Failure Analysis & Prevention

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Lecture - 34
General Procedure of Failure Analysis: Application of Fracture Mechanics II

Hello, I welcome you all in this presentation related with the subject failure analysis and prevention. You know that we are talking about the general procedure of the failure analysis and we are in the almost last stage of the failure analysis procedure. We have talked about so many aspects related with the failure analysis procedure and today we will take up the two aspects, one is how the fracture mechanics can be effectively used to establish if the failure can occur in the presence of the given discontinuity and under the given service load conditions.

So, this is what we will try to establish through a 2 examples and thereafter we will see that if required then we need to conduct the test under the simulated conditions of the material, which has failed. Sometimes the such kind of the behavior is shown by the material which is not well understood, especially this happens when the component is subjected to the service under the unique kind of environmental conditions, in which the degradation in material properties take place and such kind of the degradations sometimes causes the failure of the component.

So, in order to understand in which way material will behave under the actual service conditions, sometimes simulated service test is conducted under the conditions corresponding to the actual service conditions of the component, which has failed.

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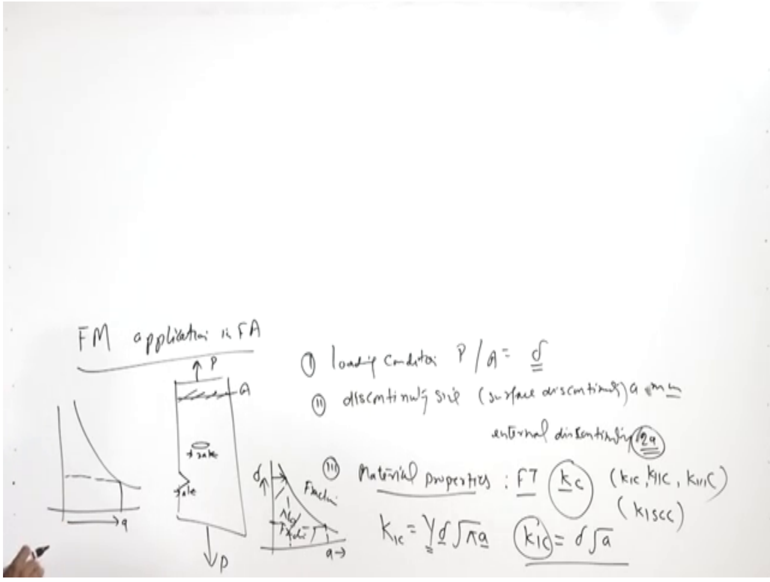

So, here we know that the fracture mechanics application in failure analysis, fracture mechanics you know that it relates with the loading conditions. So, we know that from the load and the cross-sectional area we get the service stress or the stresses which are being applied in the component then using the NDT it helps in identifying NDT and macroscope it helps in identifying the discontinuity size, say the discontinuity size is for the surface discontinuities,.

It is like say a and it is mostly expressed in mm and for internal discontinuities which are within the surface internal discontinuity is taken as 2a because we in final equation we use basically a only, so internal discontinuity of the 2a length ah, it is like this the component subjected to the external load P having the cross-sectional area A and using these two we determine the applied stresses that is sigma and say if the discontinuity is present inside then its length is taken as 2a and if the discontinuity is present at the surface then its length is taken as A.

So, in addition to these two aspects means the loading conditions and the consideration of the discontinuity with regard to the resistance to the failure third aspect is the material property, material property which is able to register the growth of crack means because the discontinuity is already present in the material.

So, material property which is used here is the fracture toughness and mostly it is the KC or as per the type of loading it can be like K1c or K2c or K3c depending upon the mod of the loading suitable type of the fracture toughness parameter is used and if the component is exposed to the corrosive conditions under the tensile loading then we use K1scc which means that the fracture toughness in the stress corrosion conditions.

So, this is the material property which is also quantified, and we have already discussed that the discontinuity size and the sigma apply the stress for the failure resistant they follow a particular relationship where in the K1c say is given by the 1 constant which is a geometry related constant then sigma under root pi a.

So, sigma is the applied stress, a is the crack size or discontinuity size and Y is the geometrical parameter which in case of the thick sections and very wide sections it is taken as 1. So, under the simplified conditions, this becomes equal to the sigma K1c is equal to sigma pi a. So, here because this is the material property which is constant, so for various combinations we are able to have the size of the discontinuity which can be tolerated. So, in this situation this is the zone which is of the no fracture zone and after this, in this area the fracture will be occurring.

So, here from this diagram, we can see that therefore the different combination of the stresses, there are different sizes of the tolerable discontinuities and beyond that what we will see that the fracture we will take place. So, for the low stresses, the discontinuity size is tolerable, size of the discontinuity is larger as compare to the case when it is of the higher stress value. So, it can be in either way like if the larger discontinuities need to be tolerated then the applied stress need to be, they should be reduced.

So, now considering this background, now we will take up the 2 cases wherein it has been demonstrated how to determine for a given service conditions whether failure will be occurring or not or for a given service conditions what will be the tolerable crack size in order to avoid the sudden fracture through the growth of the crack.

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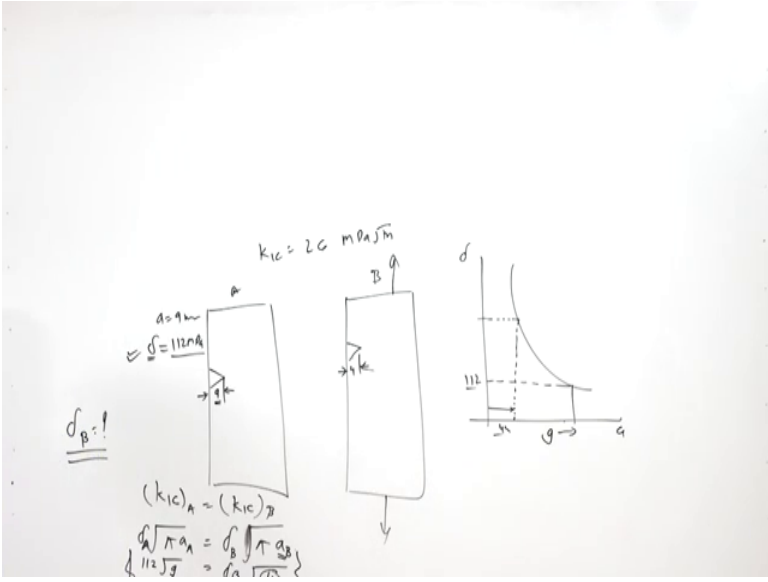

So, here like I have 2 cases, in one of the cases, like say this is one and the same component of the same material in one of the cases say both the samples A and B are made of the same metal having the K1c value of the 26 MPa to the under root M, this is the unit of the fracture toughness of the material of which components are made, say the component A is having the crack size of the 9 mm,.

so the value of A is 9 mm for the case A and it is a subjected to the applied stress of 112 MPa, so this is the sigma value for the case A while in case of the size of the discontinuity is 4 mm ah, this one is 4 mm and since both are made of the same metal system, so it is required to find out how much stress it can sustain prior to the fracture.

So, from this diagram if we see when we are having the discontinuity of particular size, this is the kind of the stress conditions, this is you can say the failure stress sigma, so failure stress is the sigma for this one for the 9 mm size of the discontinuity.

Since both these metals are made of the same metal, so when the discontinuity size is more say 9 mm then the applied stress value for causing the fracture is say 112, but when we find that the crack size is just 4 mm then applied stress value to cause the fracture, here we have sigma and here we have A value ah, so for the smaller size of the crack say of the 4 mm, the applied stresses will be on the higher side. So, if it is required that how much size it can tolerate then that we can determine simply since the both the metals K1c for A is same as that of K1c for B.

So, if we write like sigma pi A for the system A, so sigma A and A, like this we can write for distinction the case A and case B. Similarly, for the another metal sigma B under root pi AB, so we know that here the sigma A is equal to 112, pi is common both the sides, it will be canceled and A is the crack size here it is 9 mm is equal to.

So, here sigma B is needed and pi has been cancelled, so this one is 4 mm ah, 4 mm is the size of the discontinuity in another case. So, from this we can easily calculate this is 9 mm, this is 4 mm and this is sigma B. So, from here we know both these values and using means just its by solving this we can determine the value corresponding to which the failure will be occurring with the crack size A. So, this will be coming out on the much higher side as compared to what is there 112 MPa for 9 mm crack size.

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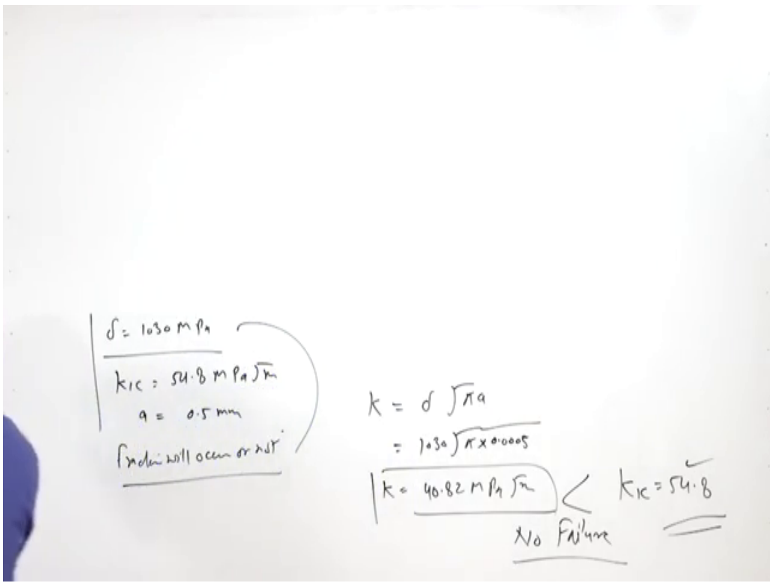

Ah Now we will take up the another case of the similar kind where like say the applied stress value is 1030 MPa in a component having the fracture toughness value K1c is of the 54.8 MPa raised to the power 1/2 under root M and like say the value of A is 0.5 mm.

So, we need to identify first whether under these set of the conditions the fracture will occur or not. So, since we know the value of the K1c, so for this condition we need to determine the stress intensity factor K using sigma pi a and here the sigma is 1030 pi and A so A is to be converted into meter. So, accordingly we have to write the value in meter, so A is 0.0005, so on solving this what we get K value that is the stress intensity factor for this situation.

A is coming 40.82 MPa raised to the power means under root M. Since the stress intensity factor under these set of conditions of the discontinuity size and the applied stress is 40.8 which is much lower than the K1c value which is a 54.8 for the material, so obviously since the stress intensity factor applied for a given combination of the applied stress and the size of the discontinuity, this one is lower than the critical stress intensity factor which is 54.8.

So in this case, obviously the failure will not be occurring, so no failure case is this. Now for this material, if you have to determine the conditions for the failure means the kind of up to what size of the discontinuity there would not be any failure if that is our interest, then that also can be determined.

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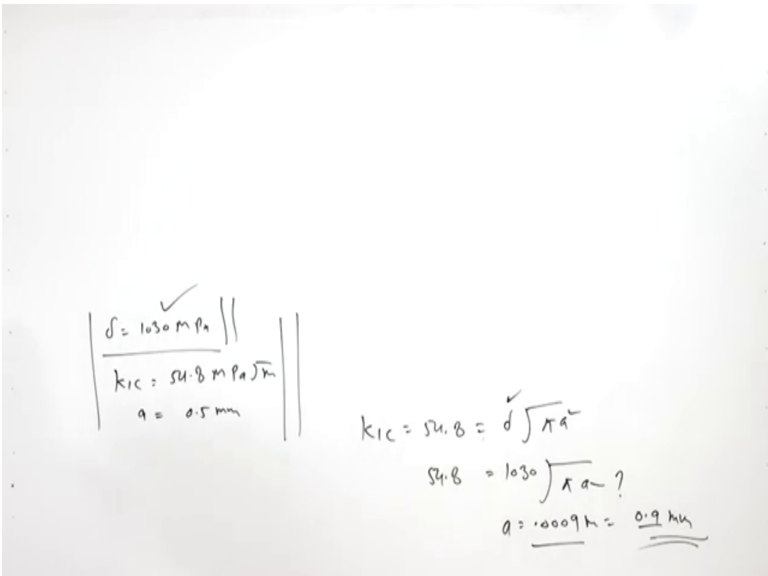

So, here since it is the failsafe design, there would not be any fracture, so we can determine either like say our K1c which is 54.8, this is constant. Now we can determine any combination of the sigma and A, so if we assume that sigma A has the same value then what will be the maximum tolerable size before the fracture, so A can be determined for the same value of 54.8. So, here what we get on solving this, basically we get 0.009 m.

So, it is in meter, so which is coming out 0.9 mm. So, this suggests that crack can be tolerated up to the 0.9 mm size and for the given same stress value the larger size of the crack can be tolerated. So, the crack growth up to the 0.9 mm can be tolerated and it will not be causing the fracture thereafter the crack growth will start.

So, this is how the fracture on mechanics principles can be used to determine the tolerable size for a given stress conditions or to determine the allowable service conditions with regard to the stressors for a given size of the discontinuity, but this is what is there for the material of the given K1c values, given K1c values means the different materials for the different values of the K1c.

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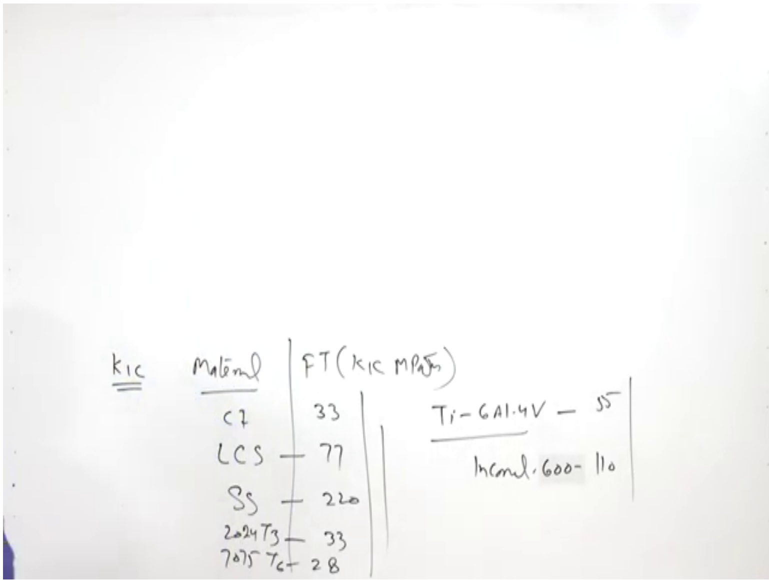

So, if we write material in one side and the factor toughness in terms of the K1c then that comes out to be different values like cast iron is very hard and brittle, so it offers the lower value of the fracture toughness like this that is 33 and low carbon steel offers the fracture toughness of the 77 units, stainless steel, like austenitic stainless steel offers around 220 units, it is very fracture tough and aluminum alloys like 2024 in T3 conditions offers fracture toughness of 33 units while the 7075 in T6 condition offers the things at 28 the fracture toughness value while for the most commonly used Ti – 6Al4V titanium alloy

It offers the fracture toughness of the 55 units and the inconel, commonly used in conel 600 offers the fracture toughness of 110. These are the fracture toughness values for the ambient conditions, say the same component when it is exposed to the corrosive conditions then they behave in completely different way. So, if the design is for the dry conditions or where the corrosion possibilities are absent, then this fracture toughness values can be used for developing the designs or developing the fracture resistant designs,.

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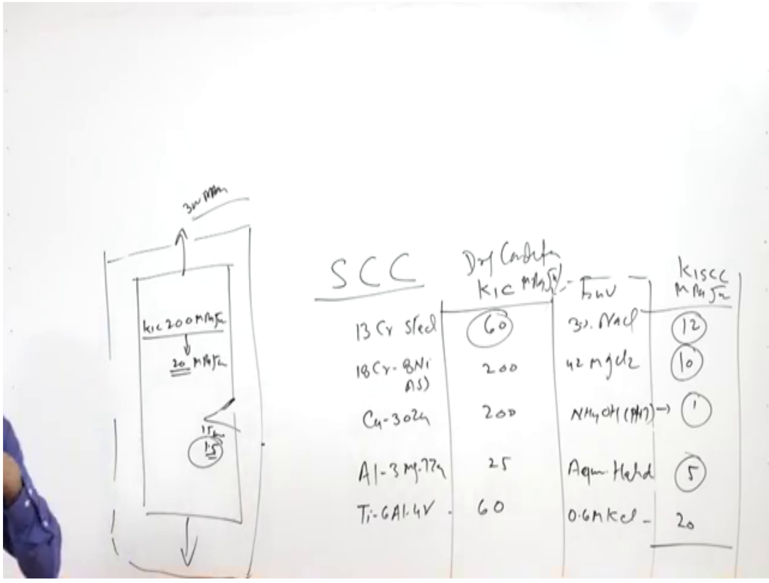

But if the component is subjected to the corrosion conditions like a product or the component is to be exposed in the special environment then as per the metal system, there are different metal systems are sensitive for corrosion to the different environments and they very adversely affect the fracture toughness of the material. K1c is very badly degraded, it may vary like say from 10 to 20 times lower than the K1c value under the ambient conditions.

So, it is very important to take care of this aspect especially when the component is to be used with the corrosion conditions then the fracture toughness value has to be considered for the K1ssc conditions, not under the dry conditions. So, here to have the idea about, I will just making like under the stress corrosion conditions how the fracture toughness of the material is adversely affected so we will write K1scc which indicates that critical stress intensity factor under the corrosion conditions when the tensile stresses are acting in the material.

So, this martensitic steel like 13 chrome is steel which is normally used in hydroturbines offers the K1ssc of the 60 units while this is in the particular environment of the 3% NaCl. So, K1c under the dry conditions dry conditions MPa raised to the power M, this is under the dry conditions and when it is exposed in particular environment the K1scc reduces very badly, again the unit is same MPa under root M.

So, how the values are degraded like the metal which was offering 60 units of the K1c value under the ambient condition, dry condition its value is reduced to the 12 while if we talk of the austenitic stainless steel like 18 chromium 8 nickel ASS which offers very high fracture toughness like 200 and under the 42 mgcl2 environment, this value gets reduced to the 10, so this is like almost 20 times the reduction in the fracture toughness value.

Similarly, the copper and zinc alloy with 30% zinc which offers very high fracture toughness which in the environment of the ammonium hydroxide, its ammonium hydroxide of the ph value 7, this reduces to the 1. so the huge drop in the fracture toughness takes place and wherever significant reduction in fracture toughness takes place,.

Those conditions must be kept in mind while designing the component for those applications then we have a aluminum 3% mg7, zinc aluminum, zinc magnesium alloy which offers the fracture toughness of the 25 under the dry conditions in the aqueous environment or aqueous halides it gets reduces, it is reduced to the 5 value of the fracture toughness while TI-6ALV4 which offers the 60 fracture toughness under the ambient conditions, the 0.6 mkcl environment this reduces by one-third.

So, we know that if the product is subjected to the corrosion conditions, especially under the tensile stresses then the tolerable crack size if we see the material which was having under the dry conditions 200 like say MPa raised to the power M 1/2 means under root M, so this is the K1c for austenitic stainless steel when it is a exposed to the NaCl environment or other halides environment what we see that the huge drop in fracture toughness takes place.

So, reduction from 200 to say the value of the 20 units of the K1c, this will directly with decreasing the tolerable under the given stress conditions of say 300 MPa if there is a drop, allowable stress is 300 MPa for the given crack size of say 15 mm, the size discontinuity allowable stress is 300 MPa and allowable crack size is 15 mm because of its good fracture toughness, just for example, but when it is exposed to the corrosion conditions under the tensile stresses it gets reduced by 10 times, so in this case the tolerable size of the crack will be reduced to 1.5.

So, with the change of the environment there will be significant reduction in the tolerable size of the crack or indirectly there will be significant reductions in the maximum stresses which it can accommodate. So, it is important to consider the fracture toughness, especially and in that particular environment when it is expected that component can fail under the stress corrosion conditions.

So, in order to prevent the growth of crack under the stress corrosion conditions the K1scc must be considered so that we will be aware of how much crack size can be tolerated for a given combination of the stress and the size of discontinuity. So, there was significant reduction in the value of the fracture toughness in the corrosive environment suggests that we need to be extremely careful when the component is expected to perform under the corrosion conditions.

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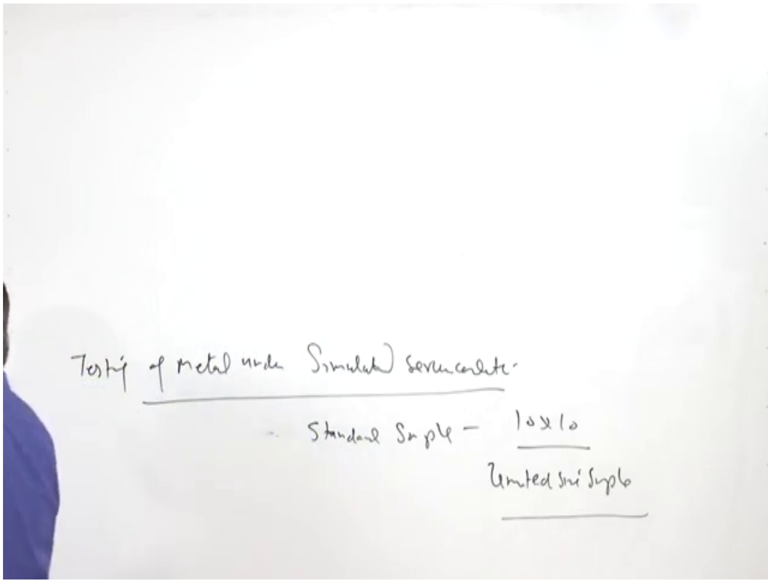

Now, next the point related with this is the that conducting the test of the material, testing of the metal under the simulated service conditions because most of the tests are conducted under using some standards, so we use basically for that purpose standard samples, for example, 10 x 10 mm crosssection for the fracture toughness or particular gauge length for the tensile sample of the particular diameter.

So, the sample size are of the limited size samples and they give the values corresponding to given set of the standard conditions of the test ah, but actually the component can behave in a completely different way when it is used under the actual service conditions which are completely different from the tests conditions, which were used for characterizing and the designing the component.

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So, it becomes important to see really in which way material will behave under the actual service conditions ah, say for example, when the component test is conducted on a small sized samples then it does not experience the tri-axial stresses state ah, but as the dimensions thickness increases then it leads to the reduced, it suppresses the plastic deformation tendency and which in turn decrease increases the brittle fracture tendency of the material.

Similarly, most of the tests are conducted in the environmental conditions like in the ambient conditions, but if the component is to be used either at low temperature or high temperature or component is to be used in particular environment, like a particular ammonia environment or a kind of sulfides or some other kind of like NaCl or some other corrosive environment is there, in which the component is expected to perform then it is always desired that for the failure analysis of such components a test under the simulator service conditions is conducted, about this I will talk in detail in the next presentation.

Now I will summarize this presentation. In this presentation, basically I have talked about how to utilize the principles of the fracture mechanics to analyze the case of the failure with regard to the applied stresses and the size of the discontinuities which are present in the component.

We can also determine the allowable size of the discontinuities or allowable stresses for a given fracture toughness values of the material which has failed. So, basically this helps in determining the role of the discontinuities in the failure. At the same time, still if you are not able to find properly that in which way failure has taken place, then it would be good idea to perform the test under the simulated service conditions.

Thank you for your attention.