Advanced Ceramics for Strategic Applications
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Lecture - 43
Magnetic Properties of Ceramic Materials (Contd.)

Welcome, we will continue our discussion on the mechanical properties of ceramic materials. In an earlier lecture, we will introduce the concept of a fracture toughness, the critical claw size or crack size and also the fracture stress. And that was based on the Griffiths theory in which their energy, the total internal energy and the surface energy terms have been maximized. And we have found that beyond a particular critical size of the crack; the crack propagates on its own it does not need any further stress to be applied, because the extension of the crack reduces the overall energy of the system.

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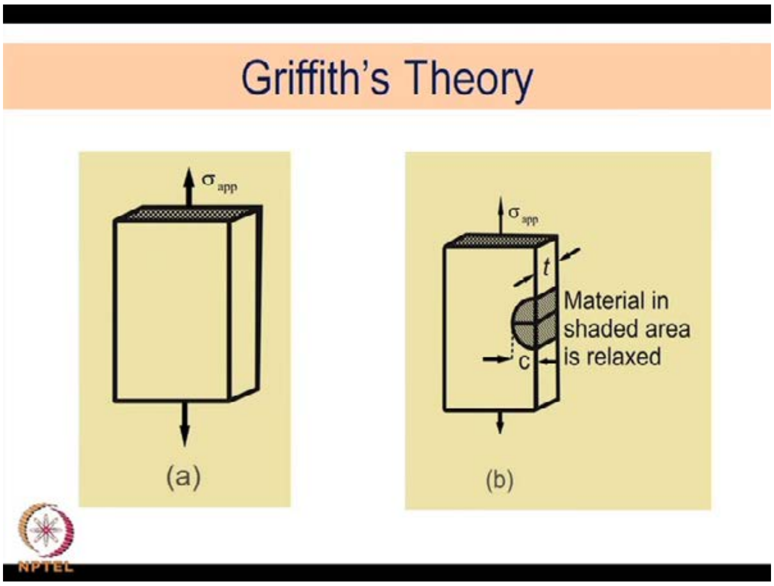

We have considered this kind of situation, where a crack is growing are initiated at the age of the sample and in normal stress applied, sigma applied has been applied perpendicular to the crack direction. So, this is certainly a one kind of a stress application of stress or orientation of the stress in use the crack length is perpendicular to the applied stress. However, that is not the only way one can apply Elliott a stress on the material particularly in relation to the orientation of the crack.

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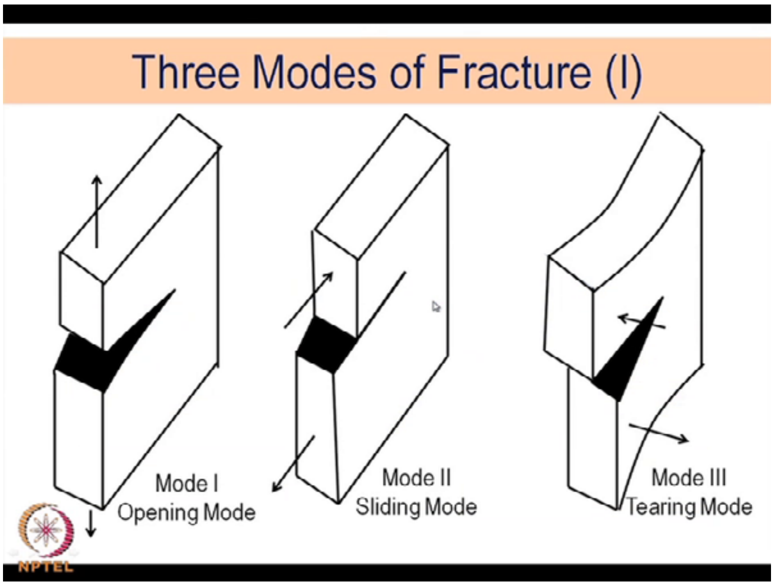

Infact, there may be different other orientations possible impact, there are 3 different modes of fracture, when the crack, the direction of the crack and the direction of the application of the stress are different. So, the first mode is called the opening mode, where which actually you have consider earlier where, this is the application of the applied stress and it is trying to open up this correct in this particular crack the crack is perpendicular to the surface and also perpendicular the application of the applied stress. So, this is what we call the opening mode and or sometimes called mode 1 in the second mode. The application or the direction of the stress is once again perpendicular, but it is a in a different direction.

So, one part of the, one side of the sample around the crack is being compressed other being expanded or on the tensile mode. So, here it is a kind of the crack is moving, the crack is moving along the application of electric a along the application of the stress, applied stress. So, this is what we call is sliding mode and one can very well distinguish between the orientation of the stress and the crack here and the stress and the crack there. Still, there is a third mode were the direction of the application of the stress is actually along the crack. So, this is in the right hand direction and this is left hand direction and the crack is propagating away from the surface.

So, impact the crack is perpendicular to this vertical surface. The stress is also perpendicular to these vertical surface only thing on the top side, top end it is used backward and here is pulled a away from the crack. So, this is called the model 3 mode 3 or the tearing mode. So, these are the different ways of crack propagation or different orientation of the crack with respect to the applied stress. As you can visualize this is one of the most easier way to crack propagate wherever, they are the applied stress is in this direction than is it easier for the crack to propagate with a much lower stress.

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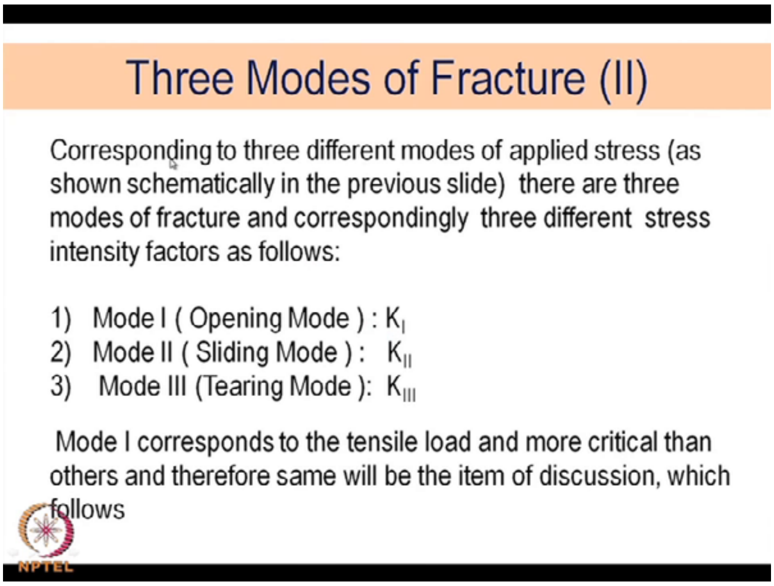

So, corresponding to these 3 modes so, applied stress, there are 3 modes of fracture judgments, which can be defined and correspondingly 3 different stress intensity practice can also be defined. So, the mode 1 the opening mode stress in density factories K I what K 1, mode 2; this is K 2 and then mode 3 is K 3. So, it is opening mode, sliding mode and the tearing mode. Mode 1 corresponds to the tensile load and the other one are searing mode, searing, this is the tensile load and more critical than others. Therefore, say only the item of discussion which follows that most of the time; whenever, you discuss about the fracture toughness. It is this kind of fracture mode, fracture mode which will be more concerned with, because that is more critical than the others.

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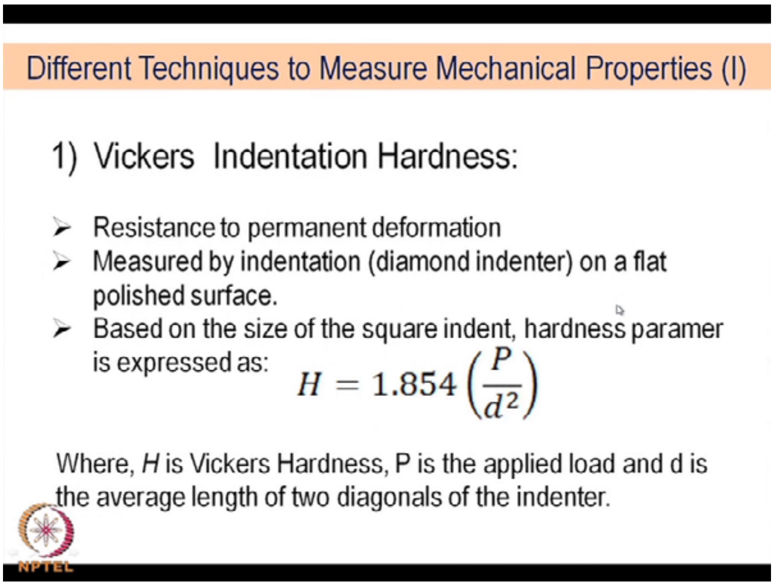

Well, I will discuss that let us try to look at the different techniques of measuring the mechanical properties. Of course, fracture toughness is one of the important mechanical properties, which we must understand or major. The value of that particular parameter experimentally will come to that how exactly the fracture toughness parameter can be major 4 different samples and what kind of specimen preparation is needed? What kind of different techniques? What kind of different loadings, can be considered.

But before that there are many other, mechanical property related parameters which also involves mechanical property of ceramic materials and latest try to sum define them and tried see how they can be majored experimentally. Very first one is the whiskers indentation hardness, while hardness is on a always a very important parameter. So, for the mechanical properties concern and it is the, most the time it is the indentation hardness which is major. So, the help of a indent invading group there and try to find out, what is the size of the group are under what kind of load. So, the whiskers indentation hardness is basically, majors the resistance to permanent deformation because, if you try to make an indent a it is should not be relaxed or a it should be a permanent indent and therefore, it is a permanent deformation.

So, whatever small it is; obviously, for compared to ductile material for brittle material or for ceramics in particular. The permanent deformation is negligible and therefore, you need larger amount of stress or larger load to make an indent, but some amount of indent can certainly be done. Since, ceramic materials are very hard, we always use diamond and that is the by definition whiskers indentation always use a diamond indenter and it is in the form of a squire pyramid. And it is done on a polished surface, polished surface is required because, the old overall dimension of the indent is very small. So, unless there is a polished surface is difficult to measure the dimension of those elements.

Therefore, is always necessary that the ceramic material must be polished ground and polished first and then on that, we make the indent. Based on the size of the squire indent harnessed parameters is expressed as not going to details, how this particular formula has been derived, but one can find out in different textbooks. The hardness parameter is in a simplified way it is actually, 1.854 into P by D square, but P is the applied load, impact as you are possibly aware that in a whiskers indenter indentation hardness test one can Barry the load depending on the hardness, depending on the surface and many other parameters. So, depending on the particular depending on hardness one can Barry the load. So, load is an important parameter to calculate the hardness. So, well H is the whiskers hardness and P is the applied load and D the average length of 2 diagonals of the indenter, is a square indent you have in out the diameter to orthogonal diameters in orthogonal reduction and take the average of it. Show that is, every simplified formula for measuring the whiskers indentation hardness.

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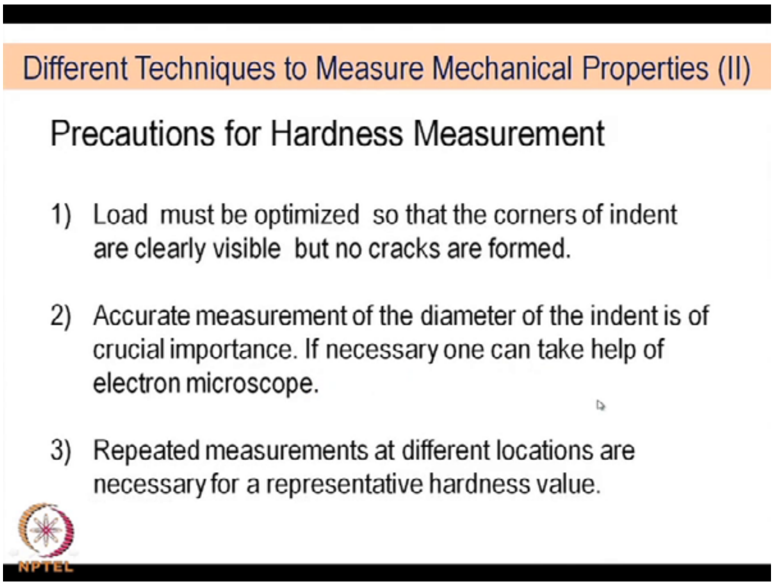

What are the different precautions you have to take during this measurement? There are few listed here, load must be optimized. So, that the corners of indent are clearly visible, but no cracks are formed, it is very important that, we should not initiate crack. So, the load you have to be optimized appropriately. So, that and you get a appreciable amount of indent, appreciable size of the indent. So, the measurement becomes easy or measurement becomes accurate, but at the same time you have to limit the load. So, that that indent does not because there is a stress concentration at the corners and that you have to take into account.

So, that there is no crack initiated at the corners, impact crack initiation means it will not give the right, that accurate measurements of the diameter of the indent is of crucial importance, if necessary on can take help of the electron microscope. Normally, optical microscopes are used to measure the dimensions diameter or the dimensions of the indent and it is in the order of a microns, certainly less than millimeter and if very fine in units their one can even take help of electron microscope for accurate measurement. Because, it is the D square coming at the hmm sorry, D square coming at the denominator and. So, any in accuracy here in the d value will certainly lead to a larger inaccuracy of the measurement of the parameters H.

So, accurate measurement of the diameter is also important, repeated measurements at different locations are necessary for representative harnessed value is sometimes it is very difficult to find a homogeneous sample for many different reasons. So, there will, grain size different than we blunt faced materials and so on. So, it is necessary that you one carries out a, a large number of fairly, representative number of hardness tests or the measurements. So, that an average can be taken and a representative value can be report. So, these are few precautions, what we always take while make taking the measurement.

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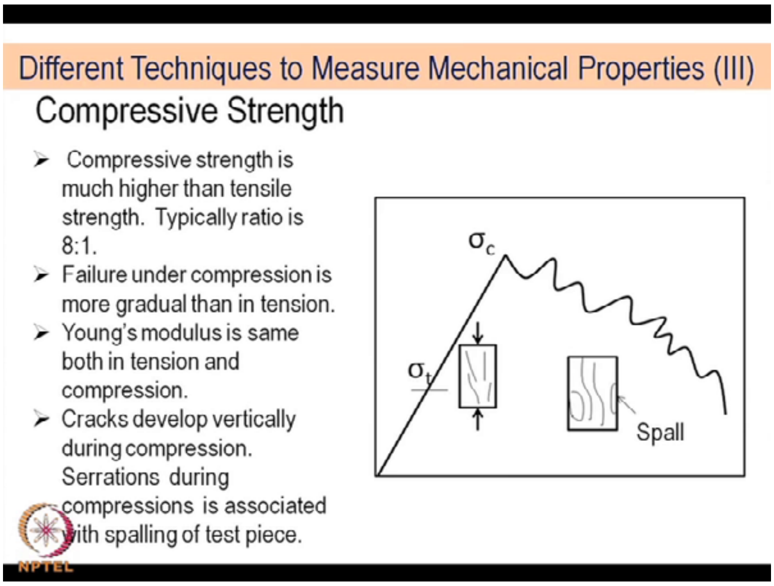

Then there is a, another very important parameter which is compressive strength. As will always notice that imports ceramic materials will never normally do not report the tensile strength because, tensile in the tensile strength is quite poor. So, whereas in the compressive load, it is much stronger. So, most of the time, for ceramics it is the compression, strength which is reported and the measurement is also quite relatively easy, because for tensile, specimens you need a complicated set, specimen and that kind of complicated space shapes are difficult to make with are and strong ceramic materials.

So, it is much easier to make compressive measurements in the form of a cylindrical samples and it also gives much better representative strength. Show compressive strength is in addition to whiskers hardness to have discussed compressive strength is another parameter, which is measure are, which is reported to provide the mechanical strength of ceramic materials. So, compressive strength is a much higher than the tensile strength that is always true for any ceramic material typically the ratio is 8 is to 1. So, if the compressive strength there is or one is the tensile load, tensile strength compressive strength is a nearly 8 times that of the tensile load, impact here is a stressed diagram. It is a, this is strain and, this is stress which has not been mentioned here, but this is a normal curve of stressed in diagram and you can see, this is the initial elastic range this is; this is the compressive stress and this is the tensile tests.

So, the tensile load it fractures here particular, I will apply compressive load, it can go up to a much higher level without fracture. So, the fracture the deformations starts here in the compressive load, in the tensile load, it just goes up to that and fractious. So, failure under compression is more gradual and gradual than intention and that is also a demonstrated here. If you have a tensile load, it goes follows this line because, of the elastic modulus are elastic deform deformation and then suddenly fractures. Whereas, that is why it is not shown here. Whereas, in compressive, load you have a more gradual breakdown or deformation, before it actually fails some of their; however, as you can see compared to a normal ductile, material fracture or ductile fracture the permanent deformation or the plastic deformation here, this not a smooth curve; is not a smooth curve it goes through a lot of serrations.

So, it appears or it represents that the fractious takes place in different kind of steps, it is not a very smooth regular progression. Young's modulus is same more or less same in both intentional and competition, the same line follows. So, far as the elastic zone is concern. So, because the young's modulus basically, the slope of this line. So, you have more or less the same slope crack develops vertically, during compression and serrations during compression is associated with spalling of the test piece. Now, this is little bit discussed we already, that you have a serrations. It is a more gradual mechanical permanent deformation, but it is not a smooth curve, there are suggestions their and the other thing is cracks normally formed vertically, a in metallic material. Normally, the crack appears at a 45 degree angle, that is the normal way normal range of serraious stress, a normal orientation the serraious stress higher; however, in a compressive tests for ceramics a crack appear like this.

And finally, it combines cracks join electrons, crack can be generated or nucleated at different sites and these vertical cracks finally, joins and there may be what we call the spolling, spolling means the part of the sample just comes out; comes out of this surface. So, towards the end of this experiment will see some of the portions of the. So, surface material just comes out a gets loosen because, the cracks gets join together, larger cracks appear and they come out of the surface. So, that is what, we call spoll. So, this is a there are some kind of features of the compressive a stress test which is carried out an ceramic materials.

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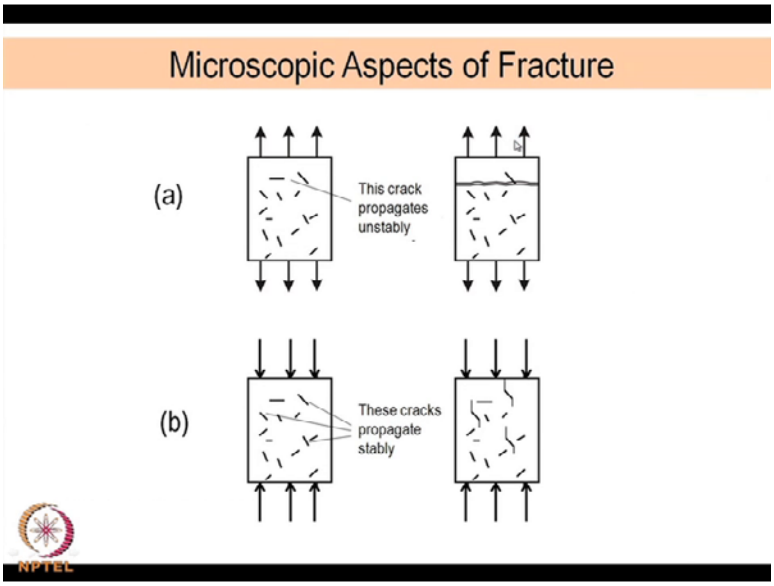

Well, these are another little microscopic aspects of fracture, both in tensile load. This part is one tensile load, decision compressive load and we have already seen, that it is the crack or impact the preexisting cracks, which are primarily responsible for the fracture of orbital fracture of ceramic materials. Now, these pre-existing cracks can generate because, of various reasons, primarily during its preparation because, of the thermal history and sometimes, there will be some kind of a dual phase material have a different thermal expansion coefficient's or generally ceramics are thermally less, thermally conductive.

So, a temperature uniformity is a problem in all ceramic preparations ceramics, always required high-temperature for the sintering and other fabrication processes. So, during cooling, if it is not an equilibrium cooling there will be always thermal stress generated in the sample and those thermal stress may lead to different kind of cracks, these cracks are pre exists in most of the samples. So, that is one of the considerations are one of the theories of pre free that in brittle solids, brittle materials particularly, in ceramics because of the thermal history. Because of the thermal a low thermal conductivity will always have thermal gradient and that thermal gradient may lead to local stress generation, thermal stress of that thermal stress we finally cost some minor cracks. Now, these minor cracks on different size of cracks may not be very critical, as we have seen the defects theory that only the, if the size of these cracks are larger than the so-called critical crack, critical a crack length then that is very dangerous.

If it is a, their crack lengths are smaller, or smaller than the critical crack length, then they are not dangerous. They will not grow they will remain there only they can grow up very high large application of the application of large external stress. So, cracks do exist in ceramic materials brittle materials are in this most on this surface, but may be inside the material also. So, in any material you have a different kind of cracks, available in a random fashion their orientations are quite different random in nature. So, that is what it is shown there. Already, there are cracks and if you are being tensile load up to providing applying tensile load, sound is cracks will be more effective or more prone to a propagation others may not be that effective. So far is the propagation is concerned and that is what this is a, a this is a crack, which is a kind of mode one fracture were are applying tensile load in the scale, in this direction and it is trying to open up whereas, this is in slightly different direction.

So, the effectiveness of this stress so, for is the crack propagation is concerned is not so much. So, the preferred or the properly oriented cracks will certainly open up and that is, what it is says this crack propagates on stable, on stable in the sense, it is almost an interest instantaneous crack growth. So, this, are very crucial and very critical and in such cracks are there in large numbers material will immediately fail. It is a very material of very low strength particularly, under tensile. So, this is what will happen after sometime, this crack with suddenly fractured the material; however, the other cracks; other cracks which are oriented in a slightly different manner they may not be that dangerous and they may not allow need to failures.

So, this is a in tensile and this is in compression under compressive loads, a these are the cracks; obviously, this crack which is perpendicular to the load will not propagate under compression. The cracks which are slightly inclined or vertical in direction, these are the cracks all, these cracks will certainly extent or propagate getting elongated, under the application to compressive load and that is what has happened. In the second stage of the final stage, these vertical cracks, there will be some generation of the vertical cracks here, these vertical cracks will finally, join with these cracks existing cracks and finally, they will be spalling. If there are very close to the surface then there will be release of some portion of the surfaces a solid material from the surface and that is what we call spalling, which we have discussed earlier. So, these cracks propagate stably.

Now, this unstably and stably these two terms must be noted unstably means it suddenly fails or it is suddenly propagates, stably means it is a more gradual change, more gradual propagation of the crack. So, under compression it will, the in the both the cases will propagate, but one constable means they will propagate petty fast and were here is the more gradual manner. So, that is why you got a, a serrations here rite in tonsil load, it will be sudden fracture whereas, in compressive load there will be gradual fracture or gradual deformation and finding fracture. So, this is what happens under tensile and compressive loads. And compressive load is more common to measure are to report than the tonsil load

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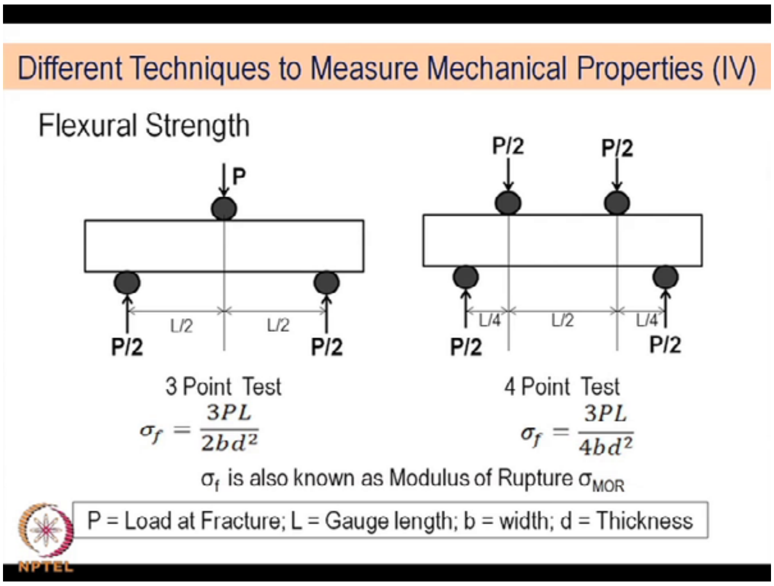

In addition to that kind of compressive measurement of the compressive load measurement, compressive strength measurement, you have another very important technique or a type of parameter, which measure is called flexural strength. So, flexural strength is of course, very common in between solids is not so, important in ductile material. So, metals and alloys do not perform this kind of test. So, much they perform in so for is metals and alloys conformt metal edges to perform tensile load whereas, in ceramics, ceramics will to perform flexible strength or compressive strength. Now, these are 2 varieties or 2 different modes of flexible strength, 1 is called 3 basically, a bending test, you have a support here on the bottom 2 different supports and on the top at the middle of the 2 supports you have a compressive load. So, it is this forces is acting oppose, this force is also acting oppose and this force is acting downwards.

So, there is of course, a there are standard dimensions for each of its measurements are not going to details of that. So, not any particular gauge length is useful, it can be measured you can always get a value, but if you want to standardize this process. There are some standard gauge lengths and standard parameters, standard length parameters, distance between the 2 probes, 2 supports than the width. As well as the height a, a all these things are standard specimens a have to be used. But there is another mode of using the experiment or carrying out this experiment, it is called a fourth point bend test or fourth point flexible measurements.

So, instead of 1 load point here, loading h u point, the middle of these 2 supports, but we have 2 different loading points. So, it is P by 2, P by 2, P by 2, P by 2 and once again, they are specific distances. Here, you can see this is L by 2, this total distance is L, this becomes a L by 2 with between these 2 loading points and here it is L by 4 and N by 4. So, that is also quite standard 1 is to follow this kind of standard. So, far is the loading pattern, on the loading points are concerned. As by doing this, as you can see in the bottom, we have a tensile load and on the top there is a compressive load. So, this actually gives you some kind of a combination of the tensile fracture and the compression fracture. So, compared to the earlier one, either you have a tensile load what we have done earlier either you have a tensile load or a compressive load, here both compressive and tensile loads are applicable or applied simultaneously by a different kind of mechanism.

So, it is by bending tests or flexible test a intent of 3 point bend test you have a this expression, this sigma fracture is equal to 3 P L by 2 B D square P is again, the this load which you have shown here A L is the length gauge length a L is the gauge length P is the load at fracture then it becomes the fracture stress. So, fracture a sigma F is known as the modulus of rupture, where remove of the fracture stress. Fracture stress is known as the modulus of rupture and that is a very important parameter for most of the ceramic material. Whenever, you are interested in mechanical property of ceramics. So, sigma MOR or modules MOR is a very common. So, that the mechanical property, value evaluation is concerned whether it can be done at room temperature or it can be done also at elevated temperature, particularly for refractory, you need what we call hot MOR. So, that is the standard test again which is carried out at a higher temperature in a 1400 degree centigrade depending on the application range of service temperature of the factories.

So, hot a MOR is a very important parameter for factories, but for many others which are used primarily at room temperature, the room temperature MOR is a an important parameters. So, once again from this, 2 expressions 1 is the 3 PL by 2 B D square, here this 3 P L by 4 B D square, that is; that is, the expression and P is the loaded fracture L is the gauge length. The distance between these 2 supports and B is the width with the, of specimen which is not seen here and D is the thickness. So, this 3 parameter length, breadth and distance thickness provides you this MOR so that is flexure strength.

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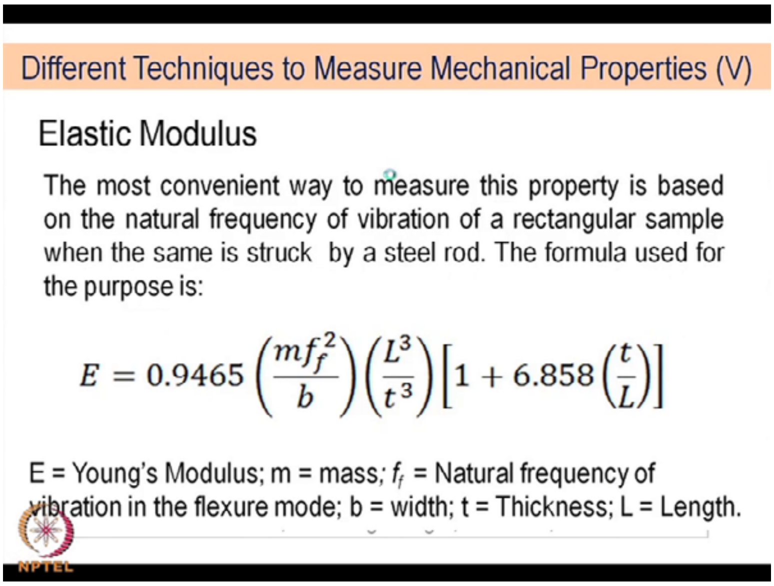

Now, elastic modulus of course, elastic modulus the best way to find out elastic modules as for definition, either you make a carryover tonsils load or a compressive load. And then from distressed a diagram from the slope of the cell stressed and diagram in the elastic range. You can always find out, the elastic modulus; however, there is for ceramics, there are much better slightly different way of measuring, the elastic modules which is not exactly the mechanical test, but it is a different test. The most convenient way to measure this property is based on the natural frequency of vibration of a rectangular sample. While the same is struck by steel rod it is a kind of tuning fork, kind of a experiment where, if you strike this ceramic with some other stress material, that is generated sudden stress on the material, then it actually starts vibrating and that vibration as a particular frequency.

So, that frequency is related to the young’s modulus of the material which is generating at frequency. So, that is the principal, that is the principle by which a the young’s modules of most of the ceramic materials are used not by carrying out the normal stress. A normal tensile stress or compressed stress that also provides you particularly compressive load also provides you some young’s modulus, but this is a nondestructive way, that was a destructive way while the samples are broken. You have do break the samples and a, whereas, here you do not really break the samples which are nondestructive way of measuring the young’s modules of ceramics samples.

So, that is what is once again to repeat the most convenient way to measure. This property is based on the natural frequency of vibration of a rectangular sample. When the same struck by a steel rod formula used for the purpose is like this the young's modulus is a once again, this is some of the slightly empirical formula. Of course, analyzed by some mathematical a means. So, ultimately of course, without going to the details of that the formula is 0.9465 m f f square by 2 above square by b and L cube by t cube and than that is an expression 1 plus 6.858 t by L. These are the parameters, these are the notations used in this formula young's modulus is of course, young’s modulus in is the overall mass of the bar, which you have used. Of course, because of total mass has a very important implications of the frequency of vibrations f the natural frequency of vibration in the flexible mode b is the width t is the thickness L is the length.

So, once you know the mass; that means, the weight of the sample also have to measure in addition to its thickness the width as well as length and then you have to measure the frequency natural frequency of vibrations. In fact, there is a computer program which actually automatically measures it. So, it measures it detects the vibration of course, there will be some damping effect also. So, it actually measures the vibration over a period of time and then find out the natural frequency of vibrations a and finally, provides you this a young’s modulus. So, it is mathematical sorry it is little complex to a otherwise measure it, but there are equipment available and the software's are also available which can directly provide you this number the young’s modulus.

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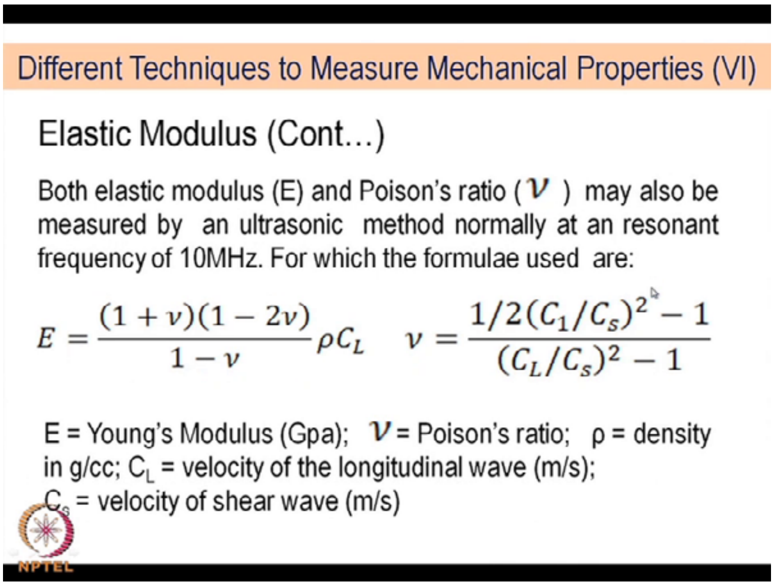

Now, then there is also another thing, 1 can measure the poisons ratio by slightly different techniques an impact that technique. Again is based on the propagation of ultrasonic sound, through the material, the material a different materials depending on its elastic module. The poisons ratio and density a, it, a it has a different velocity I mean it propagates, the ultrasonic sounds at different speeds are different velocities. So, and that is directly related to all that is somehow related to the young's modulus and other mechanical properties. So, in this technique both elastic modulus and poisons ratio measure when ultrasonic method normally added resonant frequency of 10 mega hertz for use the formula used are like this impact what it is we have earlier seen in this course there are piezoelectric transducers which can generate ultrasonic sounds or ultrasonic webs.

So, such kind of piezoelectric electric with generators ultrasonic generators can be used to measure either generate the sound or get in echo of that sound. On the other end and therefore, by measuring this kind of piezoelectric sensors and generators you can find out what is the velocity of the velocity of propagation. And from that, you can find out the; find out the young's modulus and the poisons ratio utilizing this kind of formula where E equal to 1 plus mu 1 minus 2 nu by 1 nu rho C L, and this is again a another equation for mu. So, first of all find out what is the nu and then this value can be put here to find out the young's modules what are the different parameters here the rho of course, is the density C L is a velocity of the longitudinal wave here you can see C L C S and there is another parameter.

So, these are all velocities, different kind of velocities, I think this would be not L not 1; I think it should be L. This, there is a mistake over there, this should be L C L by C S and this also C L by C S. So, C L the velocity of the longitudinal wave in meter per second and this is C S velocity of C R wave in once again in meters per second. So, from that we can find out the poisons ratio and once poisons ratio is measure than you can also find out the young’s modulus and rho b and the density here. So, this is another way you can find out the young's modulus in both the cases actually you have to either you create a sound wave or an ultrasound wave.

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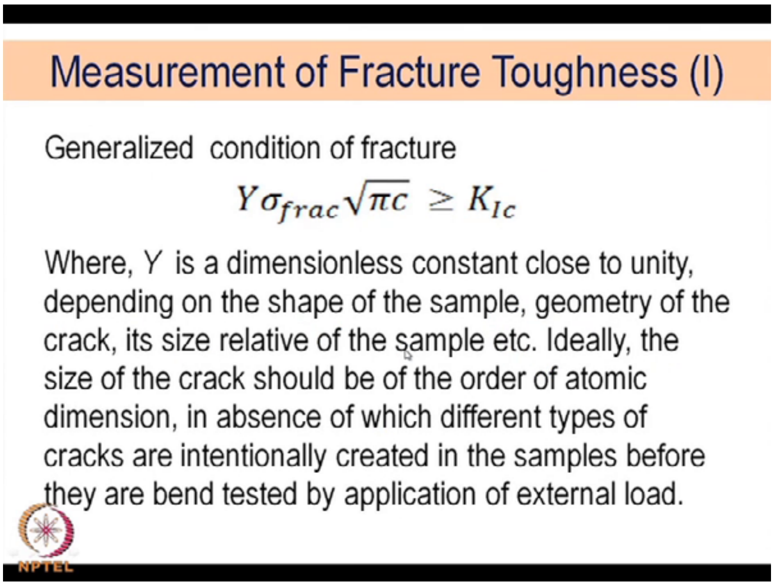

Well having discussed that, what are the different properties and how to measure those properties, mechanical properties? Next item you want to discuss, how to measure the fracture toughness; how to measure the fracture toughness of different ceramic materials. We have known that the general condition of the fracture is this sigma fracture root over pi C must be equal to K I C that is the parameter the fracture toughness. So, the fracture toughness, if this value becomes more than the actual fracture toughness of the material, then the fracture will take place. Where, why we have seen it earlier is a dimensional constant close to unity, depending on the shape of the sample geometry of the crack, it size relative to the sample size extra and ideally. The size of the crack should be of the order of atomic dimensions, which is always not true sometimes, there will larger cracks also, enhance in absence of which different types of cracks are intentionally created in the samples, before they are bend tested by application of external load.

So, as you have seen earlier that we have made our calculation assuming that, the curvature, curvature of the crack tip is of the order of atomic dimensions; however, a crack of the atomic dimension is almost impossible to be created. So, what is done a crack is created intentionally crack is created on the sample and then a bend test or flexural measurement is done to find out what is the energy or what kind of energy or what kind of stress is required to extend this crack further. So, you have a existing crack which is created intentionally on this surface and then you try to find out, what is the energy required or the stress required to propagate, it further. That is how, that is the basic technique or the basic principle on who is the fracture toughness is measure.

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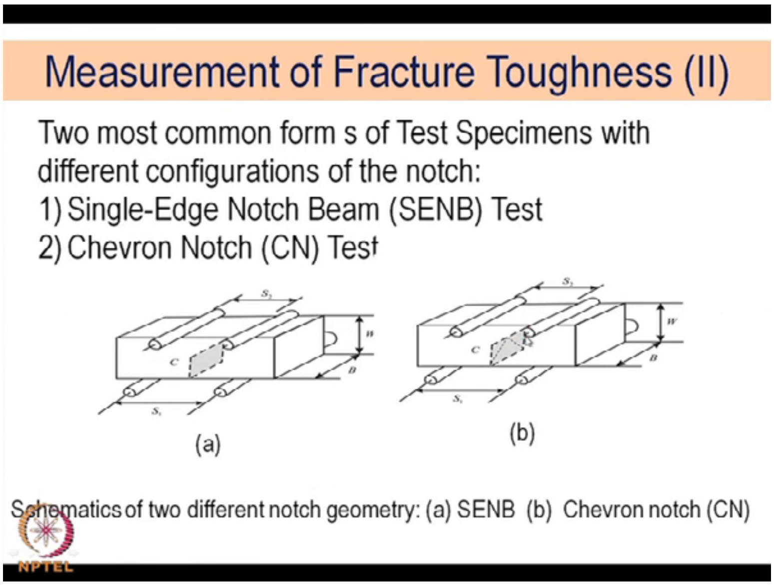

So, with this basic principle there are different techniques, different ways it can be realized this particular principle. So, two most common forms of test specimens with the different configurations of the notch. So, the crack is in actually created in the form of what we call a notch, just a minute there is a little bit of a I will make a corrections small correction here. So, there are two most common forms of test specimens with different configurations of the notch. So, I have said, first of all we intestinally make a notch and then we keep the notch in such a way that there under tensile load and that will open up the crack and open up the notch and the crack will try to propagate and from the different stress required for to open to fracture, the sample one can measure, what is the fracture toughness.

There are 2 different types of notches one can which can be created 1 is called the single age notch being test both in, both the cases actually we are measuring a 4 point bend test or four point fractural text. So, one is the single edge notch beam or in short SENB test and the other in is chevron notch test sometimes is also called venous test. So, these are soon schematically here, 1 is a simple notch has been created at the bottom surface. The bottom surface of the beam and then there it 4 bend a 4 point bend test, these distances are S 1 and S 2 here not in terms of L, which you have used earlier and then this is the b the bend and this is the height. So, on the bottom surface we have intentionally created a notch and that end of the notch; obviously, as small as possible certainly of the order of less than micro around microns some few microns and this is a linear notch whereas, here it is a kind of B V kind of notch. So, there are 2 different configurations of the notch and these two configurations give rise to 2 different formula to express or find out.

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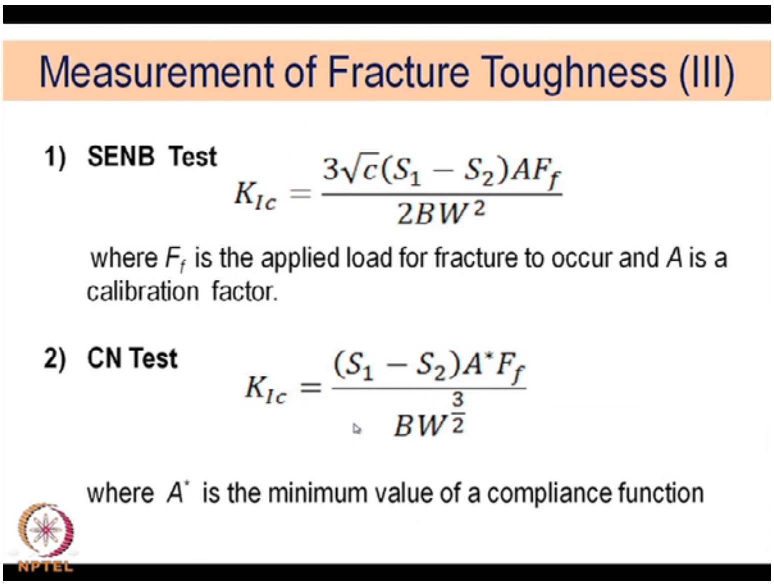

What is the value of the K I C fracture toughness? So, as for definition the fracture toughness is basically the fracture or the stress or the energy which is required to propagate the crack. So, here it is a S 1 minus S 2 to A F f 2 B W square where F f is the applied load for fracture to occur and a is a calibration factor. So, A is a calibration factor and then this is F f is the load at which the fracture takes place and B and W are the dimensions of the specimen. Where as in the chevron test or venous test, the expressions are slightly different a star once again, this is W square it is 3 by 2, S 1, S 2 have their usual significance and a star is the minimum value of a compliance function. Once here it is a constant here also, some kind of a constant. So, so once you to do the test and find out what is the fracture load or fracture stress rest of it is basically calculation.

As you can always see that, there are a lot of difficulty in getting accurate measurements. Because, they are quite sensitive to many different dimension, many different ways of different parameters, which we try to measure under this conditions. For example, the notch, how we are making the notch, what is the surface characteristics of that notch very smooth; whether, there is a some kind of serrations and all this. But 3 important parameters, which 1 must always keep in mind, that is the sample dimension may be too small compared to the stress zone ahead of the crack so. In fact, in fact this should be sample dimension should not be too small actually if the, it is too small then inconsistency will arise. So, that is what is says that possible reasons for inconsistency is that the sample dimension what it is means is basically the depth of the crack and then what is the rest of the material available for the crack to propagate? So, there may be sufficient material still available for the crack to propagate compared to the size of the dimension of the crack in both the cases.

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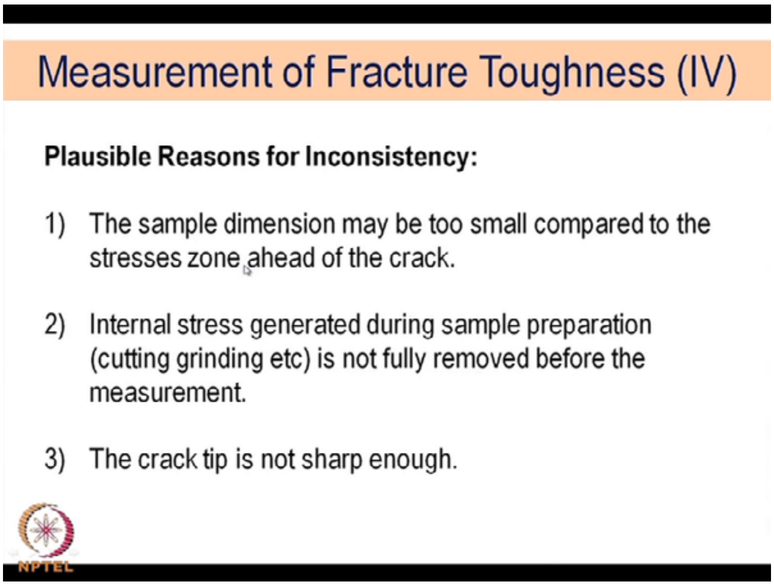

The second important point to be noted is, the internal state generated, during sample preparation cutting grinding etcetera is not fully removed. Before the measurement as I have mentioned earlier, that any ceramic material being little, there is always a tendency or possibility of generating different kind of internal stresses. During its preparation sample preparation, cutting because samples have to be cut and ground and annealing of these internal stresses is always difficult. Because, it is metals and alloys just by heating one can remove the internal stress because it is basically a dislocation moment here the internal stress generation removal is always difficult.

So, one as to take specific precautions so that during cutting and grinding the additional stress are not generated there is no stress concentration. So, things are very at its lowest energy level. So, this is another precautions one is to take and the third precaution is the crack tip is not sharp enough well it has to be sharp at the same time it is not too sharp. So, there is a again optimization required, how to generated crack and how to generate the notch which you have created. So, if it is too sharp naturally it will give a very low fracture toughness, if it is too blunt, it will give to a very high fracture toughness. So, there are standards available. Of course, how to make these notch and there is instruments available how to make such notch even for free notch there are special instruments available to do that, but you have to operate those instruments properly. So, that the right value is obtained. So, measurement itself is not very easy task, but it is not in practical also one can certainly realize these measurement.

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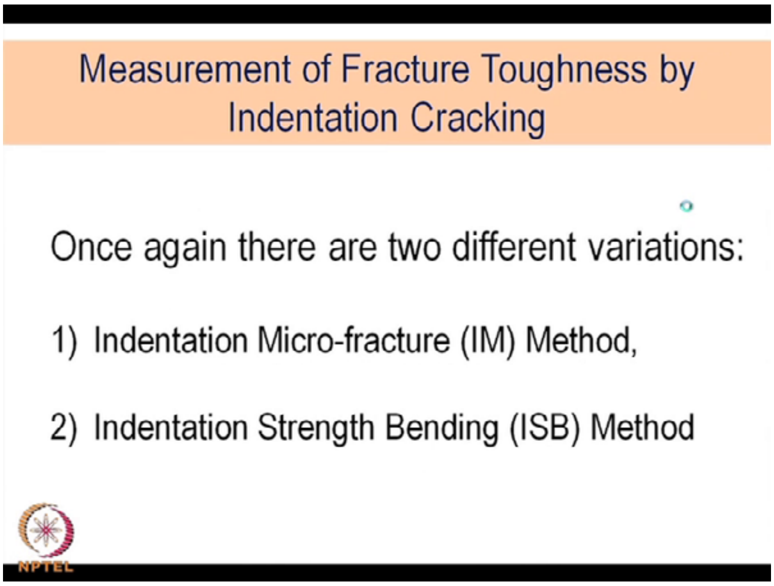

I am just give you some principles, I am not, I do not have much time or sufficient time to discuss a more them in more details. But giving you some principles, there is another technique measurement of fracture toughness by indentation cracking. Instead of creating a notch, 1 can initiate some cracks. 1 can generate some crack by indentation measurement. We have earlier see the hardness can be measured by indentation and we have also mention that in during hardness measurement, there should not be any crack the indents should be created you under certain loads in such loads optimize load.

So, there a no crack is generated, but if the load is more than that then suddenly the cracks will be generated and that crack can be also use for fracture toughness measurement. Because these cracks can be allowed to grow further under flexural strength or flexural load and from that one can major or one can make an estimate of the fracture toughness. So, these are the two ways of indentation followed by fracture. So, what is called indentation micro fracture another is called indentation strength bending method indentation strength bending methods. We will discuss his things may be in the next class.

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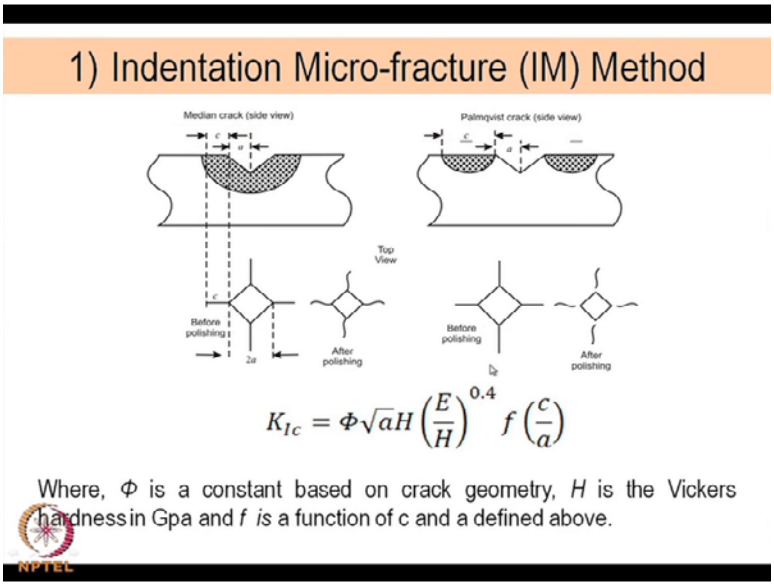

So, just to give you a broad outline, this is what we do in a indentation micro fracture; that means, we do not fracture it with do not fracture. You allow the crack to grow and from the crack length, from the crackling lengthy, you can find out, what is the fracture toughness. Under, what load this structure has been created, a this cracks has been created beyond the indentation. So, you have a indent intend forming that can be used that has been used earlier for the hardness measurement, but if the load is more than that then there will be cracks generated at the corners because, these are the stress concentration centers. So, the cracks will be generated and there will be a particular way the cracks will be generated and that from that you can find out what is the fracture toughness. So, here you are not allowing it to load further. So, from the cracks by indentation itself 1 can find out.

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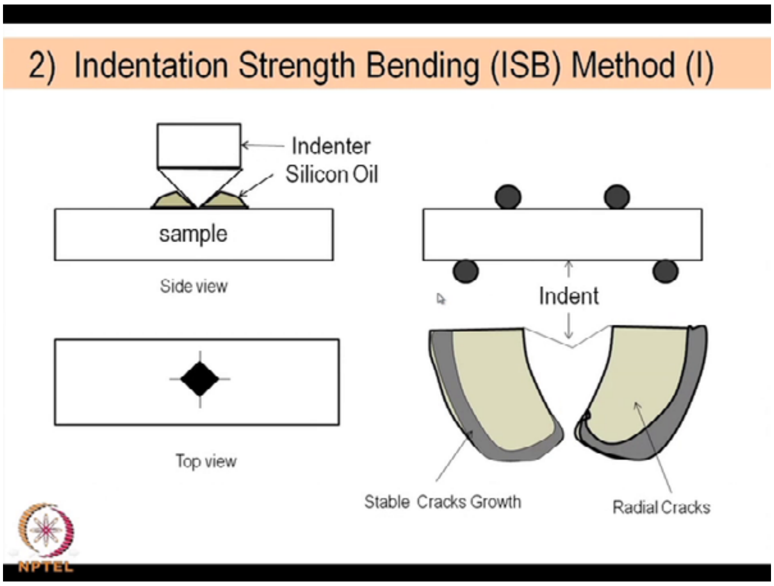

The fracture toughness, but there is another method by which one can see a indent is formed on the surface, and then it is allowed to fracture further, under a bend test. So, the indent is on the bottom of the surface and then is a 4 point bend test is done and from that also one can find out the fracture toughness. So, these are the two techniques, we will try to discuss little more about these thing and a maybe the next class. So, we will continue our discussion on the measurement of fracture toughness by indentation cracking in the next class and for the time being. Let me say good bye.

Thank you, Thank you for your attention.