Engineering Fracture Mechanics
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Module No. # 06
Lecture No. # 33
Plane Stress Fracture Toughness Testing

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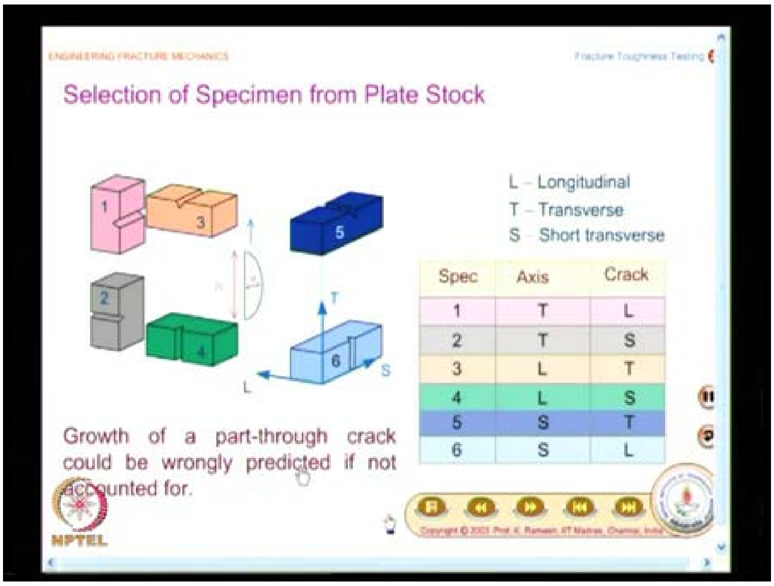

You know, I have mentioned, that in fracture mechanics, the material anisotropy is addressed, even in material testing. And I had already shown how to select a specimen from plate stock. The idea is to emphasize, that you look at, how the properties change along the L, T and S directions. So, you take specimens of different orientation, with cracks and find out the fracture toughness appropriately.

So, you will have to know, whether it is a TL, TS, LT, LS, ST or SL. In fact, I had asked you to draw only the first two, fill up the rest from the table. I hope you have done that. Particularly, when you have a surface crack, the property variation, which is a function of the L, T and S direction, can influence how the part-through crack can propagate. And you have to note, the toughness values for S T direction may be 30 to 60 percent lower than for L T direction. So, in the case of a part-through crack, if you do not know these variations, the growth could be wrongly predicted. In fact, we had also looked at, what are the other relevant standards, in connection with fracture toughness testing.

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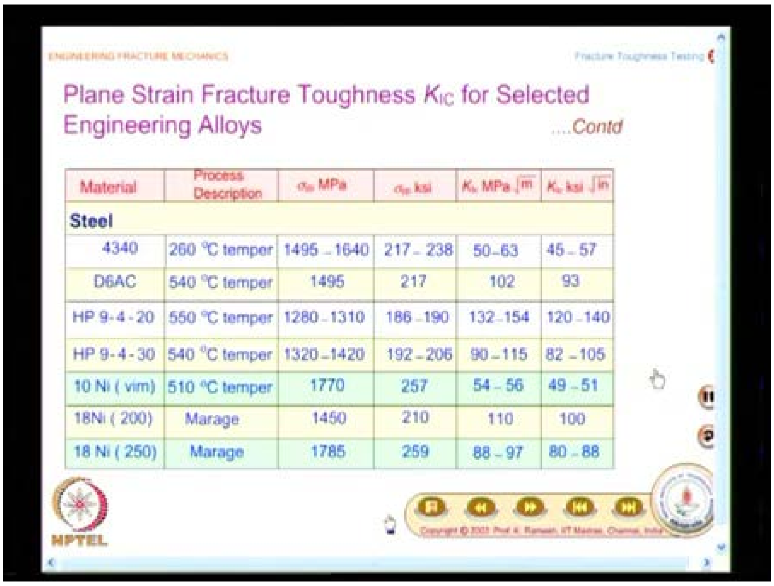

Now, what we will do is, we will also look at, sample values of fracture toughness. And we may write, just for three specimens. I have the material given; and this is the various processes by which the material is obtained. And you have the yield strength in MPa and we have the stress intensity factor as MPa root meter. So, if you look at, we are really talking of very high strength alloys. You see the list changes; from 1280 is the least value of yield strength in MPa, and it goes up to 1785 at least, in this page. For various categories of steel, for steel, 4340, the yield strength is 1495 to 1640 MPa and the K 1 C is given as 50 to 63 MPa root meter. Maraging steel is also very important. So, you could write for the other steel, when the yield strength is 1785 MPa, for that steel the K 1 C is determined to be 88 to 97 MPa root meter.

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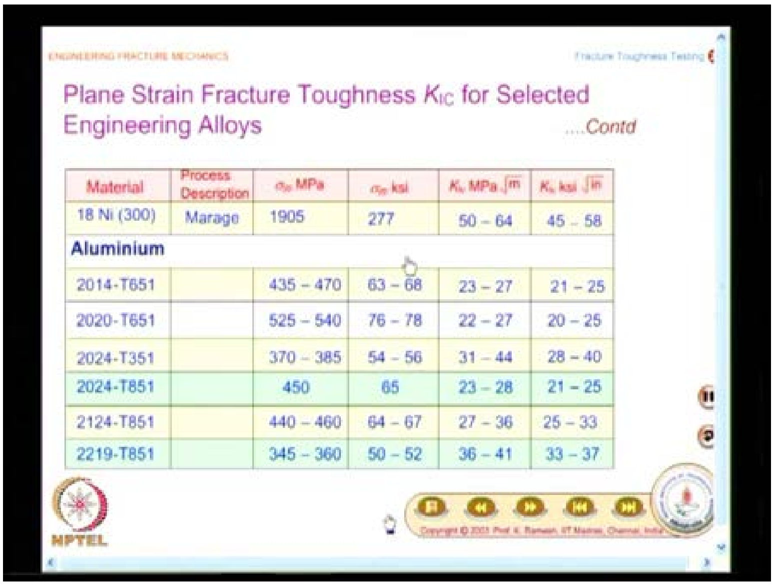

It gives you a flavor. We are really talking of high strength alloys and what is the typical variation of fracture toughness, in the case of steel. And in this slide, you have aluminum and we will again look at, for two of these alloys. And here again, you find the minimum yield strength is something like 345 MPa. We are not talking of any material below this and for 2014 aluminum, the yield strength is between 435 to 470 MPa. The fracture toughness is far below that of steel; you have it only from 23 to 27 MPa root meter. So, the knowledge base, what you should keep in mind is, fracture toughness for steel is quite high in comparison to aluminum, which we had seen graphically also earlier. So, you take up another category of aluminum. If you look at 2020, where, which has the highest value of yield strength, 525 to 540. There is no great change in the fracture toughness; it is 22 to 27 MPa root meter.

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For each category of material, you have to find out the fracture toughness. There is no correlation from the yield strength and the fracture toughness value. If the yield strength increases, it is not necessary fracture toughness value also increases. These are two independent parameters. In fact, it is the task given to material scientists, to develop materials which have high value of yield strength, as well as high value of toughness. It is a challenge for them and they keep working on it and develop exotic materials.

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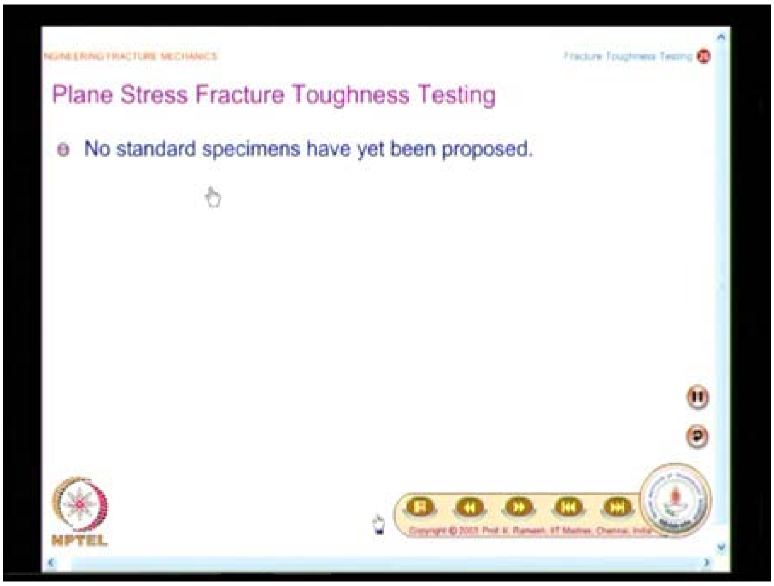

Having looked at this, we will move on to plane stress fracture toughness testing. We have seen the plane strain fracture toughness earlier. In the case of plane strain, we had seen standard specimens. You have a standardized procedure for evaluating the fracture toughness. On the other hand, for plane stress fracture toughness testing, no standard specimens have yet been proposed. So, this is the difference.

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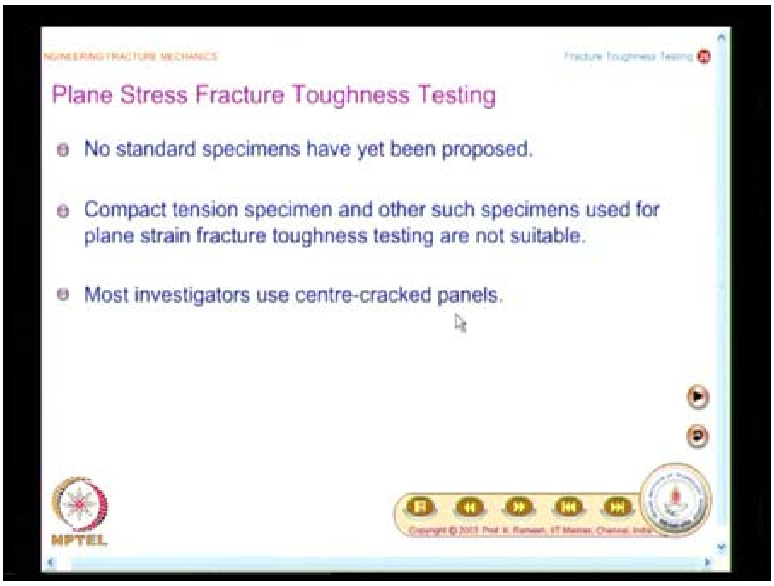

And what do people do? You have to note, the compact tension specimen and other such specimens used for plane strain fracture toughness testing are not suitable for plane stress fracture toughness testing. So, people use centre-cracked panels. And another important aspect, we had looked at in plane strain fracture toughness was, you have to develop a natural crack; only with a natural crack you can conduct the testing.

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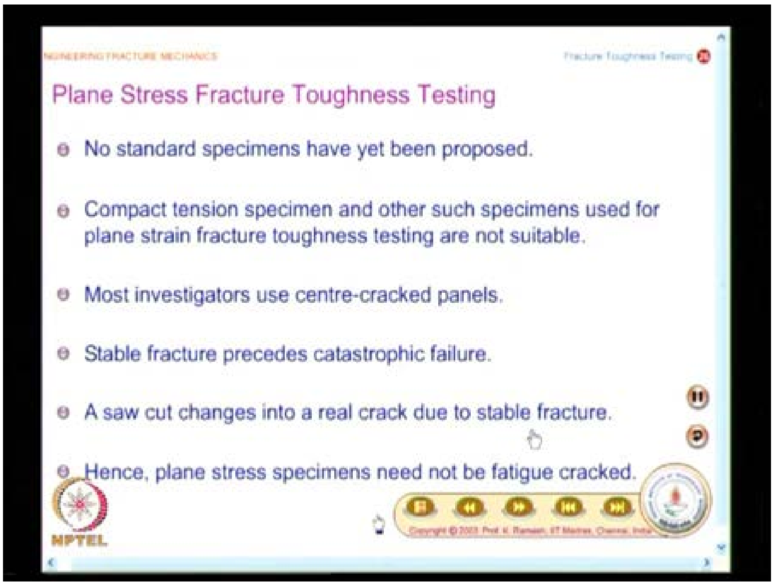

That was a big circus. You had seen chevron notch. You also saw, why chevron notch was used. It is to have control on the origin and the plane of the crack, for you to have a comfortable specimen. Then, you had fatigue pre-cracking restrictions, and so on and so forth. So, one of the relaxation in the case of plane stress fracture toughness testing is, a saw cut is enough. And what is very distinct in plane stress testing is, you will always have a stable fracture followed by a catastrophic failure.

So, what happens is, if you have a saw cut, this changes into a real crack due to stable fracture. In the case of plane strain fracture toughness, you have to develop a natural crack by fatigue loading. In the case of plane stress testing, such a requirement is not needed; a saw cut is sufficient, but there are also recommendations, how thin the saw cut should be; what should be the root radius and so on and so forth. So, the difference is, plane stress specimens need not be fatigue cracked. But this also brings in another difficulty. You have a saw cut that changes into a crack by stable fracture and then catastrophic failure follows. So, one of the difficulties in plane stress testing is, it is very difficult to find out the cracked length at which fracture occurs. There could be errors in that.

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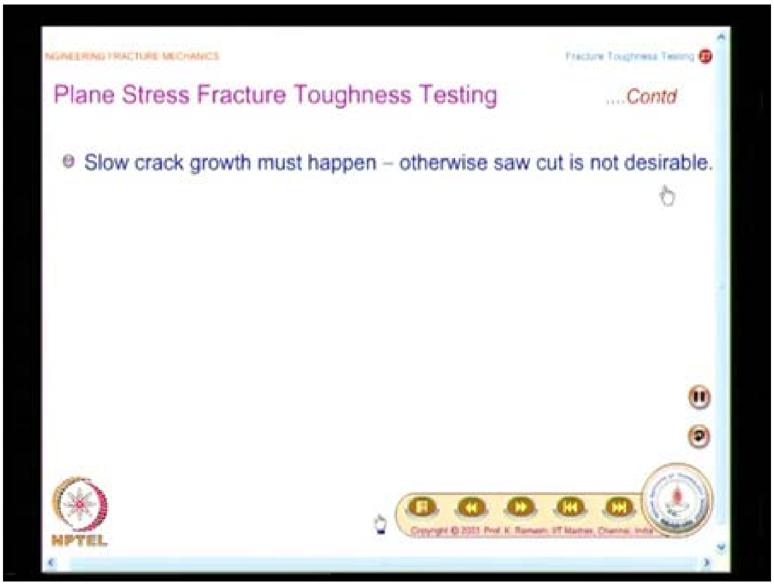

So, people have also devised how this could be handled. We will see them also. So, one of the requirements here is, you will need to have slow crack growth. If it does not happen, it is an indication that the saw cut which is used is not desirable. So, in any plane stress testing, you should have a stable fracture followed by catastrophic failure. The indication is, saw cut has to be looked at.

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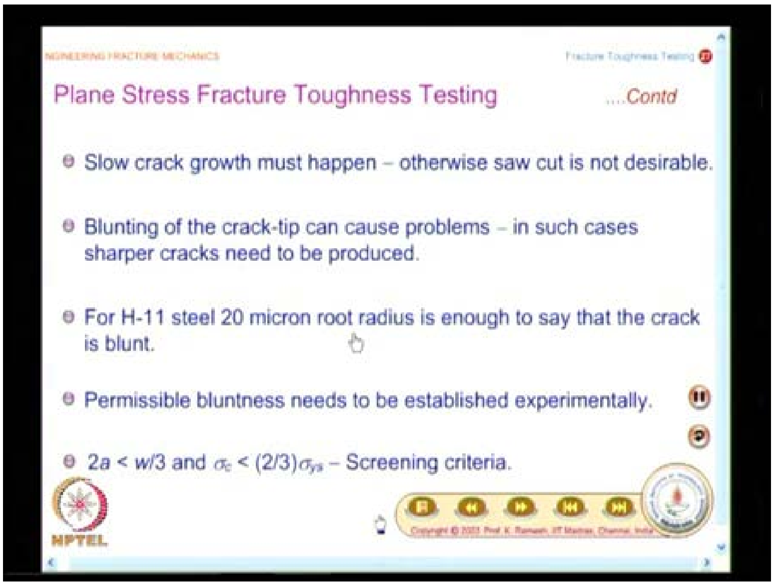

If the saw cut is of a desirable dimensions, you will always see a stable fracture followed by catastrophic failure. So, one of the problem is, blunting of the crack-tip. If you have a saw cut which is wide enough, because of plastic deformation and you know in the case of plane stress situation, you will have a larger plastic zone, the crack-tip may get blunt. So, in that case also, you have to ensure that sharper cracks are produced. See, if you go to photo elastic experiment, we will simply take a saw cut and then do it. We will say that, you take the thickness of the cutter as thin as possible, may be of the order of 0.1 millimeter or less, and then make a thin slit. When you go for plane stress testing, because of stable fracture, you invariably get a natural crack. But what people have experimentally obtained is, you need to have a smaller radius which is dictated by the material. So, if you do not find a stable crack growth, you must go and investigate how you could improve the initial crack. So, what is observed is, in the case of H-11 steel, 20 micron root radius is enough to say that, the crack is blunt. We have said, blunting should not happen; you need to have a sharper crack; and you have a definition what is considered as blunting.

If we have 20 micron root radius, the crack is blunt, which is not desirable. So, you should go for a much finer saw cut. Though saw cut is sufficient, how finer it is, depends on the material. You can get it by trial and error. And this also states that, permissible bluntness needs to be established experimentally. And you have certain screening criteria. The length of the crack should be less than one third of the width; 2 a is less than w by 3. And I had already mentioned, the moment you come to plain stress fracture toughness testing, the width of the panel also matters. And here you have a screening criteria, which says 2 a should be less than w by 3, and whatever the fracture strength that you obtain, that should be less than 2 by 3 times the yield strength, sigma y s. This is only a screening criteria.

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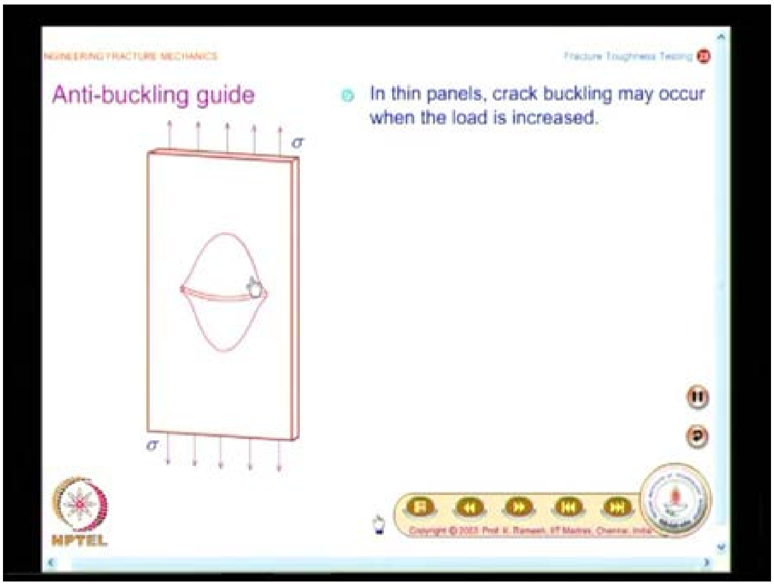

And this is a very interesting observation. I have a thin panel and I have a crack. And, the title of the slide says, it is anti-buckling guide. I will repeat the animation, so, you could see.

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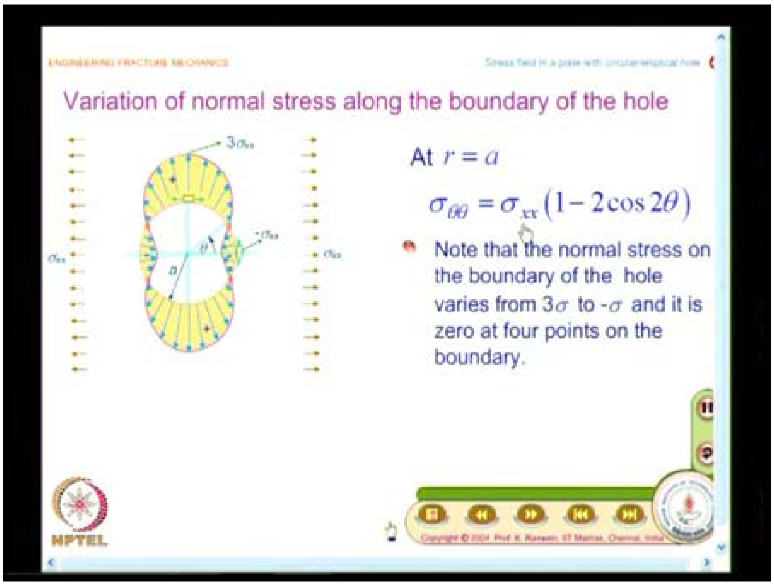

When the loads are applied, the region near the crack buckles. Do you know why this happens? I am applying only a tension. Why buckling takes place near the vicinity of the crack? You know, you have to go back to your result of plate with the hole, and let us see, what the result which we saw. I have the plate with a hole, and the hole radius is enlarged; it subjected to the uniaxial loading. Let me put, what is the stress variation over this. And if you look at the variation of stress, you find it attains a value of 3 times sigma for ((feel)), at both these ends, because the load is applied horizontally.

All of you know that the stress concentration factor is 3. What is the important result is, along the x axis, at this place, it reaches the value of minus of the far field stress. So, you have a compression here, and you have a tension here, which is easily obtainable from your expression of sigma theta theta equal to sigma x x into 1 minus 2 cos 2 theta. So, if you put theta equal to 0, you get this sigma theta theta as compressive. See, this is what I had said, when you have a geometric discontinuity, it definitely produces stress concentration. The other observation is, a uniaxial stress field changes to biaxial stress field, near the vicinity of the geometric discontinuity. And when you really investigate the stress field, you also have surprises, when I apply tension, there is also compressive stresses that could be developed on the boundary of the hole.

Something very similar to that happens in the case of a crack. So, when you apply the load, because of compressive stresses developed, and since you are having a thin panel, buckling of the panel is possible. You may ask the question, whether this buckling is desirable or not? When you do a testing, should I have buckling to take place or should I find out the values preventing buckling or having the buckling allowed?

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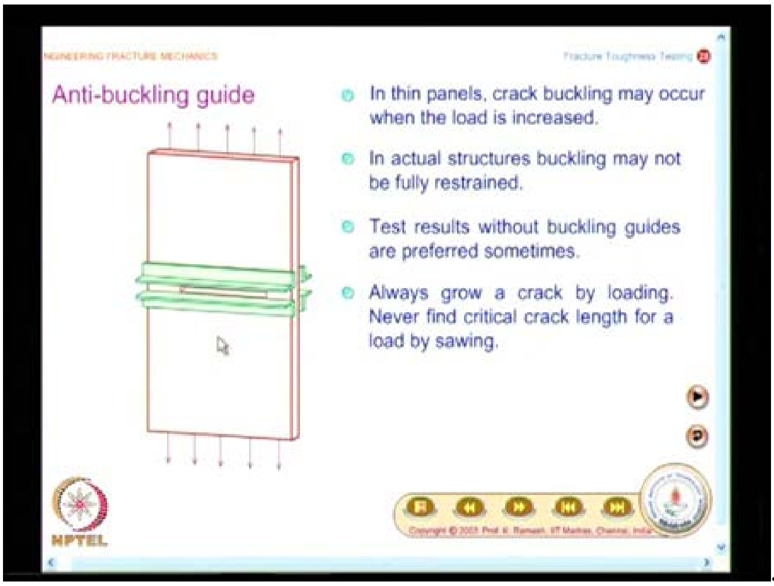

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So, this is a debatable point. We will see how people have done it. So, you have to keep in mind that, in thin panels crack buckling may occur, when the load is increased. In actual structures, buckling may not be fully restrained. So, what people say is, test results without buckling guides are preferred sometimes. Nevertheless, you draw this diagram, where you have this, special guides are provided which will prevent the panel from buckling, when loads are applied. These are guides to prevent buckling, you know, as anti-buckling guides. So, one recommendation is, perform the test with anti-buckling guides; other recommendation is, in an actual structure, when you are having thin panels, you may not always have a provision to prevent buckling there. So, it would be more prudent to have the test done as such, so that, the effect of buckling is ingrained in your test results.

So, it is a debatable point. And another recommendation is, you have to grow a crack always by loading. What we have seen, when you increase the load you will have a stable fracture, followed by unstable fracture. And, in fact, people make a video record of this plane stress testing. And they have to definitely see, there would be a stable fracture, followed by unstable fracture; this is how people filter out the results. What you are essentially doing it? You are applying a uniaxial loading, you are going to find out, at what load the whole panel has a catastrophic failure. So, what is recommended here is, do not increase the length of the crack by sawing and then find the critical crack length, which is not a desirable practice.

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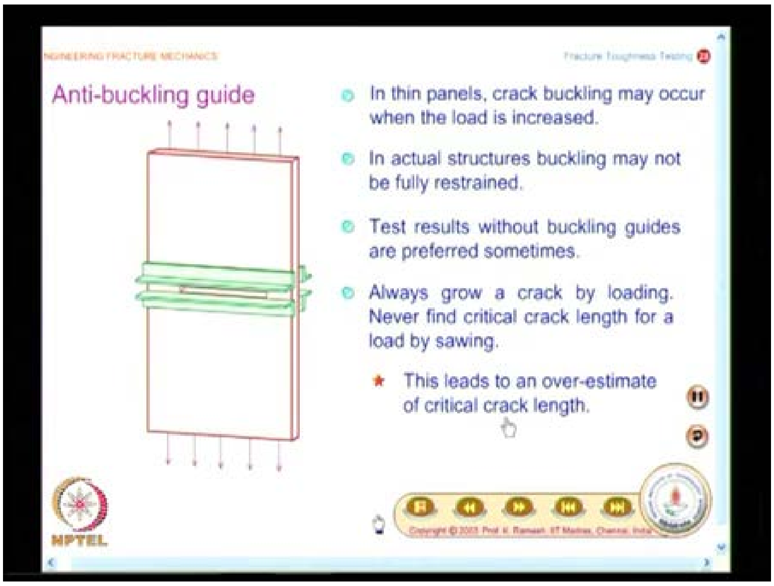

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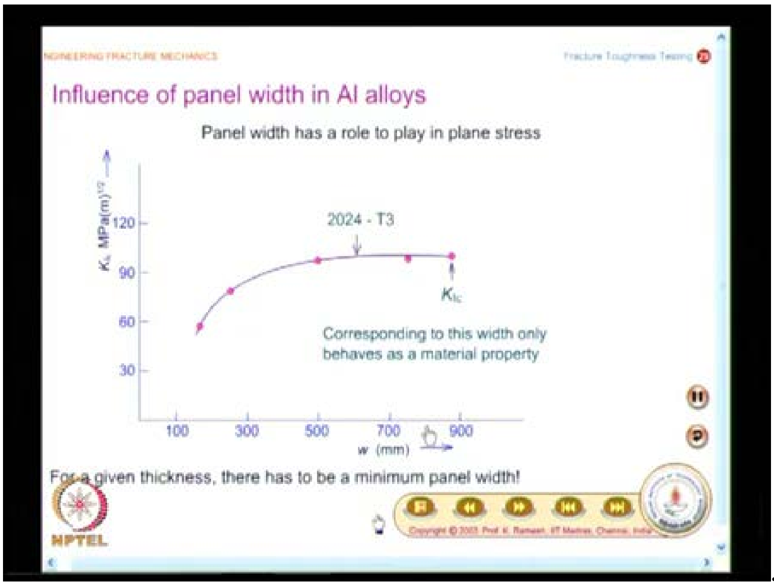

You should always grow a crack, only by loading. If you do it that way, result would be all right. On the other hand, if you grow it by sawing and finding out the critical crack length and the critical stress, it would lead to an over-estimate of what is a critical crack length; because we are going to see, there is going to be a initial crack length; there is a stable crack growth feature, followed by unstable failure, which we had seen even while discussing plane stress situation, long time back, with the help of R curve. We will again have a look at that. And what you will also have to notice is, only for a particular panel width or beyond that, whatever the property you find out as critical stress intensity factor, it stabilizes. I would like you to make a neat sketch of this.

So, you have a graph; on the x axis, the width of the panel is mentioned; on the y axis, you have the fracture toughness. And what you find is, if the width of the panel is increased, beyond a particular width, the value of K 1 C remains constant. So, the point here is, the panel width has a role to play in plane stress. If the value calculated has to behave like a material property, there is a need for a particular width. So, the idea to notice, for a given thickness, there has to be a minimum panel width. See, the testing is so involved in plane strain fracture toughness, as well as plane stress fracture toughness. In all these cases, you bring in all the parameters. This kind of exhaustive testing, you do not see in other engineering practices. So, you have to give weightage to that, when you use these results.

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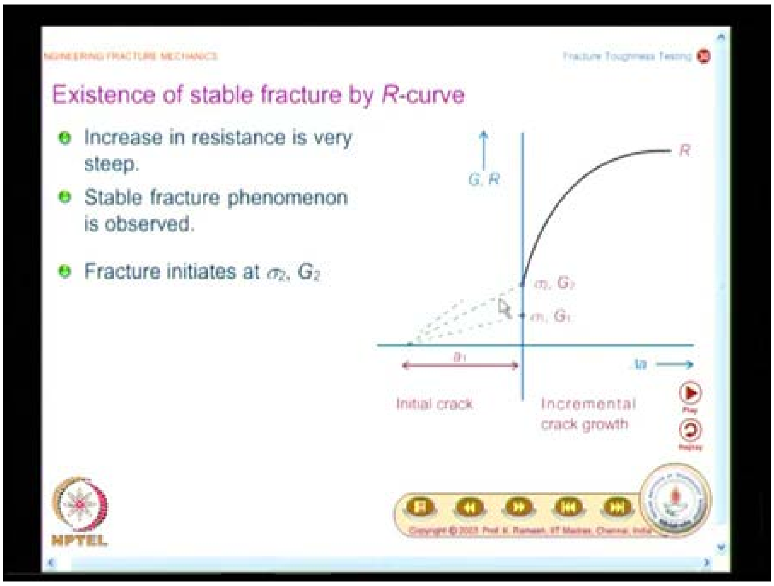

Let us go back and see and understand and recapitulate how stable fracture occurs in thin panels. And I hope you remember, this was discussed in the early part of the course. So, on the left hand side you have the length of the initial crack; on the right hand side you have the growth of the crack; delta is, delta a is given. On the y axis, you plot the energies G as well as R. And you have a R curve in this shape. Because R curve is steep like this, when you have a stress as sigma 1 and the corresponding energy release rate is G 1, which is less than the resistance.

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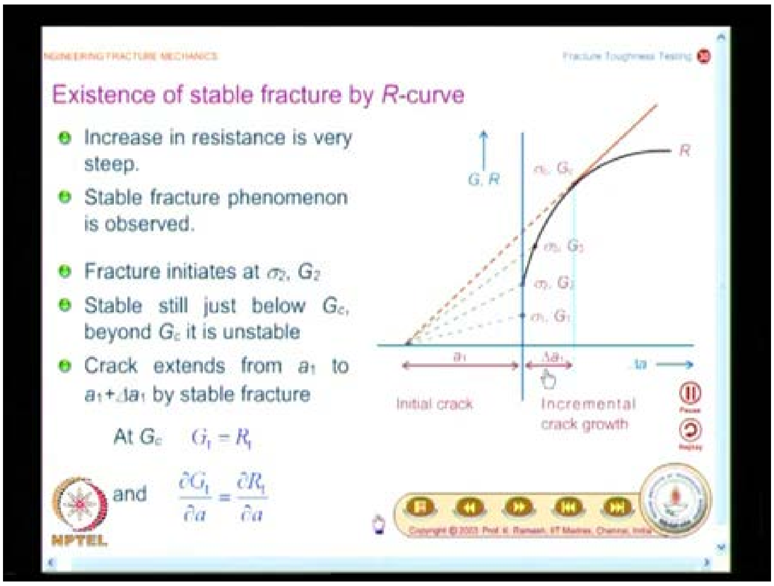

So, crack will not propagate. But the moment I reach sigma 2, where G 2 is equal to R at this point, when the load is slightly increased, you will have a stable fracture. If the load is stopped, crack also will stop. If I keep on increasing the load, after sometime, you will have a unstable fracture. We had seen it earlier, but now, with better understanding, we will be able to appreciate this aspect. So, when the value of the applied stress reaches the critical value sigma c, and the corresponding energy release rate is G c, the line becomes tangent to the R curve. So, from the point here, which is dictated by sigma 2, to sigma c, you will have a stable fracture of the incremental length equal to delta a 1. So, this is where the question comes. For any panel, you need to know what is the fracture strength, and what is the critical crack length.

The question is, would you report a 1 as a critical crack length or a 1 plus delta a 1 as a critical crack length? If you have not looked at the certain issues, you will simply say a 1 plus delta a 1 as a critical crack length, which is wrong. You cannot have a 1 plus delta a 1 as a critical crack length. Ideally, a 1 is the crack that you have; because of fracture process, it has extended from a 1 to delta a 1; it is not a growth mechanism like fatigue or stress corrosion or any one of this.

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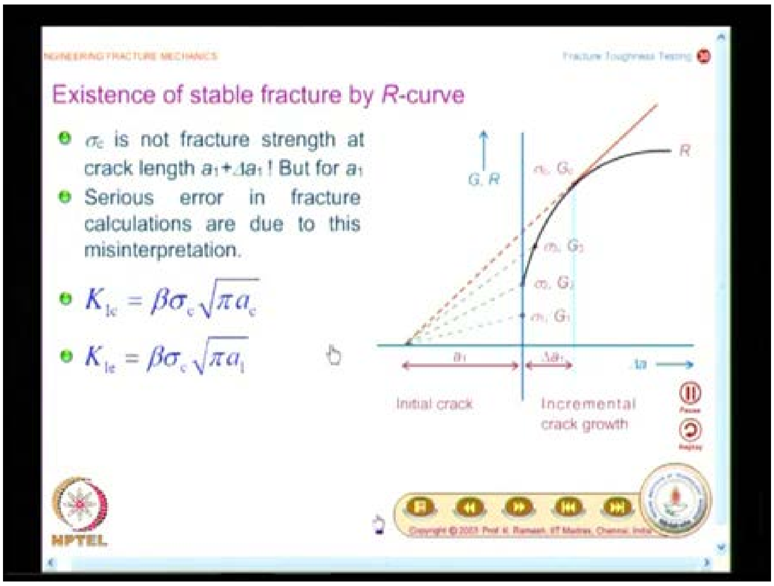

You have a stable fracture, followed by unstable fracture. And you know, people say that, there have been several confusion in the fracture literature in the early days. And we have also looked at, whatever the observation we have made now, could be summarized as two conditions, which are necessary and sufficient for catastrophic failure. G should be equal to R, that is a necessary condition and the sufficient condition is, dow G divided by dow a equal to dow R by dow a. So, that is satisfied when it becomes a tangent. And the issue, what you look at in the literature is, sigma c is not fracture strength at crack length a 1 plus delta a 1, but it is for a 1.

So, people have come out with another alternate terminology. If you go by what is K 1 C, you will simply say beta is your factor for finite geometry. It would be a function of a by w and so on and so forth. Sigma c root of pi a c is what we are accustomed to; that means, you have to give what is the critical crack length a c. You may not be able to even measure it properly. So, people came out with apparent toughness, which is K1e. It is given as sigma c square root of pi a 1. We would see this graphically. Once you look at the graph, you will be able to appreciate this alternate definition.

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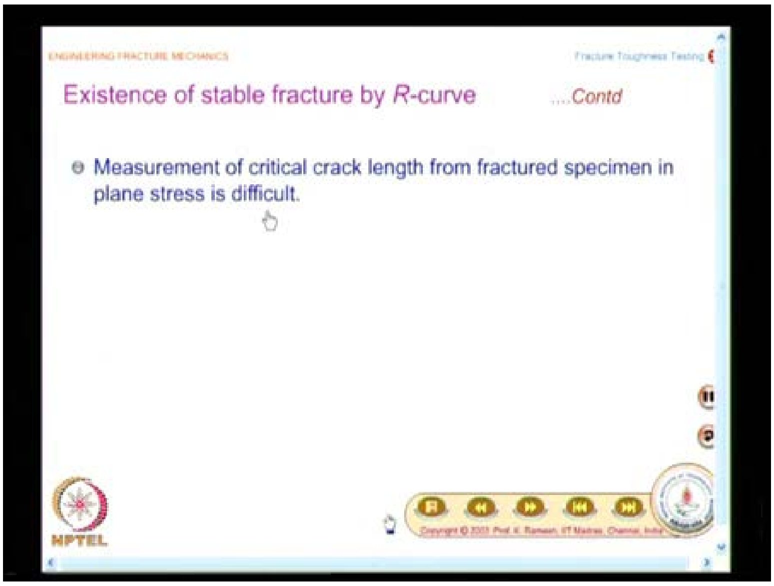

So, in thin panels, you will always have a stable fracture, followed by unstable fracture. As I mentioned, measurement of critical crack length from fractured specimen in plane stress is difficult. This is because, you will not be able to distinguish between original crack length and the phase followed during stable fracture. You will have certain difficulty in measurement.

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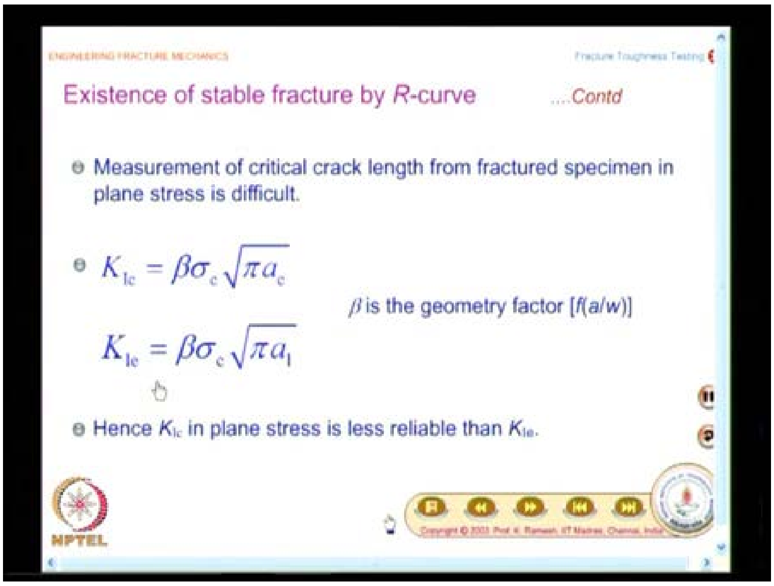

So, it is difficult to find out K 1 C equal to beta sigma c into square root of pi a c. So, people have recommended alternate definition, where you have K 1 e equal to beta sigma c square root of pi a; this is known as apparent toughness. So, you will find in the literature, what is the toughness at which crack initiates; what is the toughness at which it has a catastrophic failure; and what is the apparent toughness. So, you have all three definitions. Here, we see what is the value of toughness at which crack has a catastrophic value. And this is an apparent toughness. You could also have another one, where you have the stress as sigma sigma 1 and or sigma 2 in our, as per our diagram and you have this as pi a 1.

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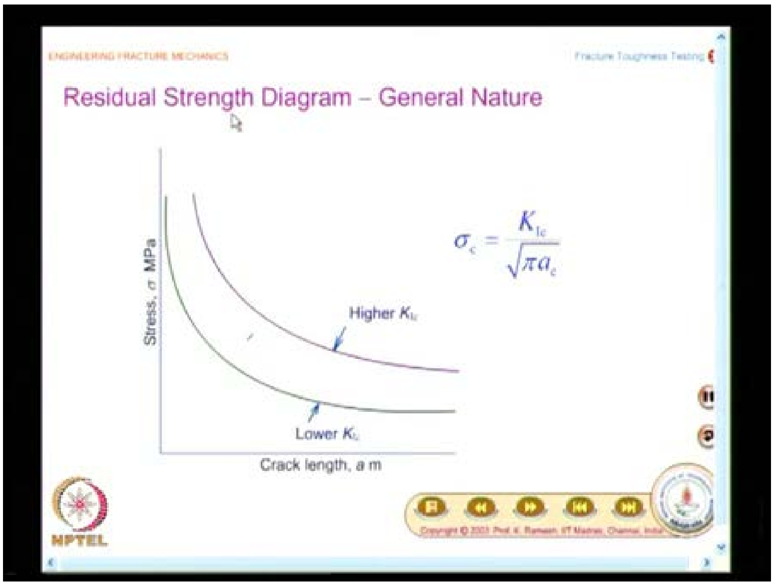

That would be the initiation fraction, fracture toughness. And another important concept that you need to learn here is, what is the residual strength in the presence of a crack? Because, thin panels are used in aerospace structures. The idea of fracture mechanics is, whether my design is safe. If I have a crack, what is the residual strength that I could anticipate from it? And what you have here is, a graph between crack length and stress.

So, as the crack length increases the stress that I could apply would be smaller and smaller. When the crack length is very small, you could apply a very large stress. In reality, it cannot be infinity as it is shown; it would be limited by your design strength or at least, the yield strength of the material. Because it is a thin panel, you will have stress (( )) yield criteria being valid; that way we will modify and see. This generally gives, from the value of toughness, how these residual strength diagrams would appear. For a lower value of toughness, the stresses that you could apply would be lower; for higher value of toughness, the stresses that you, you could apply could be higher. And you should also keep in mind, in finite panels, failure can occur by net section yield also. If the crack length is sufficient be long enough, and you have the net section which is small enough, for a particular combination of loads, more than fracture, it would be plastic collapse, that would dictate how the panel will fail.

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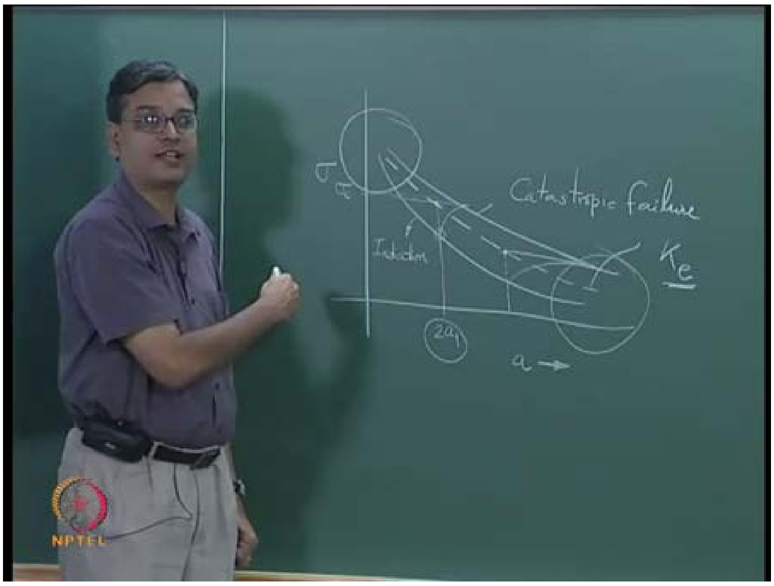

Now, what we will do is, we will look at how we can appreciate the apparent toughness. See, we have seen how a residual strength diagram would in general appear. So, I have a graph between crack length and I have the stress here. And you could have a graph something like this. Suppose, for a crack of length 2 a 1, let me say, that is 2 a 1, at a particular value of stress, you have a crack initiation; and what would happen is, you could have another graph like this, the crack would propagate like this and at this value of stress, which is sigma c, you will have a catastrophic failure. Once the crack length increases and touches this line, you will have a catastrophic failure. And here crack initiation takes place. And from this graph, what we are trying to do is, we want to develop the concept of apparent toughness.

So, for apparent toughness, what we are going to do is, we will have this stress, this line is inclined. So, I will write this as horizontal; I will have this and I will mark this point. For a crack length of 2 a 1, I have one point from this experiment, which will give the apparent toughness; similarly, I can do it for all the points. For example, suppose, I have a longer crack; to start with I have a crack length of 2 a 1. Suppose, I have a longer crack, crack initiation would occur at a smaller value of stress; and you will also find, that this will go a longer distance, and you will find the fracture toughness stress is that way; and you will be able to find out another point on your apparent toughness. Suppose, I join all of them, I have the graph corresponding to K e, that is the apparent toughness.

So, what you have here is, when you have the crack of length 2 a 1, crack initiates at a particular stress level, catastrophic failure occurs at this stress level, but you develop apparent toughness in such a fashion, the failure stress is sigma c, but initial crack length is a 1. Whatever the discussion that we are going to do later, you could construct it based on the apparent toughness; or you would also find graph giving initiation toughness, apparent toughness and the toughness at which catastrophic failure occurs. All the three graphs, people do it.

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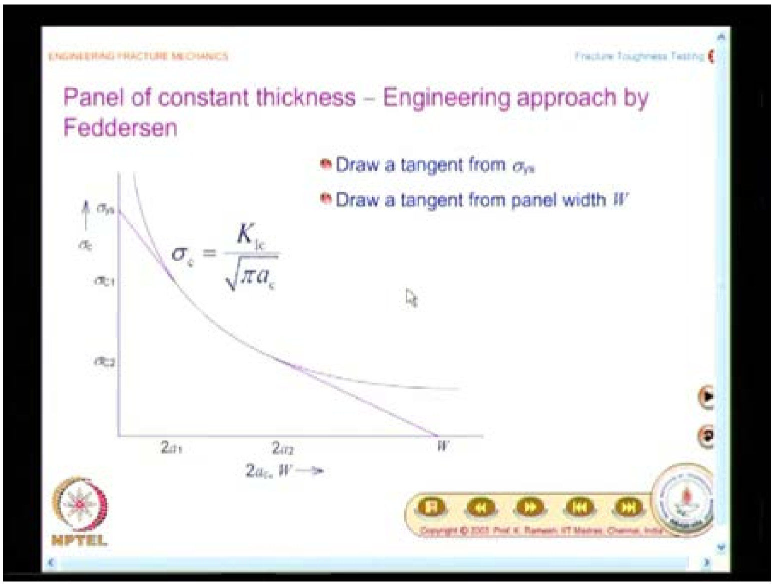

Now, the idea is, we want to find out, how do we handle data in these two zones. There is a simplification given by Feddersen. And we will do it, for one typical toughness. Similar graph, you could do it for other toughness values. And this is the approach, given by Feddersen. Mind you, it is an engineering approach. It is very practical, from field point of view. We are going to learn certain details about it.

So, on the x axis, you have the crack length and you could also see the panel width marked. You could also have the width of the panel, because, it is essentially a length measure. On the y axis, you have the failure stress. And I have written it for K 1 C; you could also write it for initiation fracture toughness or apparent fracture toughness. That will only confuse the diagram. So, I have taken one diagram. This diagram shows what? When crack length is small, you can have very large values of stress, which is not possible, physically. And if you say, it is a panel of small thickness, you will have a maximum stress as sigma y s because, (( )) yield criteria is the one, which is applicable for plane stress situation.

So, I could take this as a point, to start with. So, you have to draw a tangent; you construct the graph as it is being discussed. You have a initial graph, which is dictated by sigma c equal to K 1 C divided by root of pi a c. Now, you draw a tangent from sigma y s. This will meet this, at a particular value, which could be easily determined from your analytical geometry. I am not going to get into the details; I am going to give you the final values. So, that means, the residual strength diagram, will have a straight line portion plus a curve. You know, this goes beyond the panel width. Suppose, my panel width is this much, what is the useful range of my residual strength diagram? So, the recommendation is, draw a tangent from panel width W. So, for a width of panel W, the residual strength diagram would be a straight line portion, a curved portion and another straight line portion.

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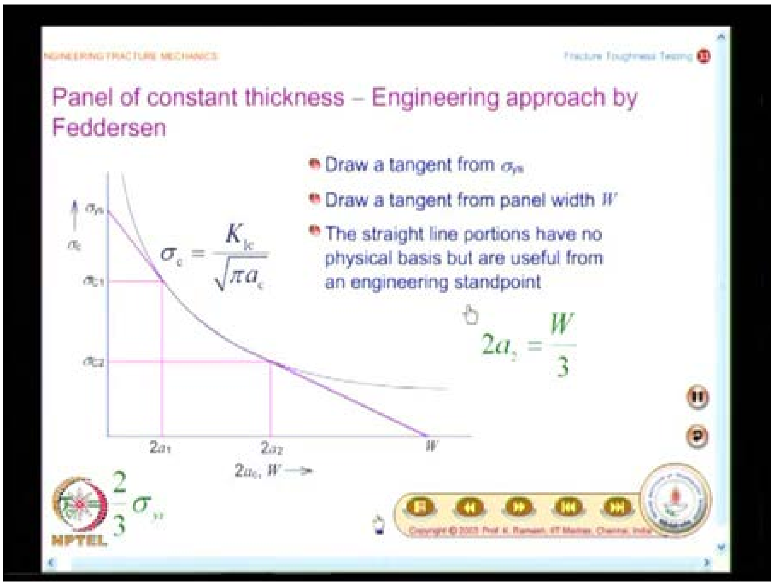

You know, this was the recommendation given by Feddersen. It is an engineering approach; very popular. People use it left and right. And what is now shown here is, what are the corresponding values of the crack length, when I put a tangent from sigma y s? The failure stress would be sigma c 1, that is given as two third of sigma y s. So, this is the reason in the screening criteria, we have said that, the failure stress should be greater than 2 by 3 sigma y s or less than 2 by 3 sigma y s. It was 2 by 3 sigma y s, less than that.

So, it should happen only in this region. So, you want to preclude what happens in this region? And if you draw a tangent from w, you have this as the corresponding point as 2 a 2 equal to w by 3.

So, your screening criteria is depicted here, in this fashion. And what you will have to keep in mind is, the straight line portions have no physical basis, but are useful from an engineering standpoint. Now, you will find many people, who are practicing engineers, they have contributed to fracture mechanics. They have brought in certain thumb rules and simplifications and they have made your life simple for applying fracture mechanics concepts to practical geometry.

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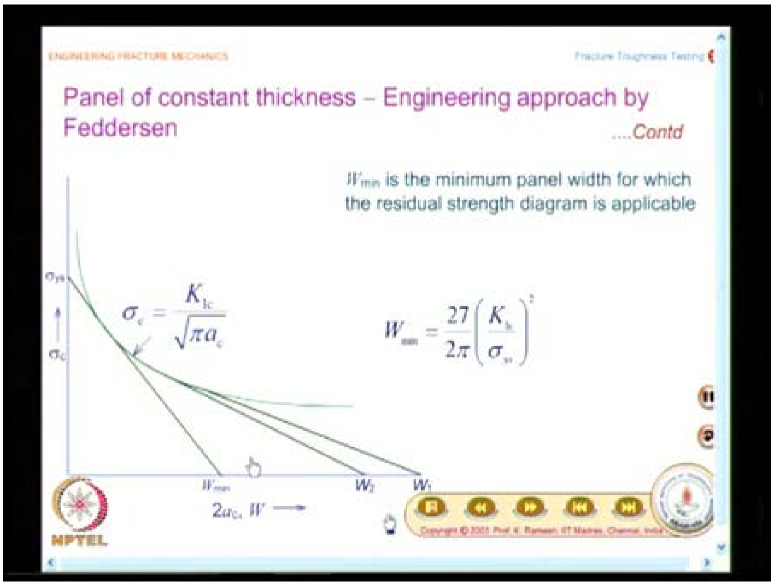

So, this is the way, that here it is given. So, you are not taking the complete curve; you will have a straight line portion, a curve and a straight line portion. From this, you could also go and find out, what could be the minimum panel width. We will see that. Suppose, I keep drawing tangents from the panel width; at one panel width, what you will find is, you will have only a straight line; there would not be any curved portion.

So, that dictates what is the value of the minimum panel width. So, you need to have that as a minimum panel width, for you to do the fracture toughness testing. It should be greater than that. And this minimum panel width is given as 27 by 2pi multiplied by K 1 C divided by sigma y s whole squared. So, what, summary here is, W minimum is the minimum panel width for which, the residual strength diagram is applicable. Because, ultimately, when you want to use fracture mechanics concepts for design, I need to get residual strength diagram. Once you go to elastoplastic analysis, you will have failure assessment diagram. They are called f a d. In the case of linear elastic fracture mechanics, you will have a residual strength diagram. I suppose, you have been able to draw the graph and it is very simple. You have to appreciate the concept and you will find that, there has to a minimum panel width, where you have only a straight line and that dictates this. So, you need to have a panel longer than that. Once you understand it, constructing this diagram is fairly simple.

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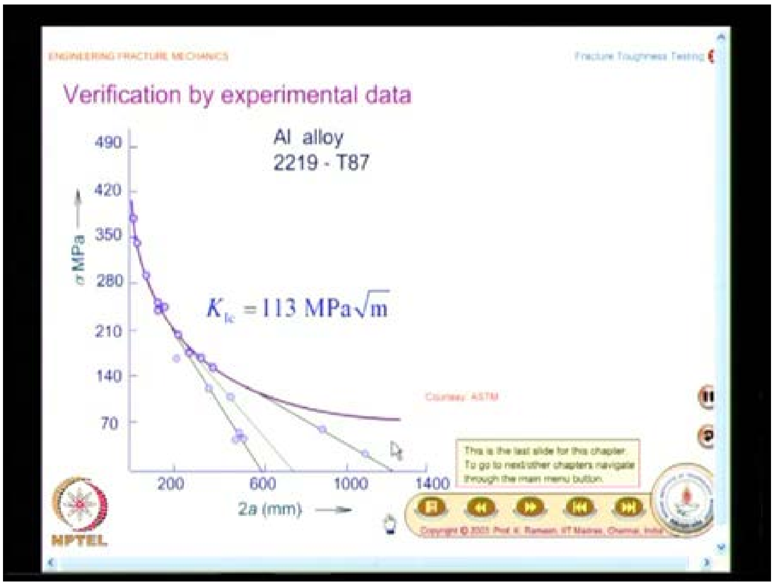

Now, the important aspect we have to look at is, is it justifiable? See, whenever people bring in any empirical approaches, the only way you can justify it is, conduct actual tests; and see whether your test results follow this pattern. As long as it follows, you are happy to accept this as an engineering analysis. And people have got this, and I have a result for aluminum alloy 2219. And I think, you draw the x axis, this gives the crack length. And you have the stress levels on the y axis. These points are drawn and you have a line passing through that. The K 1 C for this alloy is 113 MPa root meter. And using the Feddersen's approach, you can draw tangents for different panel widths.

And people have found that, from the test, some of the data also matching with these lines in the experiment and this is courtesy from ASTM. So, this gives the justification, Feddersen's approach for engineering analysis is reasonably acceptable. We can carry on with it. Someway, whatever the knowledge you have gained in fracture mechanics, you should be able to translate it to field application. So, you need to make certain engineering approximation, which is beautifully done by Feddersen's analysis. And this brings to a close of our discussion on fracture toughness testing. Now, we move on to the next chapter.

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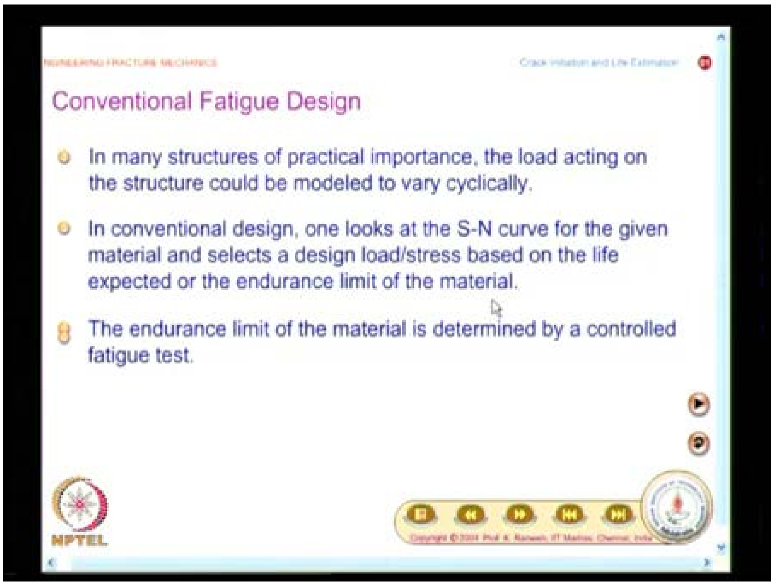

Now, we move on to the chapter on crack initiation and life estimation. And before we discuss, it is good to look at, what is the conventional fatigue design. Because, all you know, many structures experience variable loading. Very few structures have monotonic loading. So, you have to accommodate response of the structure due to variable loading. And one of the simplest modeling that you could do is, that the load varies cyclically. Later on, we will bring in Fourier series analysis and express the complicated loading as addition of harmonics and then handle the situation. And, what do you do in a conventional fatigue design? You will take the help of on S-N curve; for a given material search for the S-N curve; from that, select a design load or stress, based on the life expected or the endurance limit of the material.

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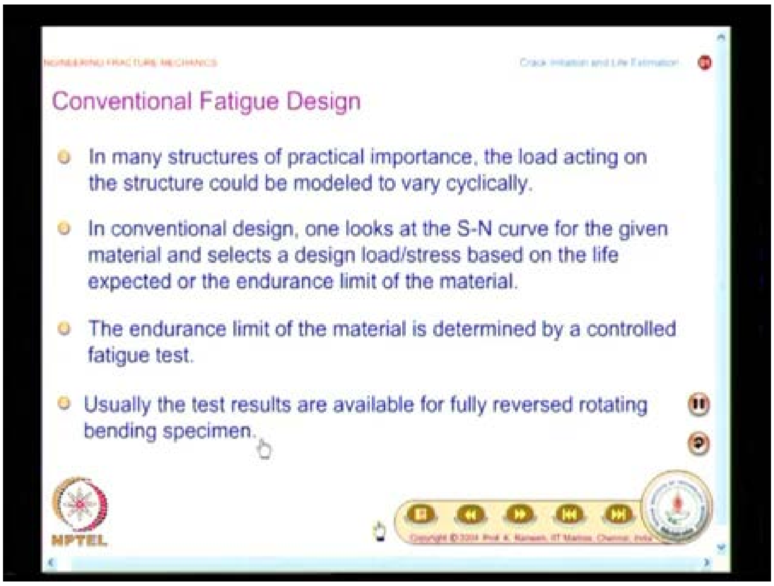

This is how you proceed. And you have to keep in mind, the modern research says, there is nothing like endurance limit for any material. At some value of stress, cyclical stress, the material always fails. May be it may take a long time to do; that is a modern understanding. But conventionally, what you do, if we have a cyclical loading, you just take the S-N curve for the material and try to use the data appropriately, on that basis of your need. And you will have to note that, endurance limit of the material is determined by a controlled fatigue test. And usually, the test results are available for fully reversed rotating bending specimen. Somebody gives you the S N curve, the default specimen configuration is fully reversed rotating bending specimen. For any other situation, you have to bring in appropriate correction fractures to those results.

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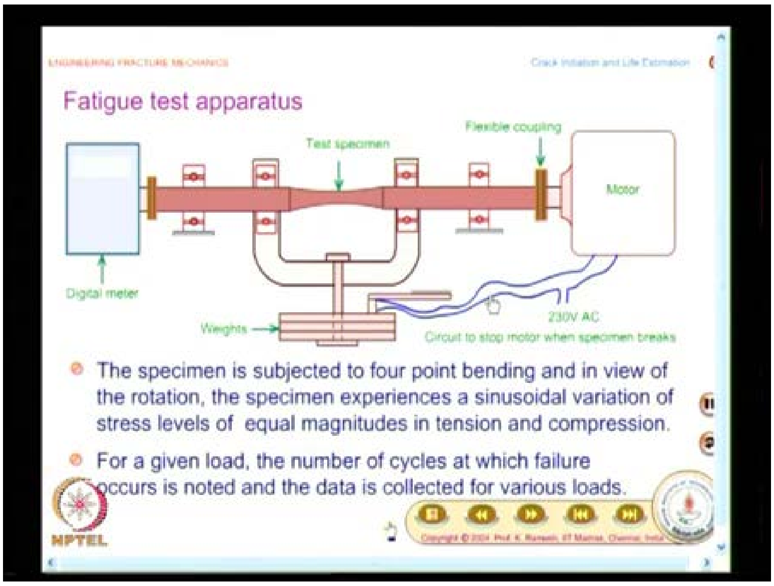

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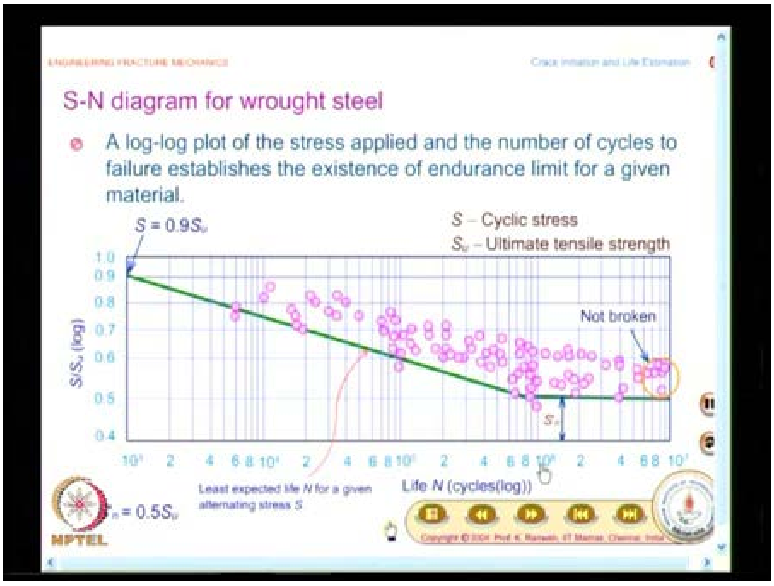

Those results are well documented in fatigue literature. And the point I would like to emphasize here is, what do you do in a fatigue test. You have a four point bend specimen; you apply the loads and you note down, when the specimen breaks, what is the number of cycles? That is how, even the circuit diagram is designed. You are only noting down, at what value of cyclical stress and what is the number of cycles, the specimen breaks. You are not monitoring what happens when you have a crack, how the crack proceeds and so on and so forth. Based on this, you have collected data from a fatigue test and the famous S-N diagram for a typical steel is given. It is a log-log plot, what is given and you will have a scatter. Any properly conducted test would have scatter.

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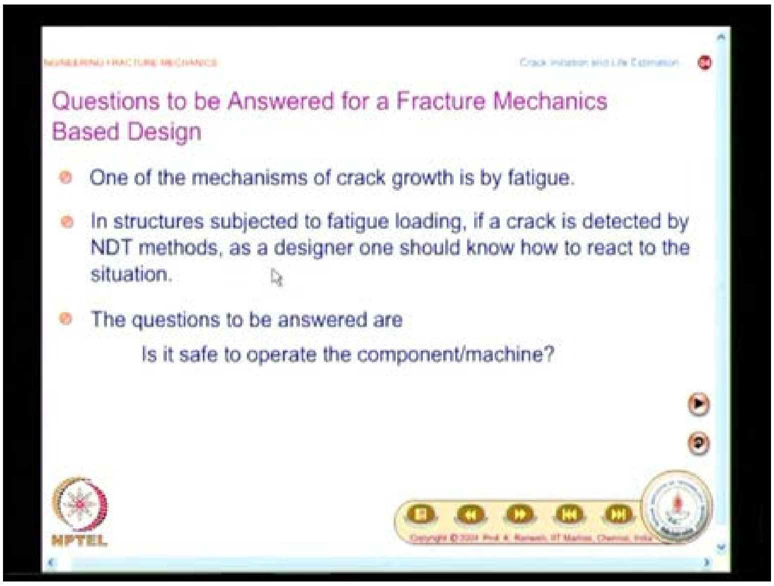

And you draw a line, which is the least expected life N, for a given alternating stress S, and you find out what is the endurance limit; and this is how you proceeded in a conventional fatigue test approach. Fatigue based design, you will do only this. The moment I come to fracture mechanics, I am going to ask more questions and you have to keep in mind, one of the mechanisms of crack growth is by fatigue; the crack grows in service.

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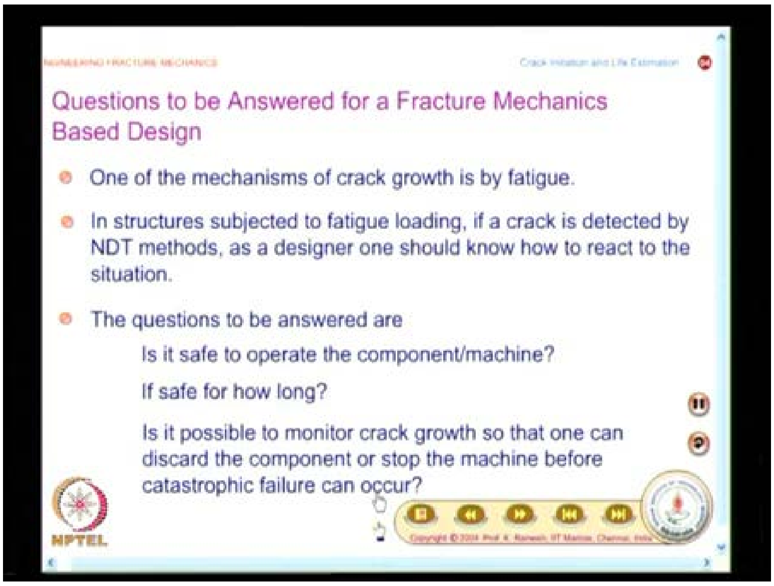

So, in a fracture mechanics scenario, if I have fatigue crack growing, suppose you have a N D T method which detects the crack, as a designer, how one should react to the situation? Is this, that you get alarmed a crack is seen, so discard the specimen, discard the structure or you do corrective measures. And this has to be based on scientific advice; you cannot have a random judgment. The questions to be answered are, is it safe to operate the component or machine; if safe, for how long; is it possible to monitor crack growth, so that, one can discard the component or stop the machine before catastrophic failure can occur. Something related to these questions we have asked earlier, what a fracture mechanics course should help. Those questions we are asking again and you should keep in mind, these are very important issues; particularly, if you look at an aircraft, every takeoff and landing is considered as a cycle. In the long flight nothing much happens, but takeoff and landing are very crucial.

Every takeoff and landing, you know, you will have engineers to come and inspect certain aspects of the aircraft and after so many hours of flying, they have a schedule what components have to be looked at.

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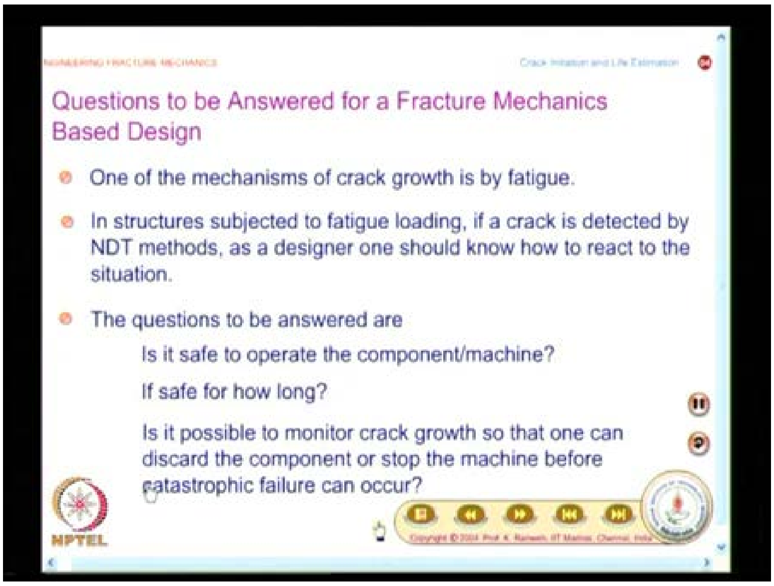

So, you have a schedule developed. So, if you have to develop a schedule, which is also going to give you safety for the passengers, as well as the structure, you have to have a scientific basis and decide these schedules. A fatigue test result is definitely not suitable to answer these questions. So, you need to definitely go in for additional tests, collect additional data; once you collect data, what you do with it? Because, data has to be presented in a form, that you can use it. There has to be some kind of ingenuity in presenting the data. That is what you would see in the next class. We would see, what is the contribution of Paris in utilizing this data.

We would also look at, what are known as crack growth curves and voluminous data collected has to be used and presented properly, for you to make sense out of it. So, in this class, we essentially focused on plane stress fracture toughness testing. The important point we highlighted was, you do not need a fatigue crack; even a saw cut would do. That does not give you an allowance to take saw of any size; there is a restriction on what should be the root radius.

So, that dictates how fine your saw should be. Invariably, you should have a stable fracture followed by unstable fracture; and people make a video record of this plane stress fracture toughness testing. So, if there is no stable fracture, they would discard the test. And we have seen the panel width also plays a role and one of the outcome of this test is, residual strength diagram, recommended by Feddersen. And we have also discussed what is an apparent fracture toughness. And we have also looked at the experimental justification of the engineering analysis by Feddersen.

And finally, we had looked at, what are the basic procedures adopted in a conventional fatigue based design and in a fracture mechanics based design, what kind of questions that we need to have answers. That would require collection of additional data and presentation of data in a useful fashion for us to use. All these, we would see in the next class. Thank you.