Dynamic Behaviour of Materials

Prof. Prasenjit Khanikar
Department of Mechanical Engineering
Indian Institute of Technology - Guwahati

Lecture - 44
Dynamic Fracture 1

Hello everyone, so we have arrived at the last chapter of this course that is dynamic fracture. So we have discussed in the last lecture, the earlier lecture about shear bands and now we will talk about dynamics fracture, I hope that at least some of you have some at least you have taken a course on fracture mechanics and I know that for undergraduate students most of you have not taken any course on fracture mechanics.

So we will briefly discuss the very basics of fracture mechanics. So this will be on fundamentals of fracture mechanics, but if you are more interested to learn about basic fracture mechanics I would suggest some books please go through it.

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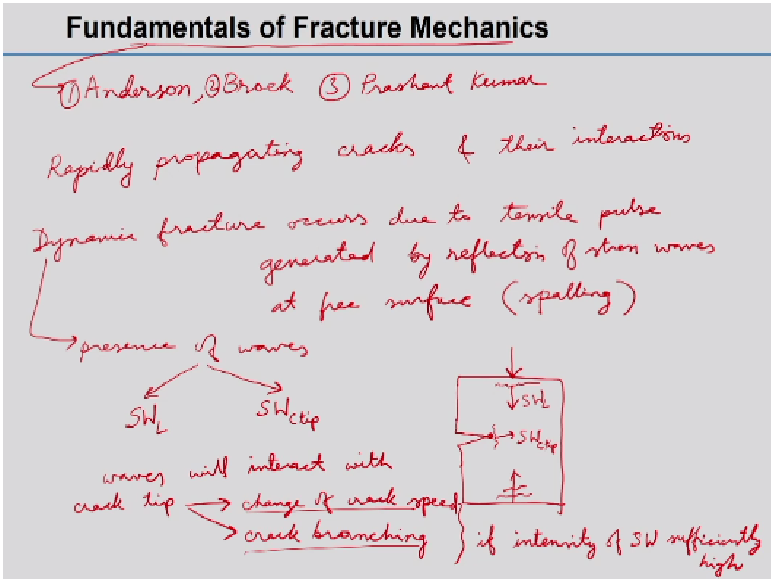

So the books by Anderson or this is for fundamental of fracture mechanics. So this book by Anderson or another book by Broek and the third one, so they are different books, 1, 2 and the third one by Prashant Kumar. So these are the books I feel are good for your fundamentals of fracture mechanics. So what we will discuss in this lecture is, the rapidly propagating cracks.

Because as you know the dynamic fracture is different, repeatedly propagating cracks, we will discuss about that and also their interactions. So what happens is this cracks generally occur so dynamic fracture occurs due to tensile pulse generated by reflection of stress waves at free surface okay. So this is as we know we call as a falling fracture or failure when the tensile pulse generated from the reflection.

And then dynamic fracture is unique because dynamic fracture is unique because of the presence of waves so that the difference between (()) (03:43) fracture and dynamic fracture. So these presence of waves that can be 2 you know source of these waves. So what will happen suppose if you have a material undergoing fracture, let us say we have a crack here and there is some loading from the top let us say.

And what will happen is the wave will generate from the loading and it will come, this wave will you know travel due to the loading and also some stress will be released from the crack tip as well. From this crack tip. So these are the stress waves. So first stress wave I would like SW stress wave from the loading, so SW loading and lets say SW. So the second one we can write the stress wave from the crack tip.

I will write as crack tip, so there are these kind of you know, 2 kinds of stress waves can be there and what will happen is some stress can be you know travel back from the free surface and that can generate tensile waves and then these wave we interact with the crack tip and then what will happen this here what we are writing is the presence of waves from the loading and the presence of wave from the crack tip okay.

So these waves will, stress waves will interact with crack tip and this will result change of crack speed, either change of crack speed or crack branching, that we have discussed about crack branching in our initial lectures. So provided if intensity of stress will be sufficiently high. If intensity of stress wave sufficiently high, so you know this can change the crack tip or crack branching can happen that means multiple cracks, which eventually lead to fragmentation.

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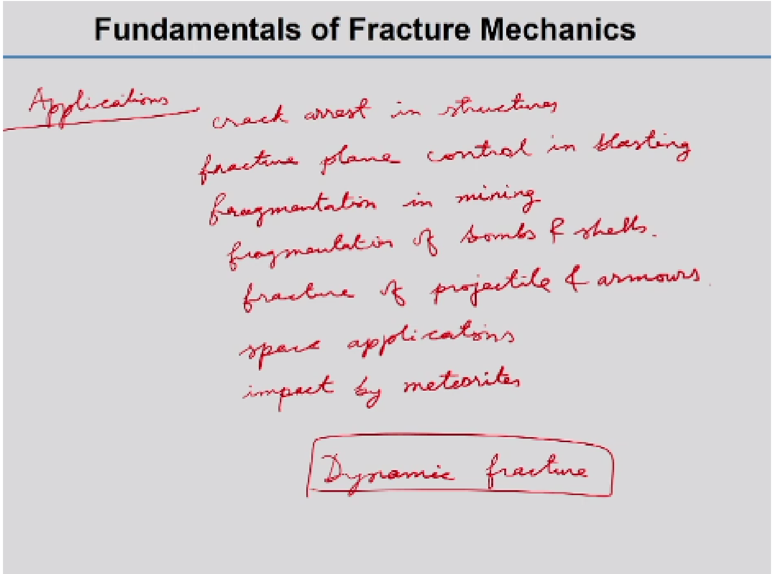

These dynamic fracture studies are important for different applications. So these applications include let us say for crack arrest in engineering structures and then fracture plane control in blasting that means for you know some control blasting we can control the fracture plane and then fragmentation in mining and then military applications like fragmentation of bones and shells and then fracture of projectile and armours.

And then even, I mean space applications so, which also include like I mean the impact of structures, impact of structures by meteorites. So these are the applications for these applications dynamic fracture is very important. The dynamic fracture knowledge is very important for these applications. So that is why we are studying this applications.

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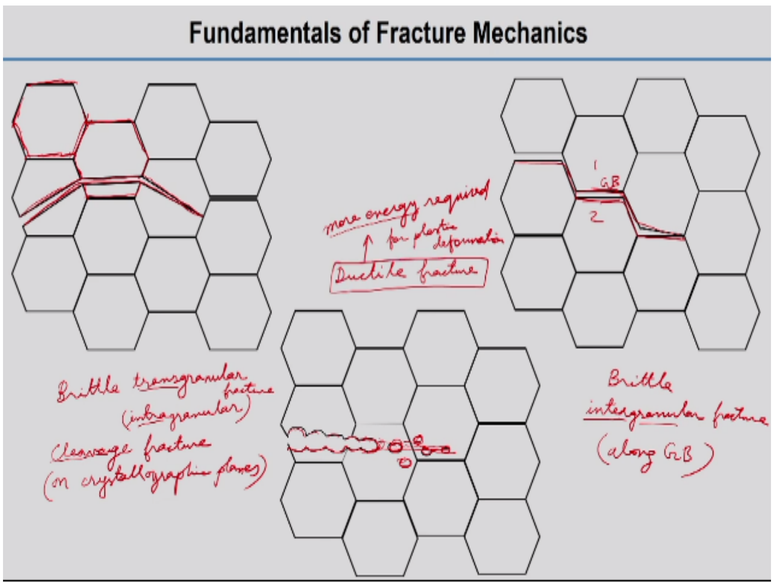

So we will talk about now the materials background of the fracture. So there are 3 different types of fractures. So here there are 2 brittle fracture mechanism we are showing here, brittle and here is also brittle, but it is a different one and the third one, this one is a ductile fracture, so this one is ductile fracture. So the first one we go with the brittle, we call brittle transgranular or sometimes it can called as intragranullar fracture.

I should write fracture here, and this one is called intergranular. Sorry probably I did not tell you these are the grains. I hope most of you already understood should these are the material grains. Grains are not exactly hexagonal, it will be a regular shape, but for our, you know convenience we are drawing some hexagonal grains here with the same size and shape. So these are some material grains as you can understand these are for metallic material.

We are drawing these grains and these grains maybe in a micrometre level let us say 50 micron or 100 micron. So now you have the crack here, this crack is going inside a grain and this crack is dividing the grains into 2 parts so that is called transgranular fracture and this is another name of these cleavage fracture. Cleavage fracture because it happens on particular crystallographic planes.

Let us say mostly it happens in a BCC materials, suppose some planes let us say 111 plane or 110 planes, the fracture happens, that is why it goes inside the grain, but the other brittle fracture intergranular that means it goes along the grain boundary. If you see the grain boundaries this is grain number 1 and 2 there is let us say, then this is the boundary. So this is the grain boundary.

So along the grain boundary, it fractures. So that is why it is called intergranular, the other one was intra or transgranular and the third one is called ductile fracture. So the ductile fracture if you can see that there are some voids shear and then these voids are joined together, so what happened is here more energy are required. So I would write here, in ductile fracture more energy required for plastic deformation.

So before fracture there will be plastic deformation. So that is why more energy is required. So basically what happens is the tip of the crack whenever you have a crack, there will be some, you know, this crack will be blunt and then ahead of the crack void will generate and these void will grow and by plastic deformation and then it will create a you know continuous crack like this.

But because of the more plastic deformation in a ductile material, it needs more energy to overcome the new surface generation, crack surface generation. So that is why it is called the ductile fracture or it takes the more energy than the brittle fracture.

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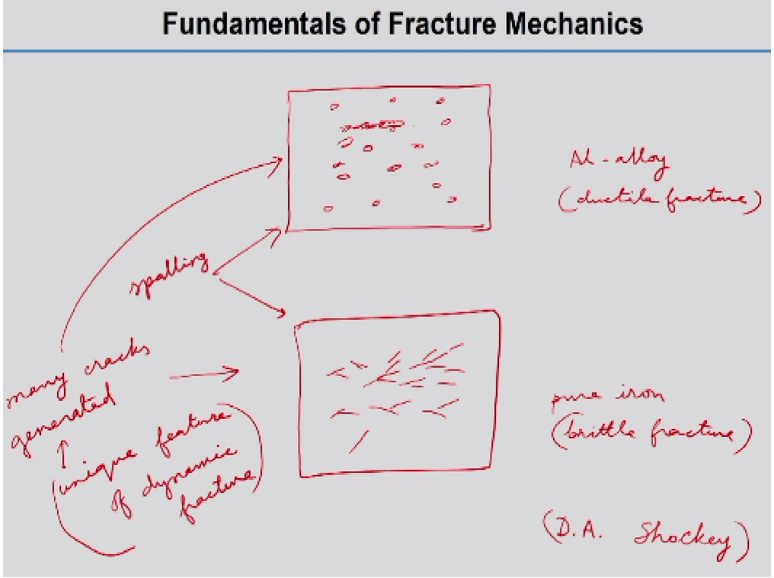

So different materials the fracture if you see the micrographs you can see clearly different brittle and ductile mechanisms, suppose in the Martin Meyers book you can see some micrographs where let us say aluminium alloy and pure iron, which shows that at high strain rate loading the iron got some you know these cracks, small cracks and lot of cracks as you know there are multiple cracks generates in dynamic fracture.

So this is a brittle kind of fracture, brittle fracture and if you see in a aluminium alloy, so the reference is actually Shockey I think, he took it from D.A. Shockey SRI international. So for aluminium alloy there will be void generation and some of the voids will come together, some will be you know alone standing on the aluminium allow. So these void generation shows it is a ductile fracture.

And this basically both of these happen because of the following in a brittle case we can see that there are many cracks generated that is a unique feature of dynamic fracture. In (()) (15:35) fracture, there will be probably a single crack, not that many cracks and even for the void and the ductile fracture mechanisms you can see these you know cracks generated at many sites, the nucleates in many sites.

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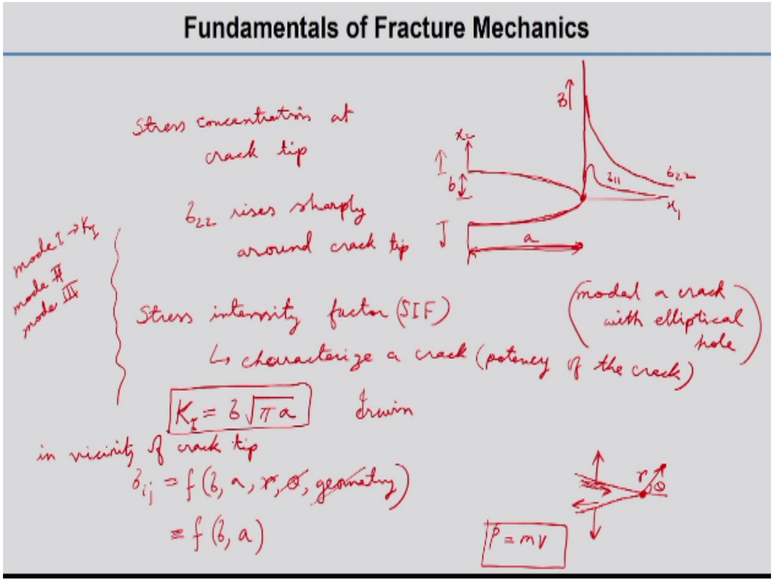

So we will now talk about little bit of fundamentals of fracture mechanics. So this traces at the crack tip are much higher than the uncracked material that most of you probably have studied. So let us say you can imagine an ellipsoid and actually elliptical hole this is. So this is used for modelling a crack and if you see at this point, the stress will be very high. So let us assume that this is x2 direction and this is x1.

And this distance half of the crack opening, this half of the crack opening is b and this is let us say half of the crack length is a. So this is to model a crack with elliptical hole. So just to show you the high stresses here. So if you draw as a y-axis as sigma, so what happened is sigma 22 in the 22 direction the sigma 22 stress will look like this. This is sigma 22, if you see that and near the crack tip it is a very high value.

It actually kind of a singularity, it sharply up, you know up and then probably the sigma 1 will look something like this, sigma 11. So we are more concerned about sigma 22 because that will open up this crack, it will open up. So basically what is that is stress concentration, at crack tip. So that means at the crack tip stress is very high as compared to the uncracked portion of the material.

And sigma 22 rises sharply around crack tip that you can see from the figure. Now there is a parameter called stress intensity factor, which we will call as SIF, stress intensity factor to characterize crack, I mean the propensity of the crack actually. Crack potency of the crack. So how potent the crack is to whether it will propagate or not. So these stress intensity factor is K, which is equal to sigma root over pi a.

So what is this sigma and a are, as you know the sigma is the stresses, near the crack tip then a is the crack length, you can see crack length, half of the crack length. So how it comes, what happens is basically in the vicinity of the crack tip, the stress components are a function of sigma, the stress and then crack length then r, theta and geometry. So if you have a crack like this.

So r means it at this position this is r and theta is this one and then if you are talking very close to the crack tip, that means this R and theta and even if we for a given geometry these we can you know ignore and then we can say that this is only a function of you know sigma and a, so Irwin, so this is the person who first defined this stress intensity factor, he proposed the stress intensity factor.

So because sigma and a, 2 variable can be reduced by only one variable K, which is stress intensity factor. So it is something like you know we use momentum P = m into v, so for mass and velocity, you know we can reduce these 2 variables with a single variable called the momentum P. Similarly, the stress intensity factor. So what we can do is we can convert this sigma and a into you know one variable.

Then it will be easier for us to you know do the calculations. So I would write here this is actually ki instead of only k because there are 3 types of you know crack opening mode. Mode 1 we call as a Ki and there are mode 2 and mode 3. So this please you will study in a fracture mechanics book. So what happen is, so if a crack is opening directly like what I can show you here in a tension mode.

So this is called mode 1 and for mode 2 this will have a shear, it is called in plane shear. So the one crack surface will you know move in this direction, the other will move in other, this is called mode 2 and the third one will be in the we call out of plane shear. So that is on the you know perpendicular to the plane of the slide. So that shear will be in the out of plane shear. So please study these from a fracture mechanics book. So that is why we are writing here Ki, that Ki is the mode 1 stress intensity factor.

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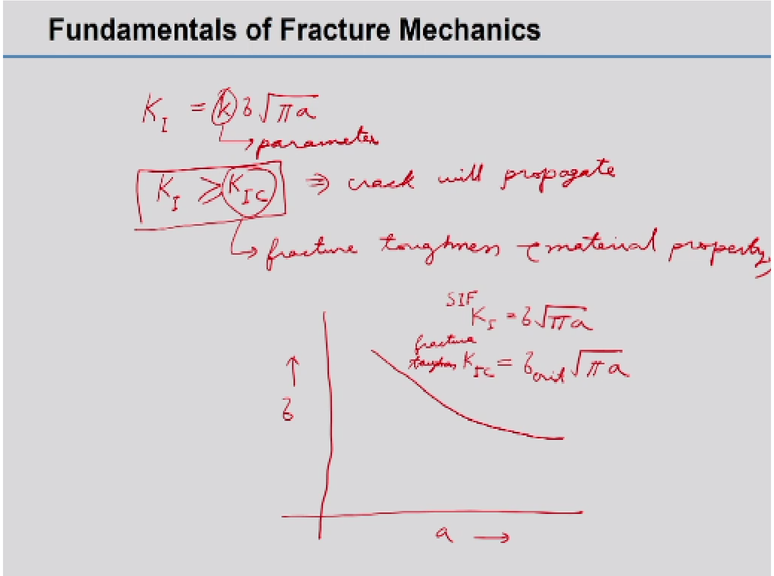

So for different geometry of the crack or different boundary conditions, so what we can do is we can generalize the Ki = K sigma root pi a and if Ki is higher than a critical value Kic, then the crack will propagate. So this k is parameter that depends on you know for different boundary conditions or different geometry. So here this Kic, this critical value is called fracture toughness.

And that is a material property, so now if you plot any stress sigma with a, so it looks like this, which you know increase of crack length, so stress required to propagate a crack will decrease as we have a Kic fixed value for a material. So that Kic will be sigma critical into pi a. So what we did is from Ki, we had sigma equal to pi a. Now if you are talking about the fracture toughness Ki is the stress intensity factor that is a variable.

And if it increase this and exceeds this limit then this fracture toughness we can define like this toughness. So as you can see that with increase of crack length the stress required for propagation of crack will be lower.

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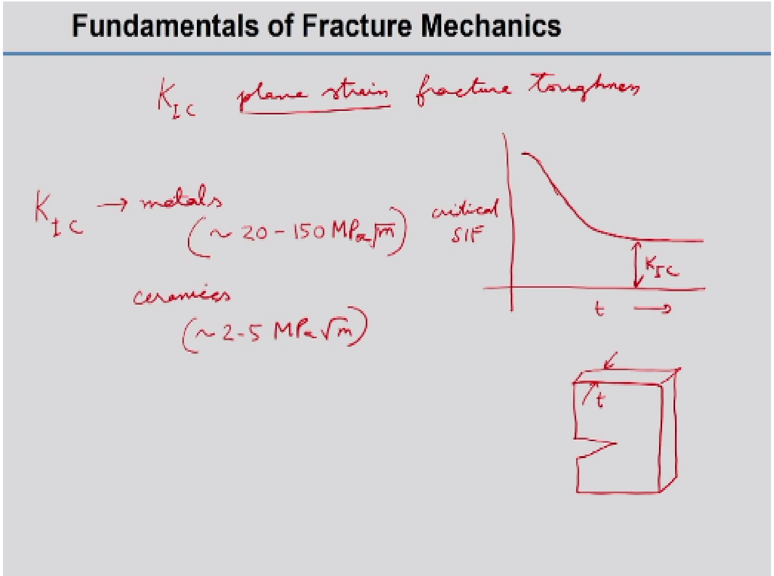

So we call this Kic as plane strain fracture toughness, fracture toughness why we call as the plane strain because when you are talking fracture on a very small thickness plate that means if you are talking about the crack like this and your thickness of the plate, let us say the thickness is very small than the fracture toughness critical SIF value will vary with thickness. So it will vary something like this and then it will be constant at a higher thickness.

The higher thickness that actually that is related to the crack length. So this is the Kic value that is why we call as the plane strain. If it is enough of plane stress that the small thickness it is not constant, so it will vary. Kic values are different for different materials that we can understand and this Kic for metals are very high, they are very ductile material and this value can be 22-150 megapascal I mean square root metre.

So this is for metal and for ceramics as it is a brittle material and then it has a lower fracture toughness so that can be 2-5 only megapascal square root metre.

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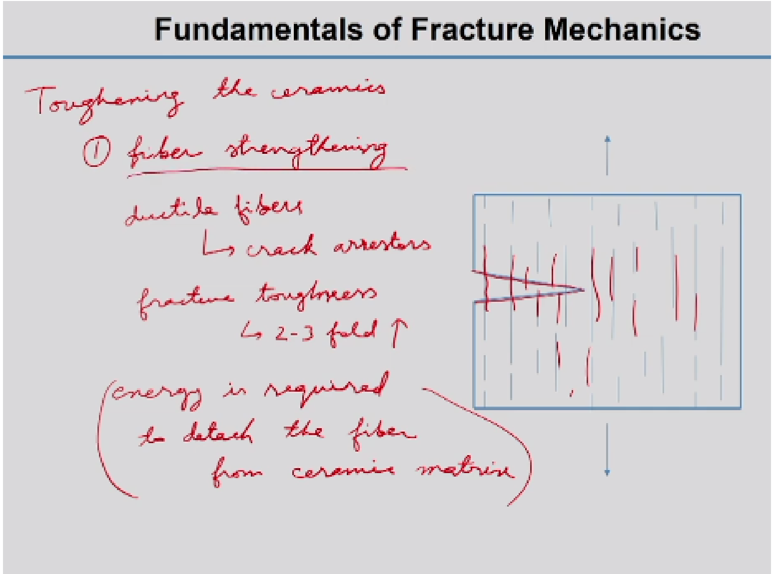

We have some mechanism to strengthen the ceramics methods for toughening the ceramic. So this is the first method is fibre strengthening. What we can do is there are some fibres we can give, some fibres we can give and this is the crack. So these fibre, the ductile fibres, these fibres are ductile fibres and these fibres act as crack arrestors that they can arrest the crack. So the fracture toughness can be increase, this is we are talking about ceramic.

Toughness can be increased by 2 to 3 fold, increase can happen and then why it happens exactly, the reason behind is because energy is required you know to detach the fibres from the ceramic matrix. So there is additional energy required from the ceramic matrix. So as you know otherwise they have very low toughness, but it can be a little increased with fibre strengthening. This is the number 1 method.

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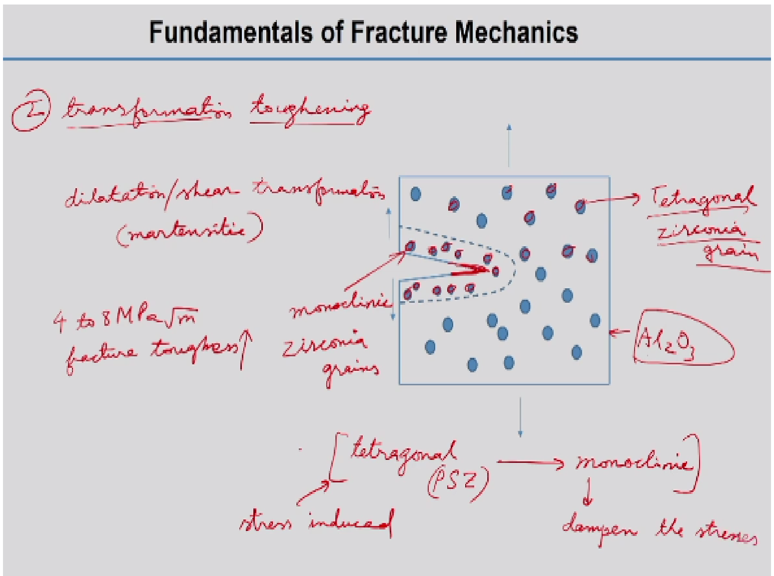

Second one is transformation toughening. So in this case, so there are some let us say this example is a alumina, the intermaterial is alumina and then these particles are zirconia particles. So zirconia, zirconium oxide and these particles are tetragonal, it is tetragonal structure, tetragonal zirconia grains, particles, we are introducing and what happen is you know with dilatation or shear.

These type of we are talking about general transformation toughening with dilatation or shear transformation which is mostly in this case are martensitic transformation you know due to the stresses in the crack tip it is very high. So some of these particles will convert to some other you know particles which has a different crystal structure, they are monoclinic, the same zirconia, but monoclinic structure, same zirconia, so there is monoclinic grains.

So because of the stresses at the crack tip, so what happens this you know the tetragonal, that is actually called as the partially stabilized zirconia. So tetragonal we can write PSZ that is partially stabilized zirconia can be converted to monoclinic zirconia and in this transformation, so energy is absorbed. So in this process it is 4 to 8 mega pascal square root metre fracture toughness can be increased.

So that much can be the increase in fracture toughness, increase with these you know tetragonal zirconia grains introduced to alumina material and this is basically the stress induced whatever the transformation we are talking about is this one is stress induced. Stress induced transformation and because of these applied stresses this transformation happens and after this transformation actually relaxes the stress and this will dampen the stresses and that is why the toughening will happen.

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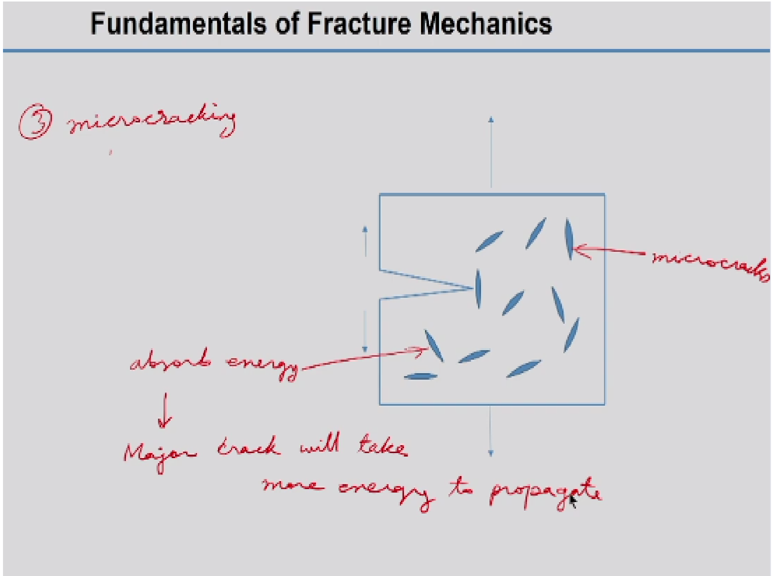

So the third process is third method to strength or actually it is not strengthen, this is mostly toughening we are talking about, toughened material is microcracking. So these are some microcracks here, microcracks if we can introduce microcracks, so these will absorb energy, these microcracks will absorb energy. So ultimately what will happen the bigger crack, you know the major crack or bigger crack will take more energy to propagate.

So this is also one way to absorb the energy and you know to increase the toughness of ceramics material. So that is all for today, so what we have discussed today is some fracture mechanics basics, so we talked about the brittle fracture and ductile fracture. There are 2 types of brittle fracture we have talked about one goes along the grain boundaries, it is intergranular brittle fracture.

The other is cleavage fracture which goes through or inside grains that is transgranular and then the ductile fracture which absorbs lot of energy because it allows plastic deformation and the crack tips are blunt and then voids are grove in front of the cracks in that case. So that is for ductile materials and then we have talked about at the basics of fracture mechanics again that the sigma is very, the stress is very high, attractive and combining the stress.

And the crack length we have another parameter called stress intensity factor which can be used to characterize whether the crack will grow or not and if it grows that the value of the stress intensity factors exceeds the critical value which is a material property called fracture toughness then the crack will grow and then after that we discussed about the you know ceramics, the ceramic has a low fracture toughness but the fracture toughness of ceramics can be increased with the help of 3 toughening mechanism. So we have discussed that. So this is all for today. So we will be continuing in the next lecture. Thank you.