in

brittle coating, it is possible to get one set of isostatics because sigma 1 to has reached a failure strain of the coating and another set of contours, where sigma 2 has increase and cross another set of cracks and they have demonstrated, that you have two families of isostatics, they are orthogonal everywhere. So, you get an experimental proof that principle stress direction are mutually perpendicular, that you get only from brittle coating; that is the advantage of brittle coating.

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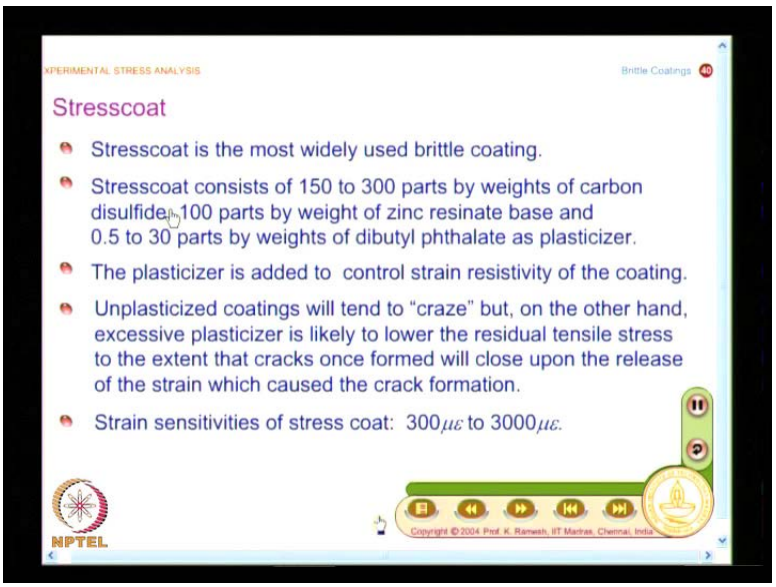

What is the type of coating that is available now? You have what is known as stress coat. I said that initial coatings were naturally formed coatings, then we saw the first coating was a mixture of (( )) and alcohol and what you have widely now is called stress coat. Stress coat consists of 150 to 300 parts by weights of carbon disulfide, 100 parts by weight of zinc resinate base and 0.5 to 30 parts by weights of dibutyl phthalate as plasticizer.

And plasticizer is very important; you know, you need to handle it very carefully, plasticizer added, it does the job of controlling the strain resistivity of the coating and if do not plasticize the coating, the coatings will tend to craze, that means, spurious crack patterns will get formed, so you need some plasticizer to be added and excessive plasticizer if you what happens? The cracks once formed will close upon the release of the strain which cause the crack information.

So, it is like we have to add it very carefully; you cannot remove it completely, you need a minimum quantity and what is the minimum quantity? It is function of your requirement and you can also control the strain sensitivity, that is what I said initial coatings were very highly stressed; only when there are very highly stressed, they will crack. But latter coatings with developments in material research, you have a coating which fails between 300 micro strains to 3000 micro strain. So, all this is done by slightly modifying the constituents to suite your requirement.

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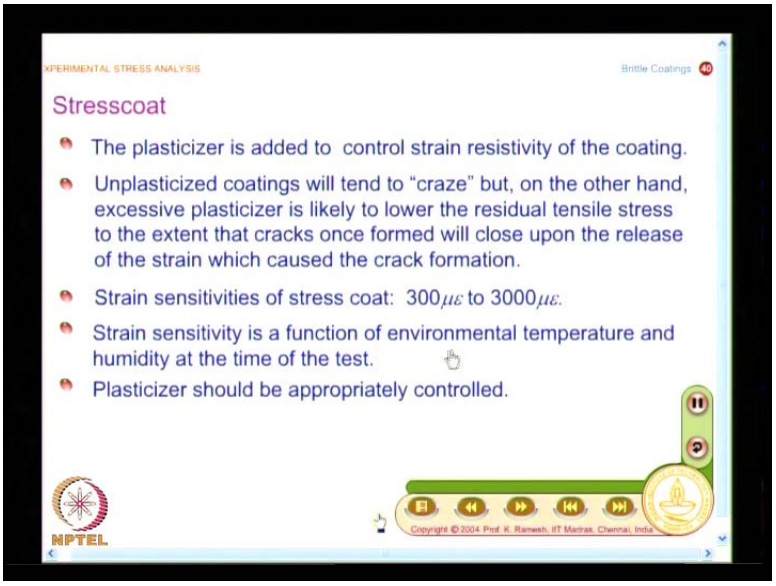

And you should also keep in mind, strain sensitivity is a function of environmental temperature and humidity at the time of the test, which we have also seen when we are talking about the calibration and plasticizer should be appropriately controlled.

You have to have the plasticizer very carefully you should handle it. So, what we have seen in this class was, we had decent appreciations of what is brittle coating technique, we have looked at what are the condition for formation of cracks; we have also emphasis for a uniaxial specimen stress in general coating experiences biaxial stress. So, it makes the interpretation and also application of failure theory complex.

And like in photoelastic coating, here also you have do a calibration and what you do a calibration is the failure strain of the coating. We also saw we can find out the failure strain of the coating and we can also expect as of a failure stress of the coating and we can also find out what is the specimen stress which causes the failure of the coating.

So, we have also looked at interplay of Poisson ratio of the coating, Poisson ratio of the specimen, Poisson ratio of the calibration specimen and I said you have one problem less if you may the calibration specimen same as the actual test material, then we also saw how to generate cracks in region, where you do not see cracks in the initial test, you can do by refrigeration.

And finally, we also looked at, in problems where you apply compression, how do you reveal the cracks, which can be done by relaxation technique and we also saw what is the material that is available now for brittle coating, that is labeled as stress code, it is a commercial name and that bricks into a close of what is brittle coating.

But I will still appreciate some of you to look at you know, suppose I have isoentatic for various loads, I have got the isoentatic, how do you use this isoentatic for finding out the magnitude of the stresses? Think about it, we will have a brief discussion on it in the next class, and then we take it up strain gauges. Thank you.