Concrete Engineering and Technology
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Lecture - 14
Fiber reinforced concrete

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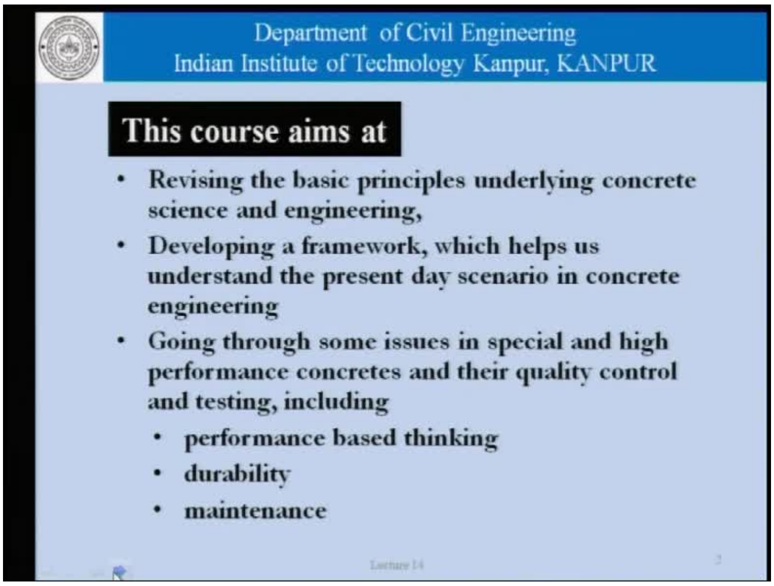

Welcome to this lecture on concrete engineering and technology. This course that we are having on the subject of concrete engineering, seeks to revise principles of concrete science and engineering as we have learned them in an earlier course perhaps, developing a framework, which helps us understand the present day scenario and concrete engineering. And go through some special issues in special or high performance concretes in the quality control from the point of view, primarily of performance base thinking, durability and maintenance of concrete structures. Now, this is something, which we have seen earlier is an outline of the course. What is going to be done or what is being done in the course?

We gone through these as well we have defined, normal concrete and now we are trying to study some special concretes, where mineral admixtures and chemical admixtures are an integral part.

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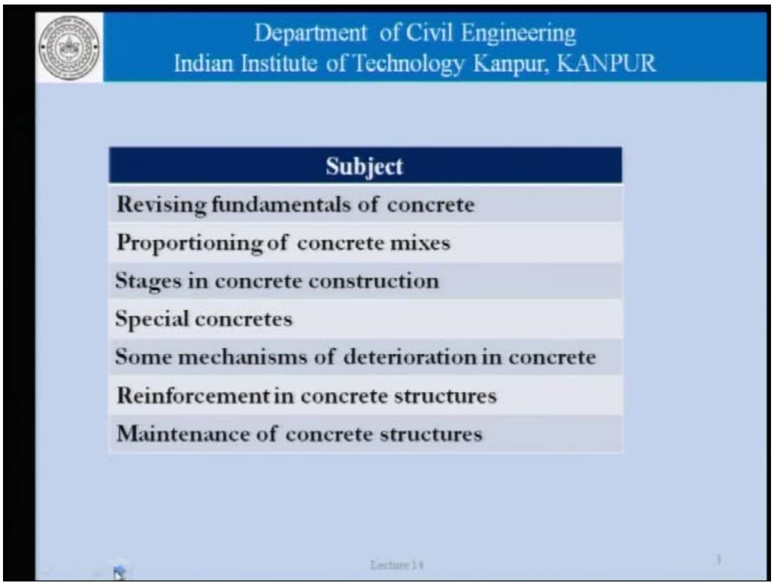

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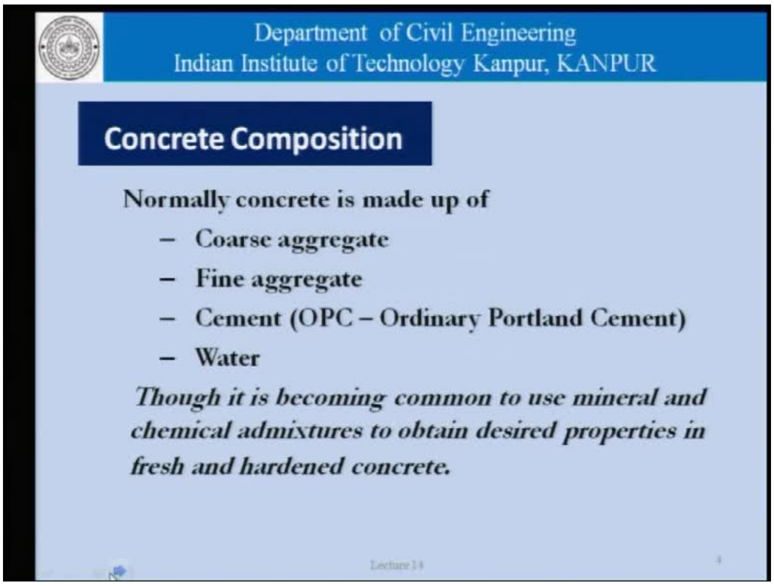

This is our traditional concrete, where we have a normal slice, which is modeled as made up of coarse aggregates, fine aggregates, cement and water. And of course, some amount of air in the system, which if it is pooled at one place or lumped at one place, as far as the volume is concerned gives rise to figure, which is something like this, where gravel and sand and cement and water perhaps mineral admixtures like fly ash and so on. All get lumped in to one place and we have a volumetric balance, where the absolute volumes of all these components add to a certain volume, which we normally take to be about a thousand liters or a cubic meter; that is what we take for proportioning of concrete mixtures.

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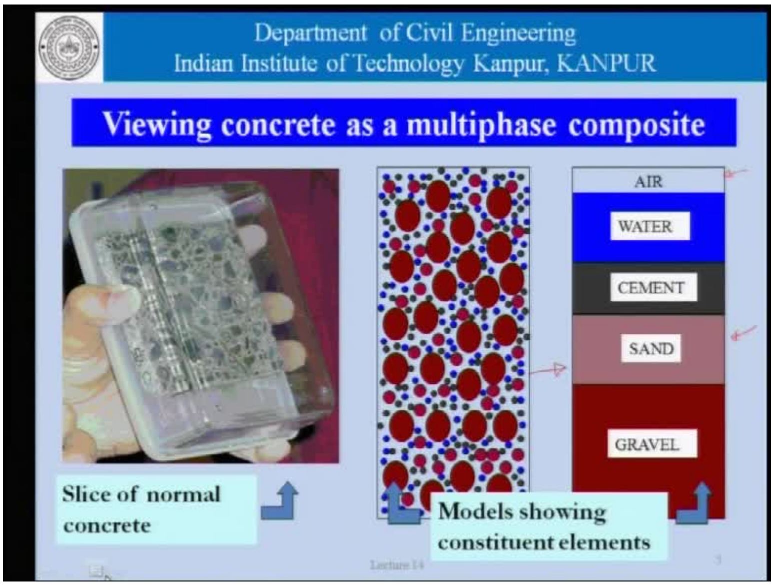

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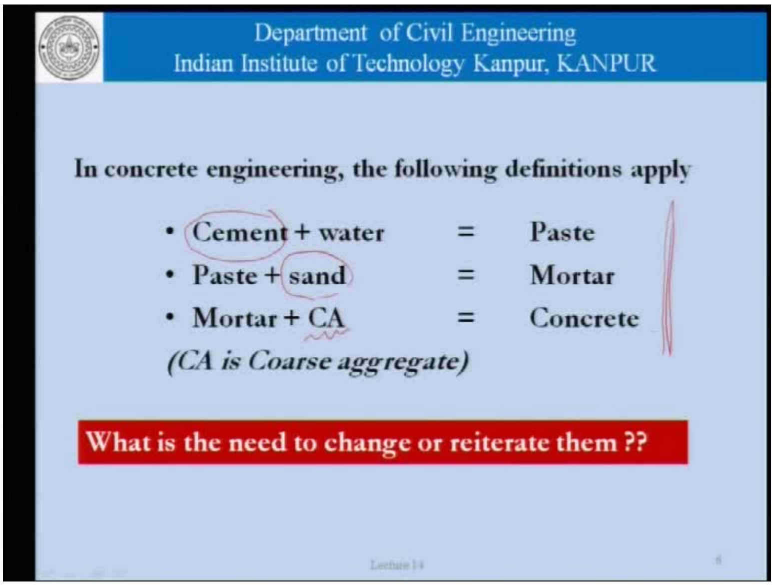

Now, this is the definition of paste mortar and concrete, and we have seen the reason for changing them or modifying them. Where we say that, it is not only cement but other materials, which have a fineness closed to that of cement; may also be considered part of the paste as far as the properties of fresh concrete occurs, on in some form even though those other mineral admixture, may or may not contribute as effectively as cement, as far as the strength development is concerned.

Similarly, as far as sand is concerned, we would like to reiterate that, there can be other material such as ground copper, slag and so on; which can be used as partial replacement of natural sand. The idea basically being that, the properties of that material, which should be as close or should be close enough to that of natural sand or normal sand; as it is used in ordinary concrete constructions. In fact the similar, statement can be made as far as, coarse aggregate is concerned, because there is always a possible day, that somebody like to use recycled aggregate and so on. As coarse aggregate and therefore, that helps us reduce the quantity of naturally occurring coarse aggregate and rock or sometimes use concrete or make concrete only with artificial coarse aggregate.

So, this definitions which we reiterated or which we stated at the beginning of the coarse, in terms of normal concrete construction is the one that is now under review and we are talking of special concretes and we have talked about self-consolidating concrete, and we have seen how some of these new materials or mineral admixtures are used and their addition, how it effects or in facts the properties of concrete.

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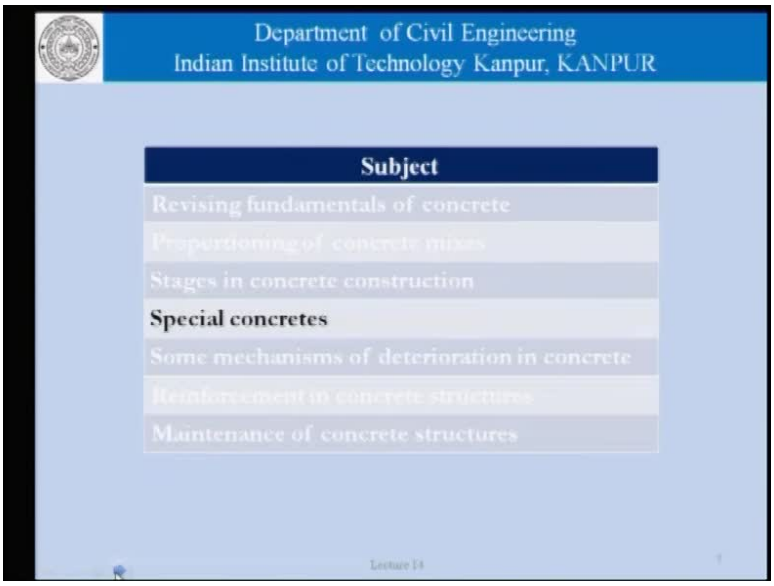

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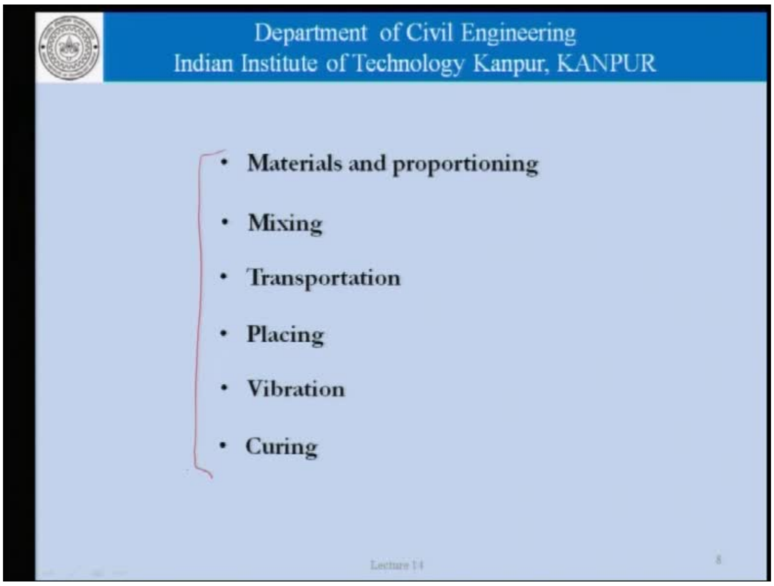

Now, continuing from there we get back to our discussion on special concretes where, we are interested to take a look at, how a concrete becomes a special in terms of materials and proportioning in terms of the mixing method, transportation method, placing method or the kind of vibration, which is carried out the kind of curing, which is carried out and so on. So, we have basically stated that for all these processes, there is a certain normal range of operation and anything beyond; that is something, which will make the concrete or the concreting operation as special. So we have seen that kind of thing happening in the case of, self-consolidating concrete and we also, discussed this matter, where we were talking about high performance concretes.

Now, today we are continuing our discussion. Now these are some of the special concretes or a concreting operations; that we are talked about use of self-compacting concrete, fiber reinforced concrete, mass concrete, underwater concrete, roller compacted concrete and shotcrete. So these are some of example, which can be considered as special concretes or concretes in operation.

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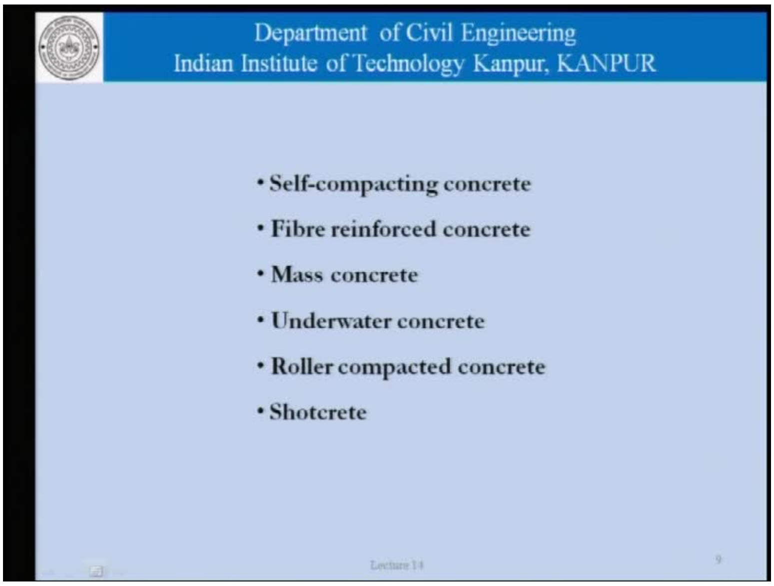

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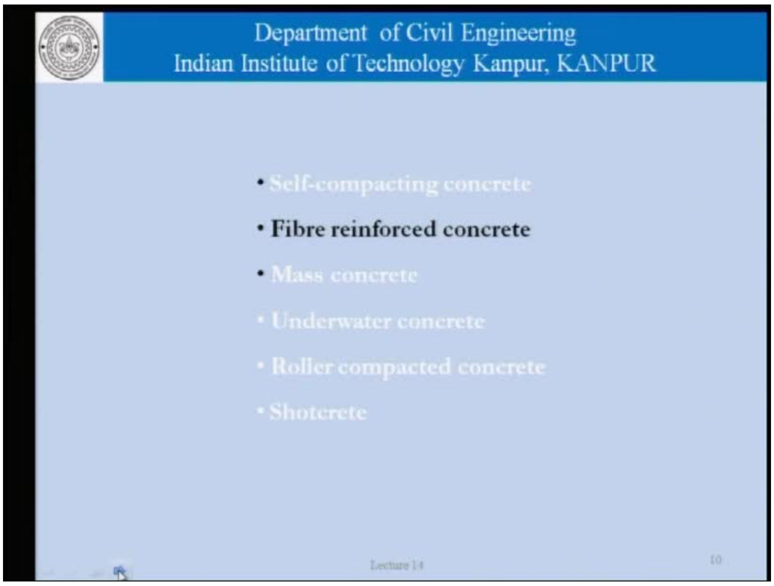

Now, in our discussion today, we will talk largely of fiber reinforced concrete, having completed some kind of a discussion on self-compacting concrete earlier. Now, fiber reinforced concrete or FRC is used to increase the tensile strength and toughness of concrete. We will talk of these properties, and there exact definitions as we go along in the discussion today.

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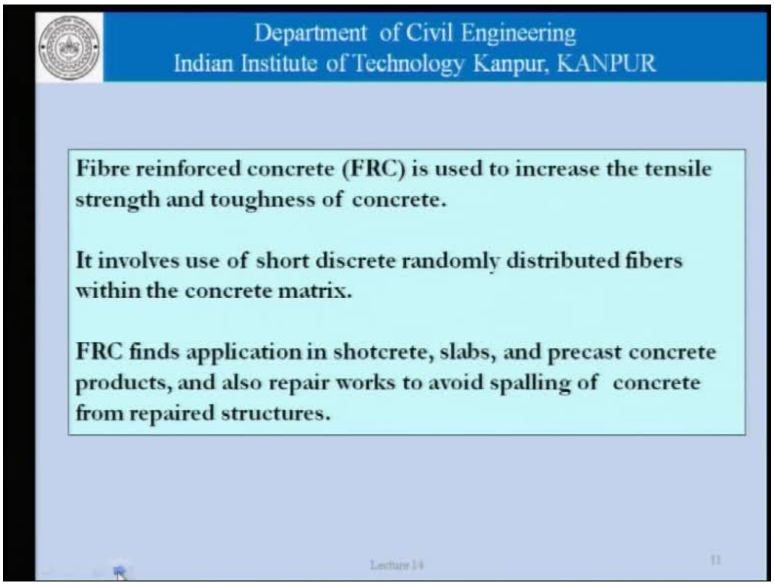

This concrete or the FRC involved, the use of short discrete randomly distributed fibers within the concrete matrix. So, these short discrete randomly distributed fibers are an integral part of the fresh concrete and when the concrete is placed, these fibers are placed along with it. It is different from the classical reinforcement of concrete, where the steel bars are placed separately; and the concrete is poured around it, in the case of fiber reinforced concrete. As we will talk about today, these short fibers are parts of the concrete.

The traditional reinforcing bars or the reinforcement may or may not be there in the concrete structure, depending on the particular application; that we are talking about as far as the applications are concerned. We will see them later on in this discussion fiber reinforced concrete fines applications in shotcrete, slabs, precast concrete products, and also the pair works to avoid, falling of concrete from repair structure.

Now, how the presence of these small or short discrete fibers helps, as far as the properties of concrete, and for example: what is mentioned, here is in terms of avoiding falling or falling off of the concrete, in the case of repaired structures; how that really happens? Is something which we need to talk about and we will do that in our discussion today.

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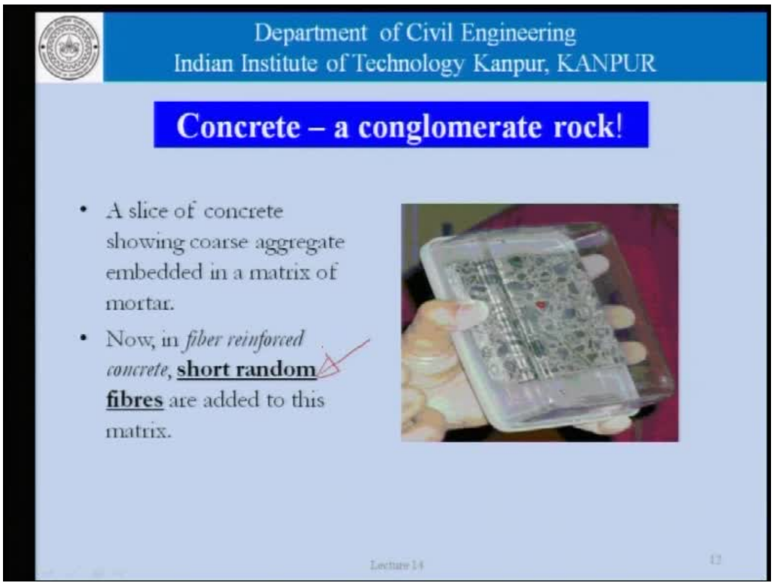

Now, once again let us take a look at the slice of concrete, and in addition to the coarse aggregate and the mortar and so on, which is present in a normal concrete. We also have the presence of short random fibers as part of this matrix in a fiber reinforced concrete.

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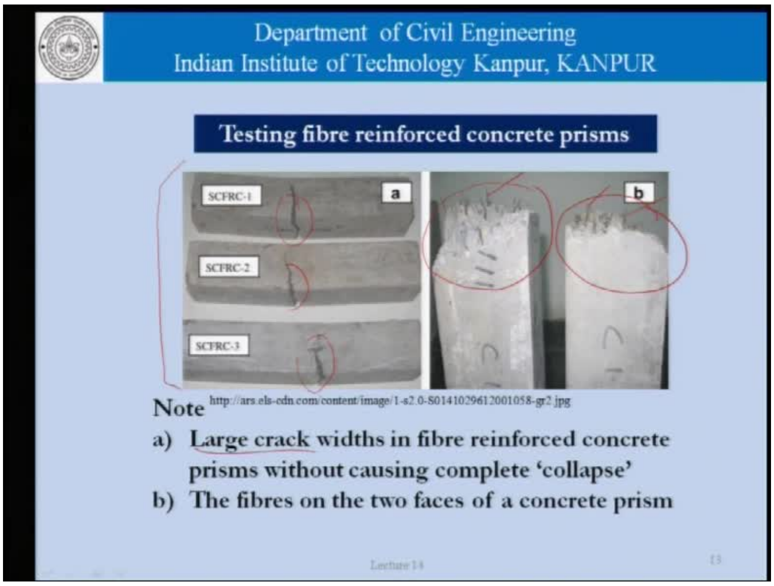

This here is a picture, of the space, of the prism with fibers in the concrete matrix. So, we can see the small fiber is sticking out, of the concrete. And if we see these three pictures here, we see that these concrete prism have been loaded and we have large crack widths at one end, and in spite of these large cracks, this specimen or the prism has not completely collapsed.

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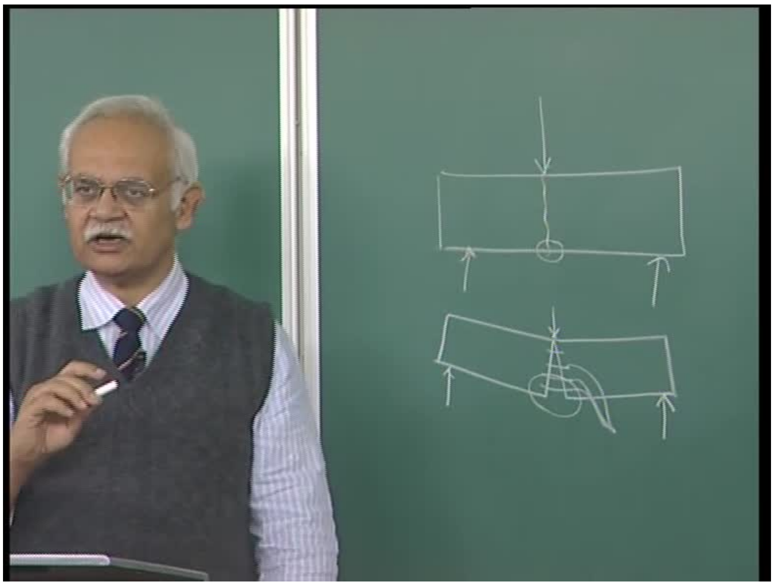

If we test our normal concrete prism, much as what we do in the case of determining the flexures strength of concrete? For example, we are testing it like this, what we would normally get is at a very small deformation, here this would just break into 2 parts much like, what happens, when we apply a load on a chalk? So, it completely disintegrates. This does not happen in the case of a fiber reinforced material or a composite and it can sustain large degrees of deformation of cracks at the bottom. In fact, one of the measure that, some of you would like to know, in fact this is an exaggerated version of, how a fiber reinforced concrete prism would behave? Where it is loaded in flexure, so in spite of these large cracks being formed here; because of the presents of these fibers, the specimen does not completely collapse.

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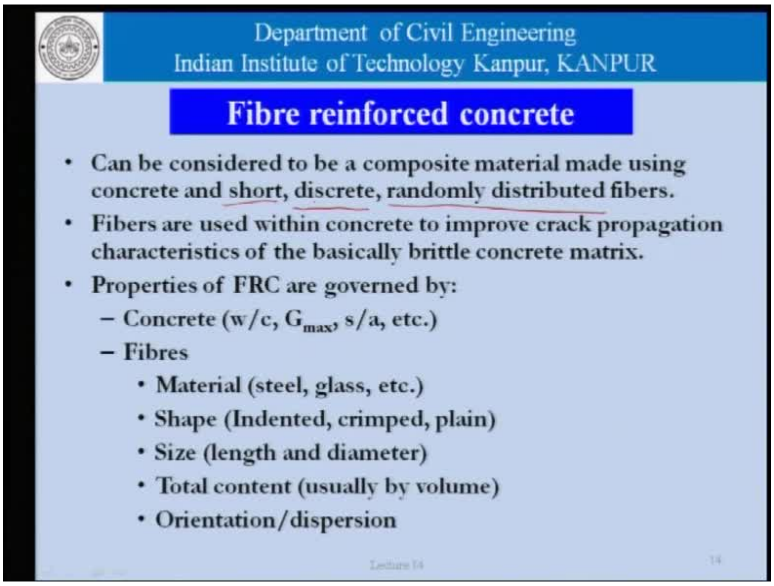

So, continuing with our discussion as far as fiber reinforced concretes are concerned. It can be considered to be a composite material, made of traditional concrete or normal concrete, which is mixed with short discrete randomly distributed fibers and there is a meaning each of these words, short discrete and randomly distributed the fibers. As we will see later on are basically short; they are discrete, that is the fiber do not lumped together; they do not behave as a group together and so on. And they are randomly distributed, that is in all the three directions. We do not take any special care or we do not use a method by which we seek to orient the fiber in a particular direction or two directions and so on.

So, if we do that is also possible but in our discussion today, we will confine our self to a situation, where the fibers are randomly distributed and we have not taken any measures in order to control the direction, in which the fibers are oriented, because it is really the direction of these fibers, which control or governs or determines the property of concrete in that particular direction.

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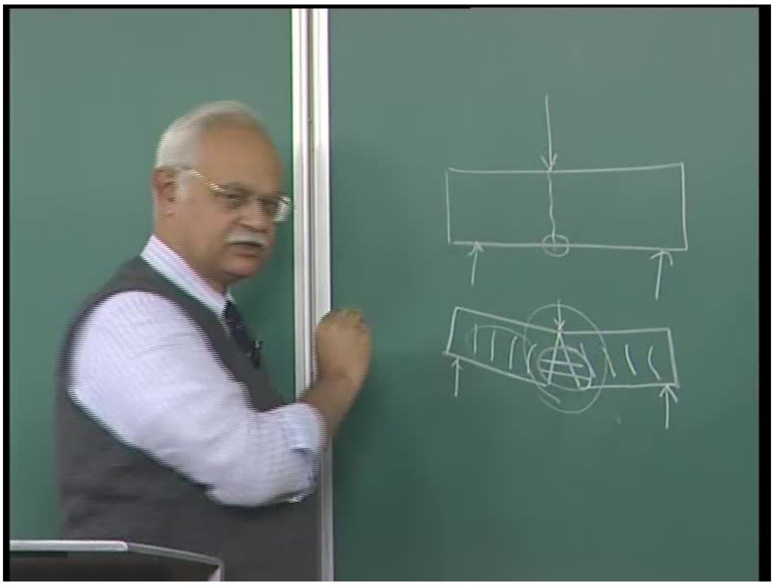

For example: In this matrix, if all the fibers were oriented in this direction, the there is no way, that this can be sustained, because there is no reinforcement; that is happening in this direction. So, we must make an assumption and that is what we will do and therefore, for normal concretes or normal fiber reinforced concretes. We make an assumption, that all the fibers that occurs in the matrix are distributed in all the three directions.

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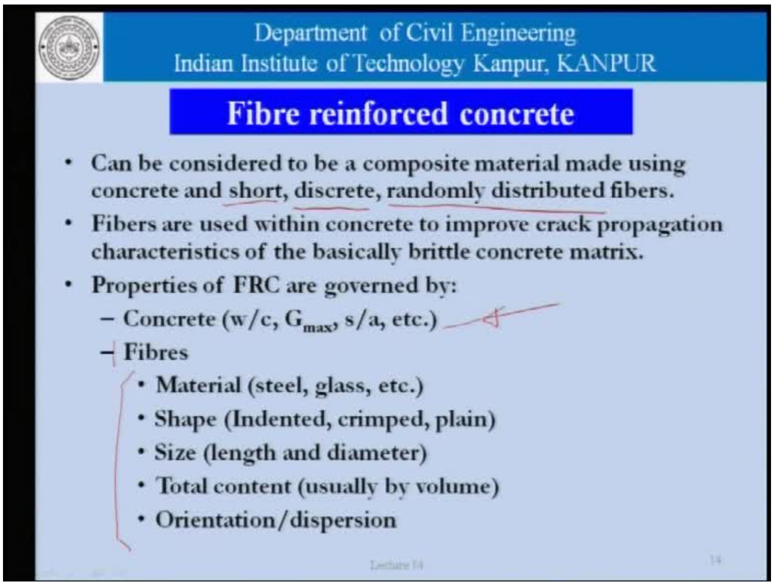

Now, the fibers present in the matrix are used within concrete, to improve the crack propagation characteristics of the basically brittle concrete matrix. As we have seen earlier, or concrete matrix is brittle and upon application of flexural load, the bottom which is subjected to tensile strength collapses, this is what is prevented by the presents of small fibers across the crack spaces, and gives us better properties in the post cracking space.

Now, as far as the properties of the fiber reinforced concrete are concerned; they are governed obviously by the properties of the concreted cell, which is governed in turn by to water cement ratio or the maximum size, the aggregate, the amount of sand used and so on, and so forth and then the properties of the fibers and the properties of the fibers are related to, what material we use as far as the fibers concerned, it could be steel, glass, carbon, polyethylene and so on. The shape of the fiber indented, crimped, plain, the size, which is the length, and the diameter of the fiber, the total content which is usually expressed in terms of volume and orientation and dispersion. So, these are the kind of parameters based on, which we can estimate or determine the properties of a fiber reinforced concrete.

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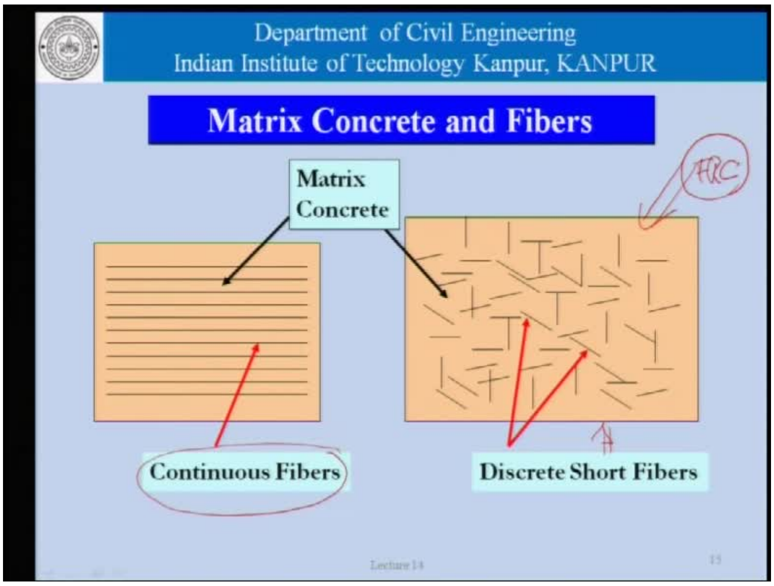

This here is a diagrammatic representation of matrix concretes and fibers. So in this picture, here we are showing continuous fibers, where fibers are long and continuous and oriented in a certain direction; and we have concrete matrix surrounding it. Whereas, in this case we have short discrete fibers, which are randomly oriented and we are talking of this particular picture as fiber reinforced concrete, as we shall talk about today.

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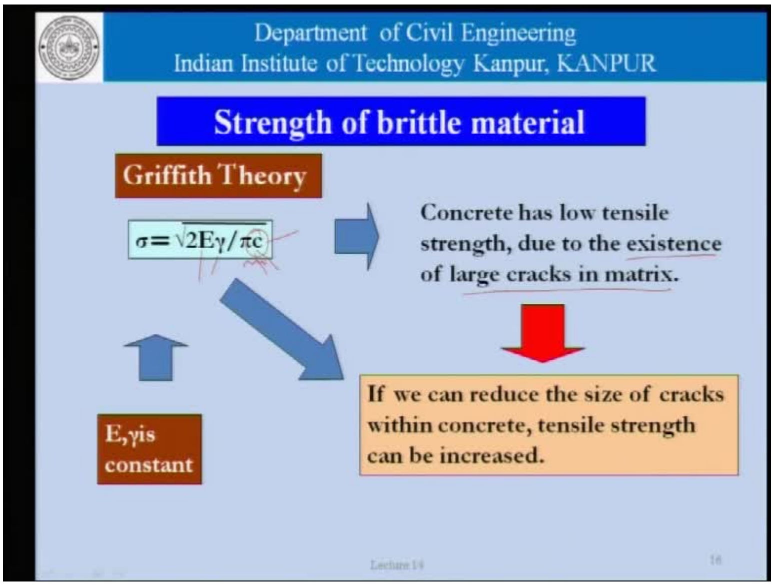

Now, small introduction to, the theory of strength of brittle materials; we will not go into too much detail of this. The Griffith Theory tells us, that the tensile strength; it is basically related to the size of the defects, which are present within the material, which is c and of course, e and gamma, which are the constant.

So, as far as concrete is concerned; it has a low tensile strength, due to the existence of large amount of cracks in the matrix. So, the concrete itself is brittle, because we have a very large value of c, that is the defects in concrete are many and very large. And now if we are able to reduce, the size of cracks within the concrete, the tensile strength can be increased; now if that is not possible, we try to bridge the cracks or these defects and that is the approach, which is adopted in the case of design and use of fiber reinforce concrete.

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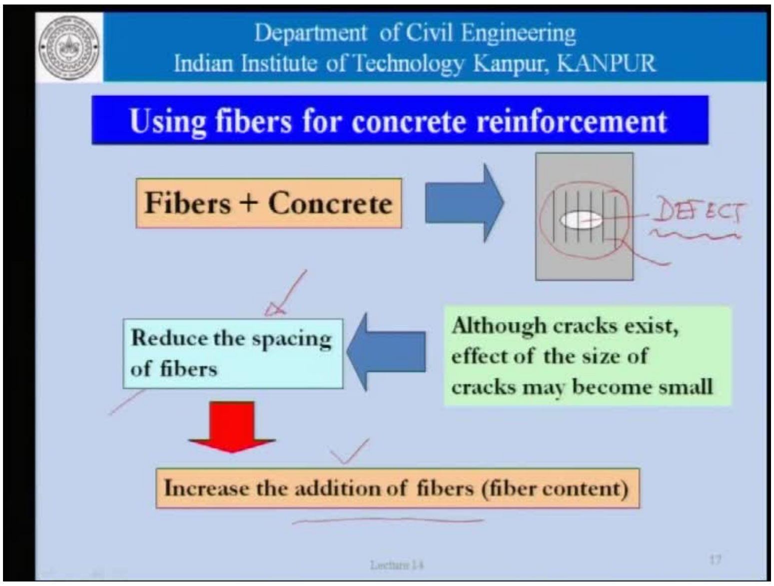

This here is a clearer picture, what I was trying to tell you, that when it is comes to fibers and concrete being put together; this here is the defect, which will cause the concrete to have very low tensile strength, if we bridge this crack with the fibers, that are shown here then the effect of this crack or defect will be reduced to a large extent. If we are able to reduce this spacing of these fibers by adding more fibers, then we get a more effective control or a more effective, addition to address the problem that might arise out of this effect and we get more and more tensile strength of course, there is a limit, to which it can be really improved.

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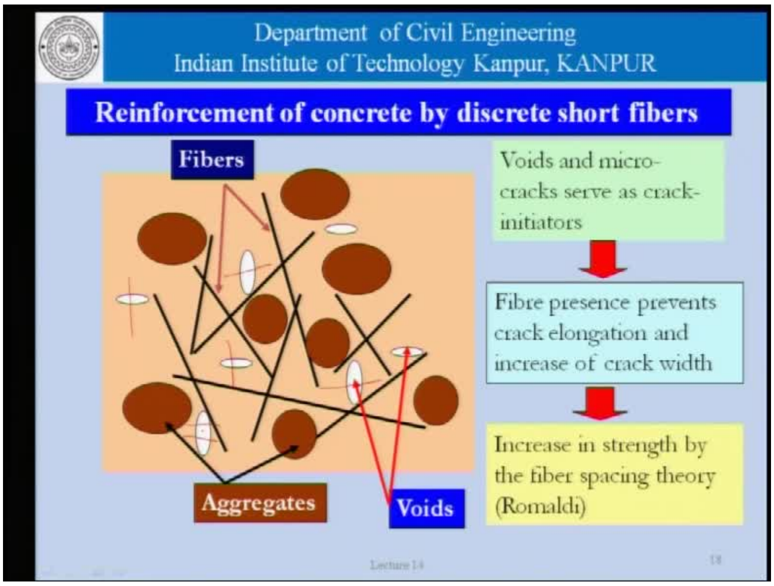

Now, if you look at this picture. Here it shows fibers the coarse aggregate and the voids so obviously it is not possible that the fibers will always cross these defects but one thing you should understand or try to remember, from this picture is that the voids and micro cracks; so that the cracks initiated, that is one the presence of fibers prevents cracks, elongation and increase of crack, width and increasing strength by the fiber spacing.

And other things, which we must understand or try to look at this picture, and draw the conclusion is the following, whether or not the addition of fibers is effective in terms of controlling or addressing this problem on account of internally present defects would also depend on the relative size, of these fibers, in relation to the size of the coarse aggregate, if we use very small fibers and large aggregates, it is not likely that, we will get a large improvement in terms of the tensile strength of concrete. And at the same time, if we use very large fibers or very long fibers, there are other problems that are associated with that and we shall see something related to, that as we go along in this specification.

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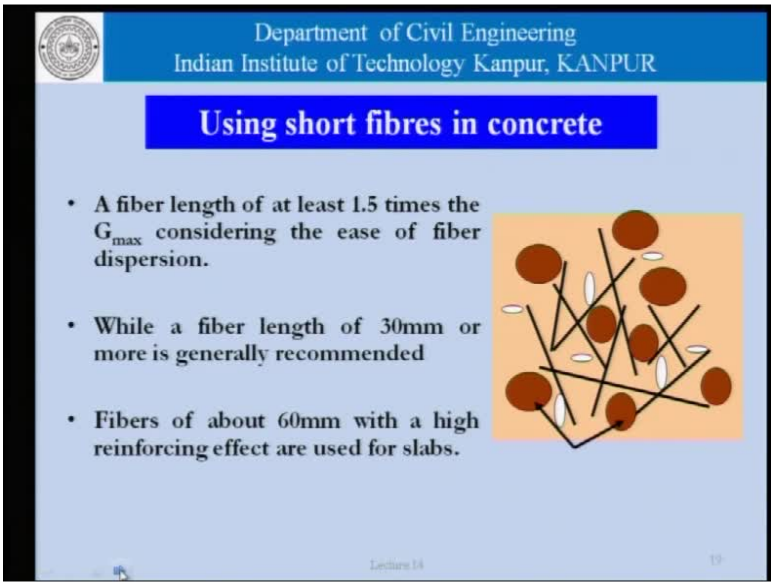

So, all things considered a fiber length of, at least 1.5 times the maximum, size of aggregates. Considering, the ease of fiber dispersion is one guideline, that we can use while a fiber length of 30 mm or more is generally recommended; and that is basically addressing the fact, that for a lot of concrete construction. The maximum size of aggregate used is in the, neighborhood of about 20 mm, so 30 mm is a ball park number, which basically says that, as far as normal concrete construction is concerned fibers, which have a length of about 30 mm are good enough, as far as there users concerned in fiber reinforce concrete.

Fibers of about 60 mm length with a reinforce, with reinforcing effect are used in slab. So we can use larger fibers but 30 mm is recommended. If we use 60 mm, the reinforcing effect is higher. The reinforcing effect of fibers, essentially depends on the length of the fiber and that is something, which we will talk about little later.

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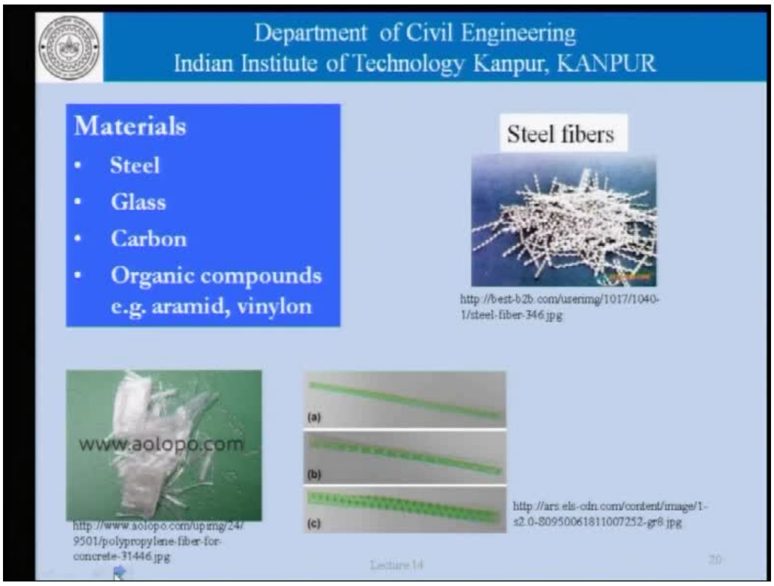

Here are some examples or pictures of fibers, steel, polypropylene and so on. This is the normal slice of concrete or a slice of normal concrete with coarse aggregates embedded in the mortar matrix, and that is what we have been seen saying some of our pictures. Now, these are some of the fibers, which are used as far as short fibers are concerned in fiber reinforce concrete, now these 2 are steel fibers, this is the glass fiber; and this is the polyethylene fiber.

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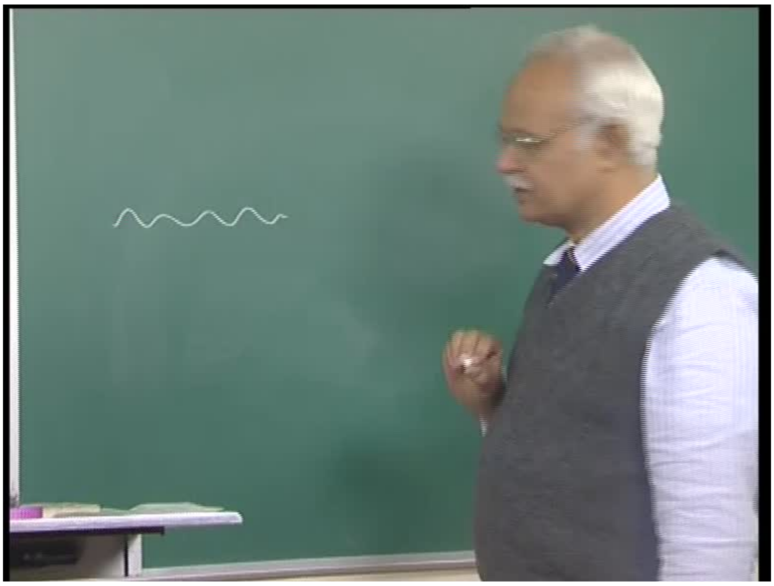

So, you can see that these two steel fibers, this fiber here for example, is this fiber here for example, is a crimped, that is it has a shape, which is something like this compare to that these fibers are straight. Even though if we look closely, there are deformations on the surface to increase the bond strength.

Similarly, if we look at the glass fibers, these are extremely short, just for by away illustration; they are very short, they are very small and these are glass fibers, which for illustration have been taken as very small, very short and we can imagine, that the reinforcing effect of these glass fibers, as far as the concrete matrix like something like this, could be very small. These here are polyethylene fibers, which are very small in diameter, the aspect ratios and so on, can be obviously calculated depending on the length and diameter of these fibers.

This is an illustration of, how fibers tend to form and group as a ball? When they are mixed with concrete? So, if we do not take special measures of ensuring, that this ball is broken and individual fibers are actually dispersed within the concrete matrix the effectiveness of fibers is very small.

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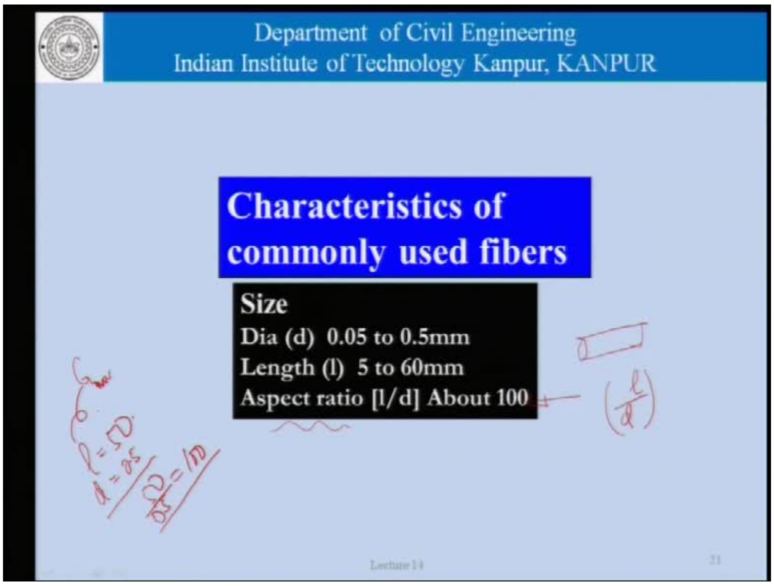

Fibers that we use in fiber reinforce concrete and this length is related to the maximum size of the aggregate. So, I leaving with your intuition to understand, how the aspect ratio is very important characteristic in determining whether or not a fiber will be effective in terms of its ability, to contribute to the tensile strength of concrete is concerned.

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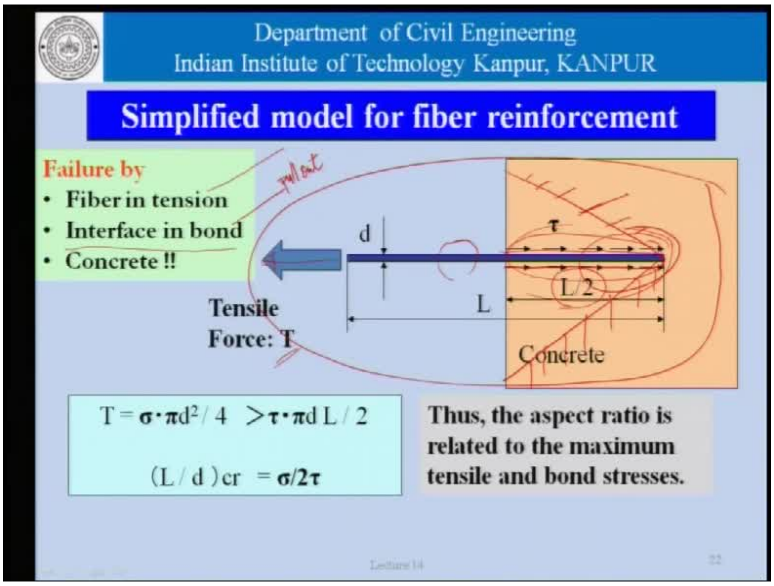

This here is a simplified model or fiber reinforce concrete. If we have a fiber, which is embedded in concrete, the way it is shown here, 1 by 2 the fiber that is l by 2 is embedded in concrete, 1 by 2 of it is the sticking out, and a force t is applied to fill this fiber out, this is resisted by the development of bond of friction within the concrete and that is to the extent of surface area and the length of embedment.

Now, there are three possible modes, of failure fiber fails in tension; that is the force is such that the embedment is very strong but the fiber gets raptured here, so the is the fiber in tension, then it can fail by way of interfacing bond, that is this bond here is not sufficient and the fiber gets pulled out from the concrete, so this is closed to a pull out of the fiber. And, then there is a possibility of the concrete itself failure, that is the fiber is strong, the bond is very strong and by pulling, this out it causes failure along the concrete or it causes failure within concrete cells, this is something, which is very common, which we see in a garden.

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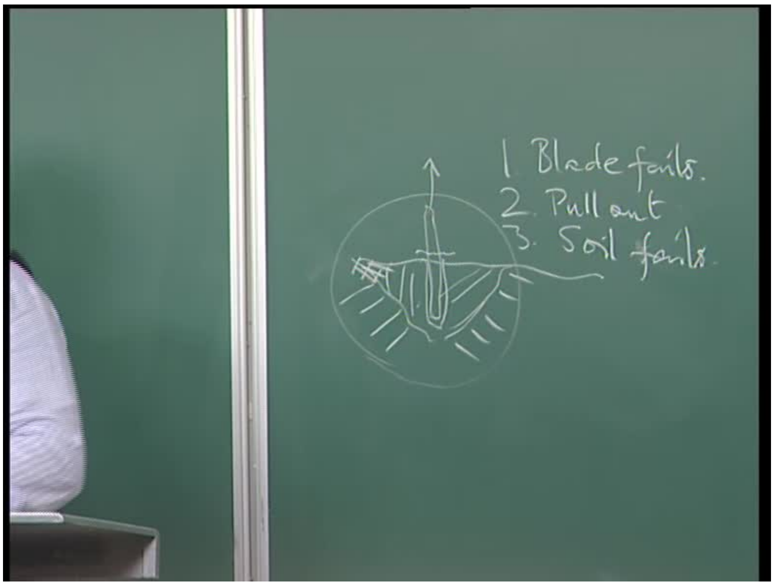

For example, let us try to understand, this with an analogy, which we see in a garden, if we have a small blade of grass, which is embedded in the soil and we try to pull it out, one thing that can happen is that, the blade fails, that is we have a failure here. The second thing, that can happen is that the blade is pulled out, that is this part that is pulled out the third thing, that can happen is that the soil fails and that is what happens, when we get this whole amount of soil coming out of the ground along with this blade, so precisely this is what is going on, when we are having a fiber embedded in concrete.

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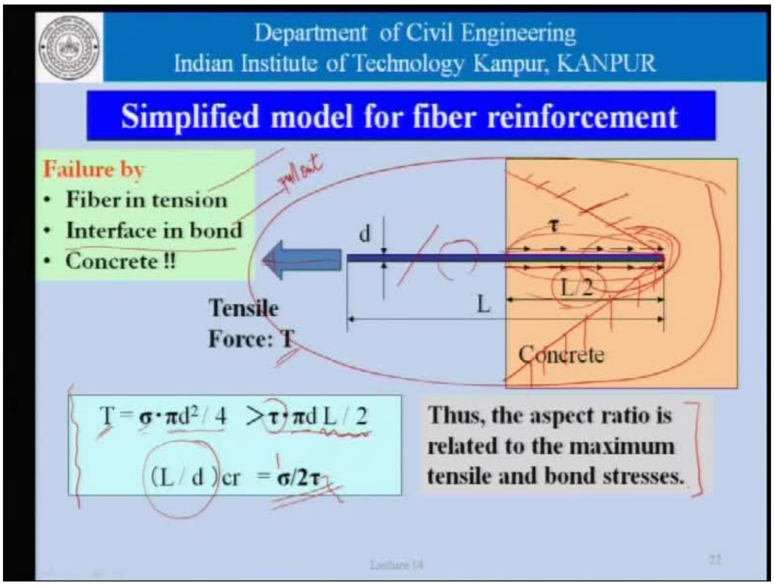

Either the fiber fails in tension or in the at the interface, get the concrete or it causes failure in the concrete itself. Now, let us try to look at a simplified equation, where this force t is equal to sigma times phi d square by 4, which is the diameter, which is the cross sectional area of the fiber and this has to be compared with the phi d, which is a circumference times the length of embedment and the bond strength, which is developed. So, once we do that kind of analysis, we see that l by d critical and that is the aspect ratio is really related to the properties like this, which is the sigma, which is the tensile strength of the fiber and tau, which is the bond strength for that particular fiber, so it is the bond strength. So, it is the aspect ratio, which is related to the maximum tensile and the bond stresses, and that is how it is importance of and that is, what is the importance of the l by t parameter?

This here is the picture, which shows that testing of fiber reinforce concretes in a laboratory, and we can see how these fibers, which are embedded on two sided of a concrete specimen and there is a perspex plate, which separate these two fibers, if they are pulled apart. We are basically trying to induce the failure here, either the fiber failure or the pull out and soon and so forth. In fact, this gives rise to the discussion in terms of, what is the property? which is required of the fiber, and that is something, which we have seen that we saw the fiber that not all fibers are really smooth; some of these fibers have some kind of crimping, so the so fiber really looks like this or sometimes, the fiber looks like this; so these ends provide more bond strength or more encourage, to each of these fibers as they are pulled out or as they are acted upon by loads, that may account concrete.

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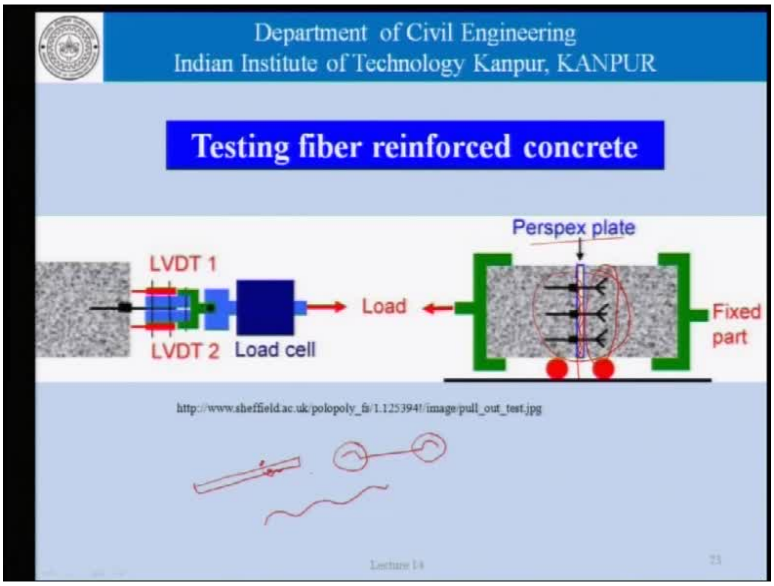

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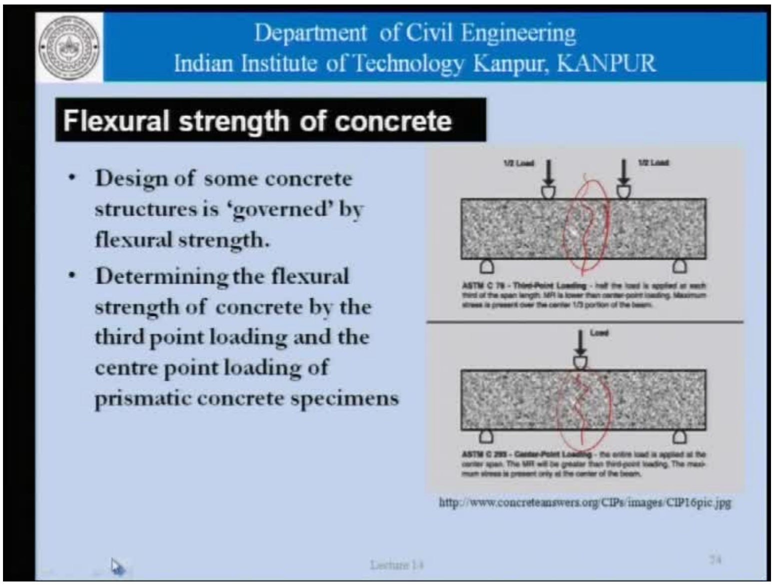

This here as the test, which we have seen for flexural strength of concrete and that is what, we were trying to show that, if these kind of tests are carried out normal concrete specimen, would show very brittle behavior, when it comes to failures at this points, is concerned which is not going to happen, when we are talking in terms of fiber reinforce concrete.

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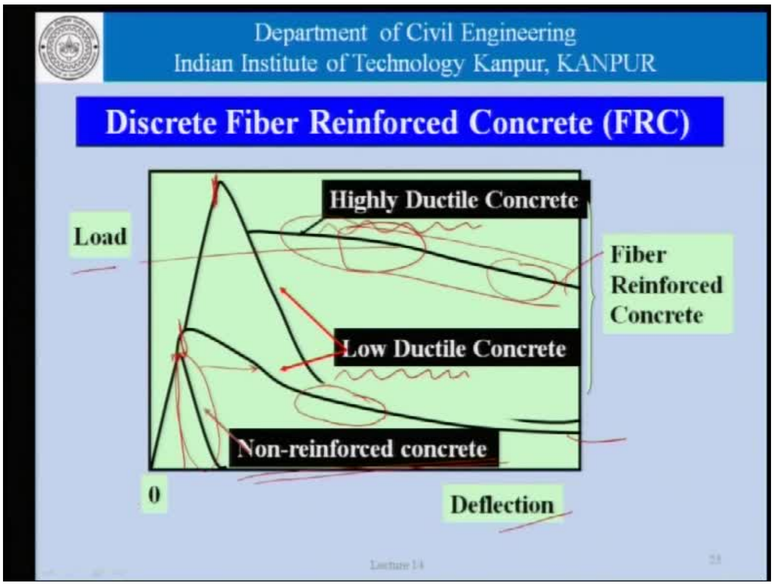

This here is the load deflection diagram, as obtained from a test like this. So, if we compare this, so if you look at this closely as far as, non-reinforced concrete or normal concrete is concerned beyond a certain point is virtually nothing that can beyond the certain point is virtual collapse. The concrete is simply not able to take anymore load whereas, in the case of fiber reinforce concrete, which is this line as well as this line depending on, how much is the fiber, what is the kind of fiber, and so on, the concrete could be a low ductile concrete or a highly ductile concrete, a ductile concrete or a low ductility concrete would be concrete, which has fibers, which give it some kind of a residual strength or a residual post cracking load carrying capacity but in a case of a highly ductile concrete, this ability is much larger.

So, there is a lot more load, that can be sustained even in the post peak region, in the case of low ductile concretes. The amount of load that can be sustained is much smaller compared to the peak load. We must remember this schematic or a qualitative description of fiber reinforce concretes, when we talk about the properties of concrete in terms of a structural design and so on.

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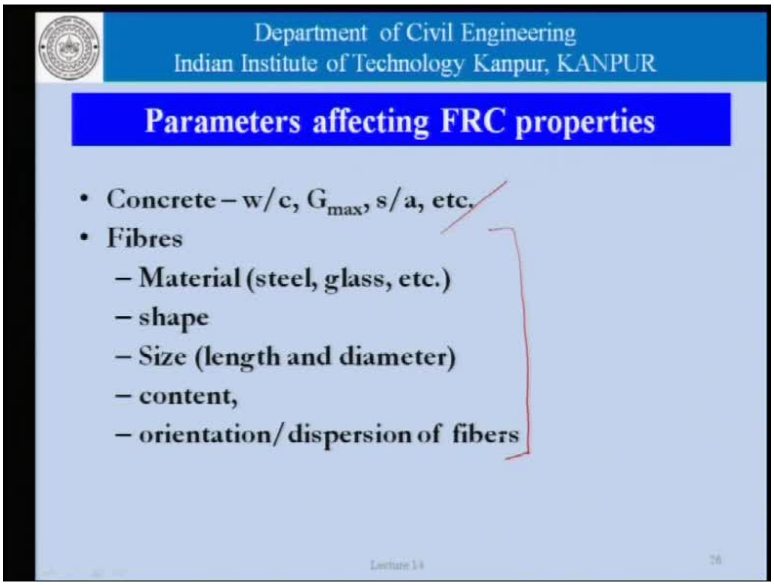

Now, we talked about this before is the fiber concrete is basically a combination of the concrete itself with some fibers, the properties or composite will depend upon concrete and the properties of the fibers.

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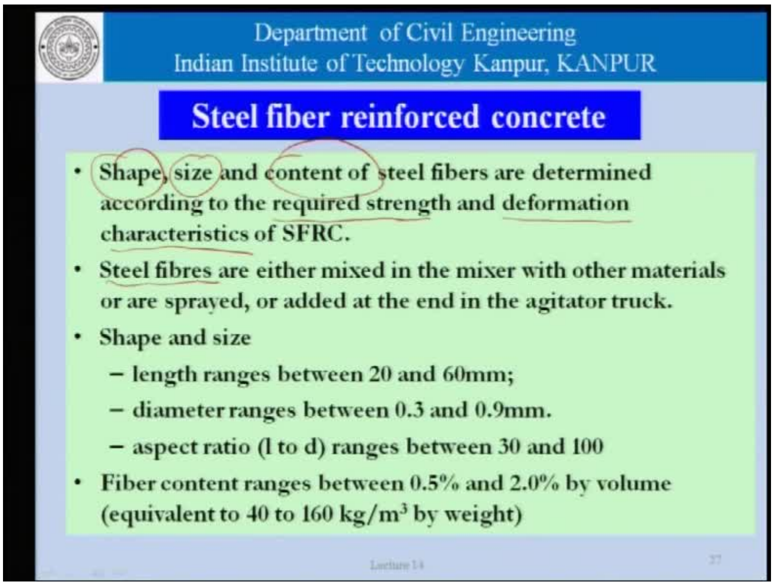

The shape size content of steel fibers, now we are talking about steel fiber reinforced concrete; that is one of the most commonly used, forms of fibers steel, is one of the most commonly used materials. As far as short fibers is concerned and therefore, steel fiber reinforce concrete is perhaps one of the most economical among the fiber concretes, which is commercially used. So, the shape, size and content of techniques steel fibers is determined according to the required, strength and deformation characteristics of the SFRC. So it is one of those composites, now or it is fiber reinforced concrete, now becomes one of those materials, whose properties can be actually engineered. That is, we required an certain strength and a certain deformation characteristics and depending on these, we choose the shape, size or the content of the steel fiber.

Now, these steel fiber are mixed either in the mixer with other materials or there is sprayed or added at the end in the agitator truck. So, it really is a matter of choice and engineers need to decide, what they want to do depending on the site conditions, that either the fibers can be mixed in the mixer itself, along with other ingredients aggregate, cement, water and so on or we can mix the concrete in the mixer and then add the fibers later on in the agitator truck as its been moved.

Now, as far as the shape and size are concerned. We know that, the length ranges between 20 and 60 mm. The diameters range from 0.3 to or 0.9 mm, the aspect ratio ranges from about 32 about 100, the fiber content ranges from about 0.5 to 2 percent by volume; that is the normal range, that is used among a fiber reinforced concretes and that is translate to an equivalent of about 40 to 100 and 60 kgs per cubic meter by weight as far as fibers are concerned in concrete.

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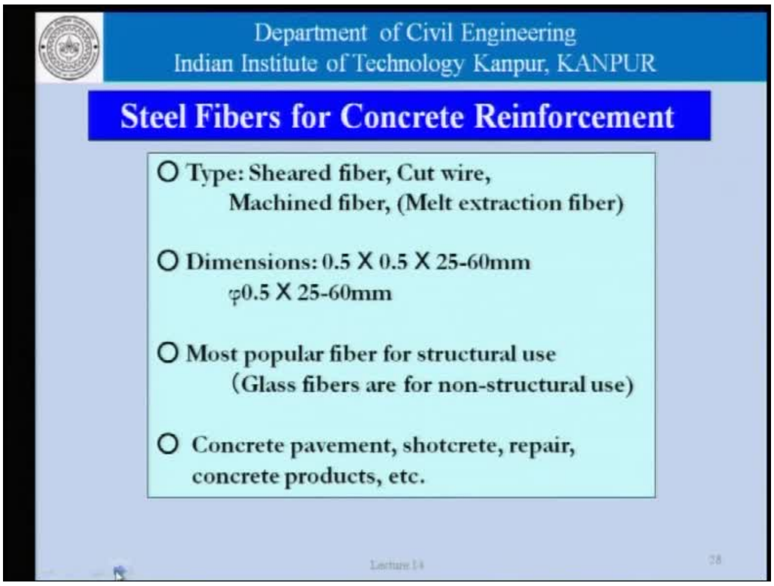

The slide again has a more discussion related to steel fibers, for concrete reinforcement. They could be sheared fibers, cut fibers, machine fibers and having a certain dimension in terms of 0.5 and 0.5, which is the diameter or the size of the fiber in terms of the cross section and varying from 25 mm to about say 60 mm and length, and the most popular form of fibers, for structure uses steel and glass fibers are generally used for non-structural applications, concrete pavement, shotcrete repair and concrete products; these are some of the target applications.

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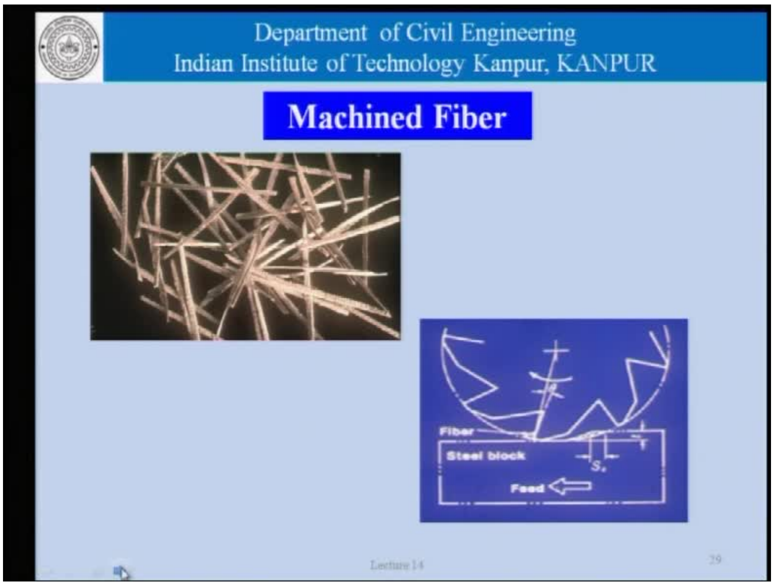

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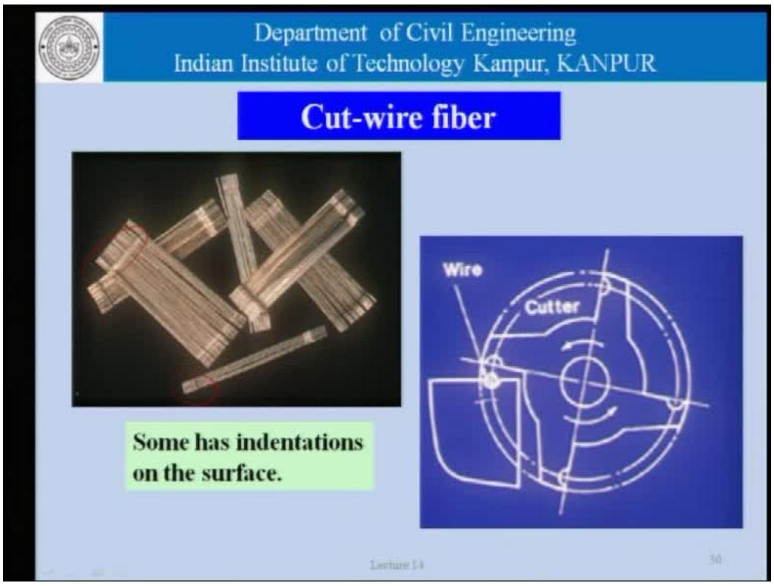

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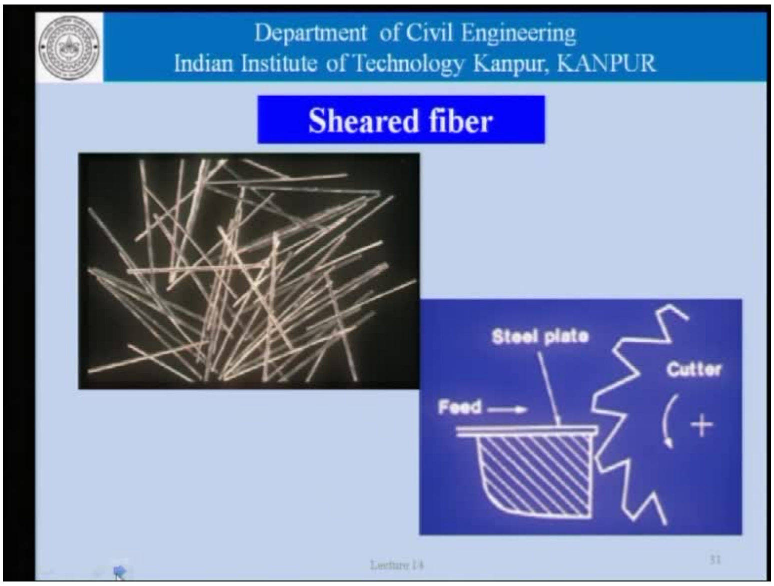

Now, these are pictures of machined fibers and the process, that we get them from this here, is cut wires and you will notice these edges, where there are indentations to increase the bond and we have sheared fibers, which again have surface some irregularity of the surface again to promote bond.

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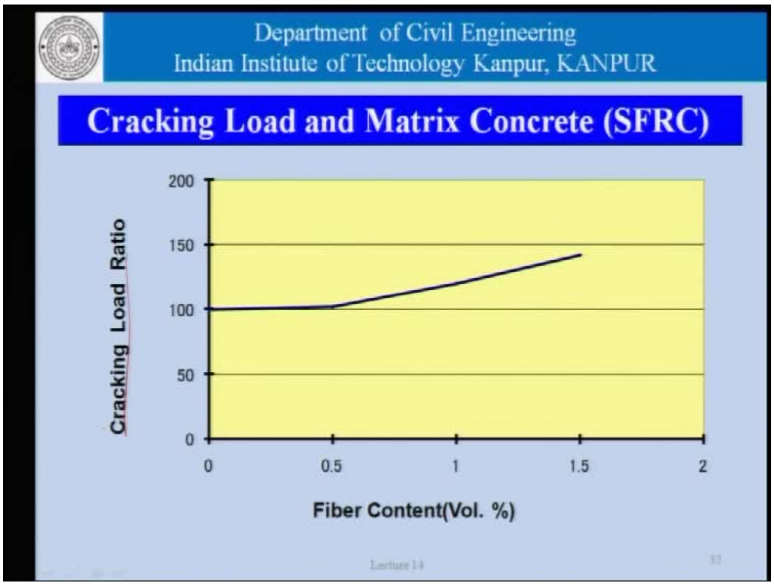

Now, this here shows, how the cracking load ratio changes as the fiber content? now what is the cracking load ratio? The cracking load ratio is the load at, which the cracking takes place in a flexural. The cracking takes place or the flexural cracking takes place as the load is applied taking, the non-fiber reinforce concrete as the base, how much does this load change as the fiber content is increased. So, as we can see that increase is more or less linear as far as steel fiber is concerned.

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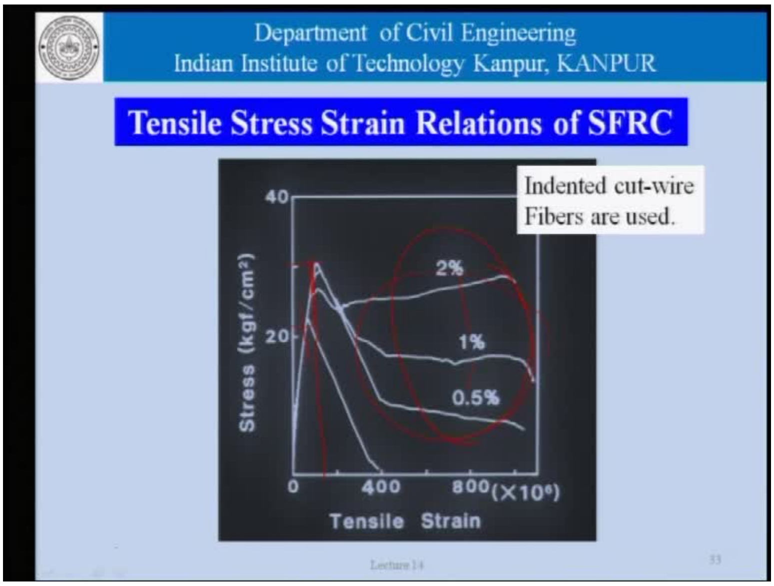

Another slide here shows, the tensile stress strain relationship or steel fiber concretes or a steel fiber reinforced concretes. And we can see that, as far as the stress strain relationships are concerned the post cracking. So if the cracking take place at these point, at these levels of strain and these levels of the load post cracking, the load carrying capacity is much higher in the case of fiber reinforced concretes and as we increase the fiber content, we get more and more load carrying capacity or the residual load carrying capacity, beyond the failures stress indeed the actual variation, as far as the stress strain curve is concerned would depend on the type of fiber, that is used the length aspect ratio and so on and so forth.

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Now, coming the properties of steel fiber reinforced concrete. Once again, a steel fibers may be assumed to carry, the stresses only after cracking of the concrete, and thus the tensile strength of steel fiber reinforced concretes may be taken to be the cracking or the tensile strength of the matrix concrete itself, and it is only beyond, that the fibers coming to play. Addition of fibers therefore, may not lead to substantial increase in the compressive or the tensile strength though the post cracking behavior, is a completely different story. As we have seen in the previous slides, that is not so much the change in the cracking load but the post cracking load ability to continue to resist deformation.

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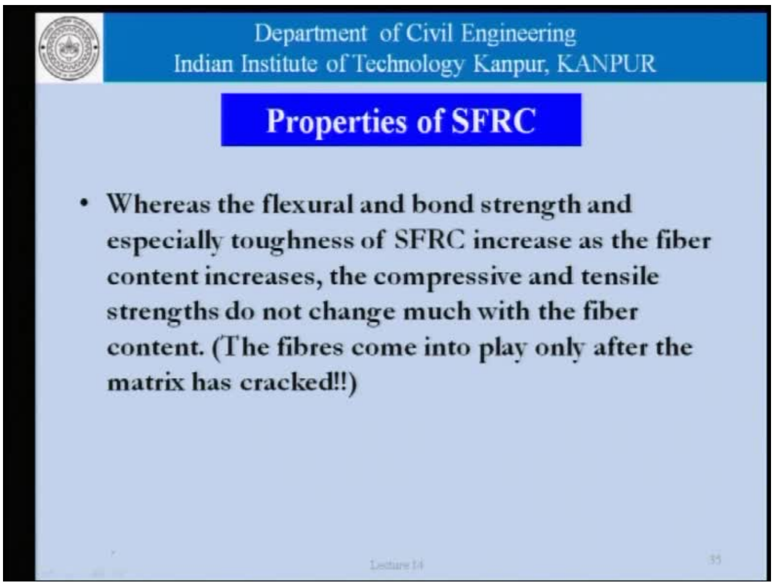

Whereas the flexural and bond strength and specially the toughness of steel fiber concrete, increases as the fiber content increases. The compressive and tensile strengths do not change with the fiber content, and fibers obviously come into play, only after the matrix has cracked and these terms toughness is something, which we need to define precisely and we will do that, in next few slide obviously. This strength of the concrete as far as water cement ratio and so on, is concerned that theory or that understanding remains the same and therefore, the compressive strength itself that is the maximum load carrying capacity, that does not really change, even if the steel is reinforced with short fibers.

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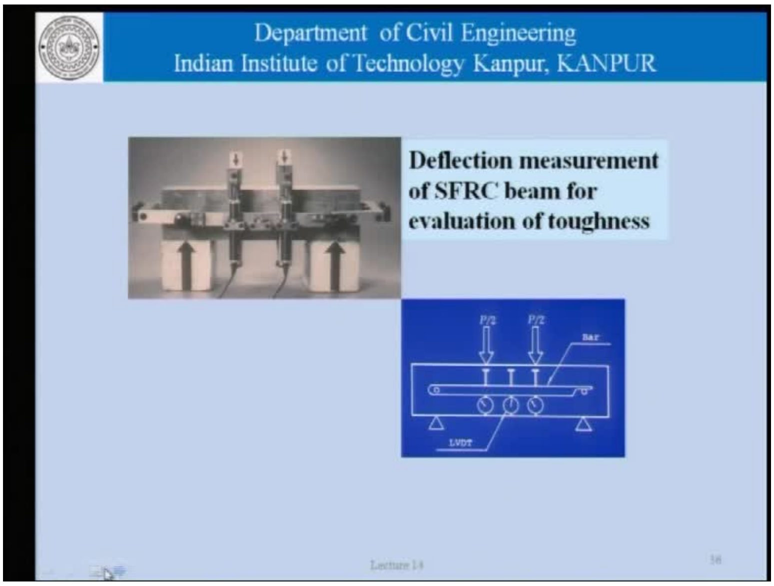

This picture essentially shows, the defection measurement of steel fiber reinforced beams for evaluation of toughness, and as far as performance criteria has concerned. We can have some of these terms, that is the total toughness toughness ratio equivalent flexural strength and the residual flexural strength ratio, which is used, so the total toughness really refers to this area under the load deformation curve measured up to a certain point or up to a certain level of the deformation or deflection compared to this for the same graph, for the same load deflection graph the toughness ratio is a ratio of this area. Here to the ratio, which is defined or to the area, which is defined by a rectangle enclosing p max and delta naught.

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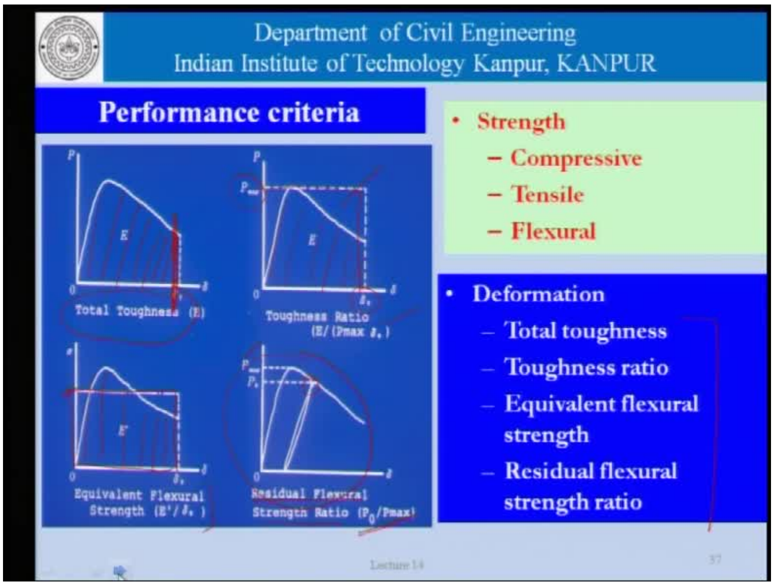

Equivalent flexural strength is nothing but this value here, which is defined in terms of this area being equal to this rectangular; the area enclosed by this rectangle being equal to the area actually under the load deflection curve and similarly, we can define the residual flexural strength ratio in terms of a cyclic loading, we can define the residual flexural strength ratio, when we carry out a cyclic test, that is we take it to up a certain level peak load bring it down and the next time, we take the load at what point as it start reducing, that is what is the ratio, we are talking about the p naught or p 0 divided by the p max, where p max is the maximum load sustained in the first cyclic. So, these are some of the terms that designer, would be more interested to know, when he carrying out the design of a steel fiber reinforced concrete beam or any other element or member.

As I have mentioned, before the load deflection curves, that we are talking about and which are at the center of our discussion in terms of the properties, of fiber concretes are concerned these would depend on the volumes of fibers. For example, this here is the variation, if we vary the volume from 0 to say 2 percent or for the different kinds of fibers, so there are these five kinds of fibers, which have been used and the area under the load deflection curve as measured up to vary level of deformation here or deflection depends on the type of fiber or the nature of fiber, that is used. So, it really a combination of the nature of fiber, as well as the fiber content, that determines the toughness, which is defined the in terms of the area under the load deflection curve measured up to a certain predetermined point of the deflection.

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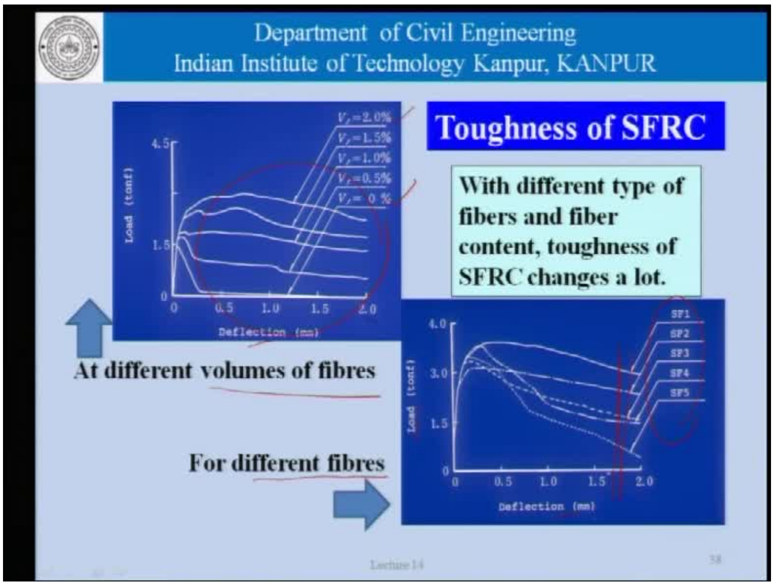

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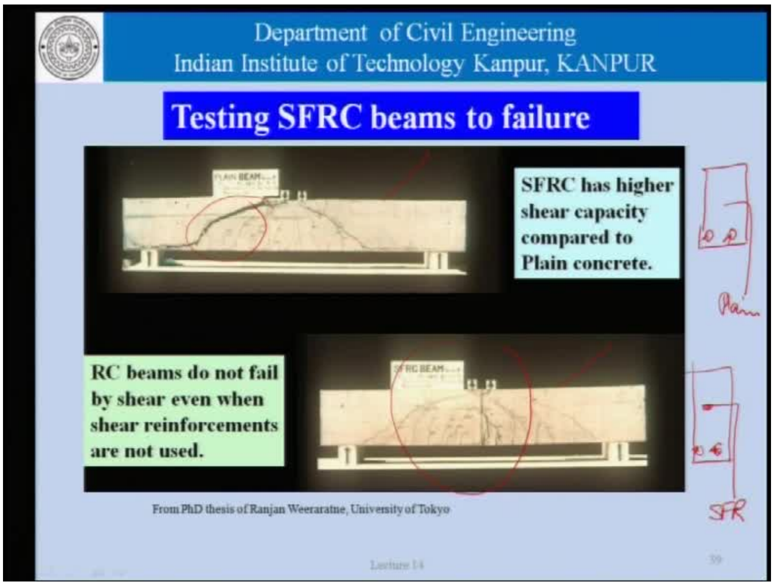

This slide, here is an extension of steel fiber reinforced concrete being used in a normally reinforced beam; so these steel beams have normal reinforcement, that is you have a cross section, we have normal reinforcement here whereas, in the case of a fiber reinforced steel beam, in addition to the normal reinforcement present, at the beam the concrete itself is steel fiber reinforced.

In this case, the concrete is plain concrete. The amount of reinforcement that is here, which is actually the reinforcement to the beam is constant or this is the same. So if you look at the failure patterns or the waves in which these two beams are failed the steel fiber reinforced concrete has a much higher shear capacity compared to the plain concrete. And as far as, this beam is concerned it really does not even fail here, we have a failure in shear, which is not something, which we see in the concrete made with steel fiber reinforced concrete.

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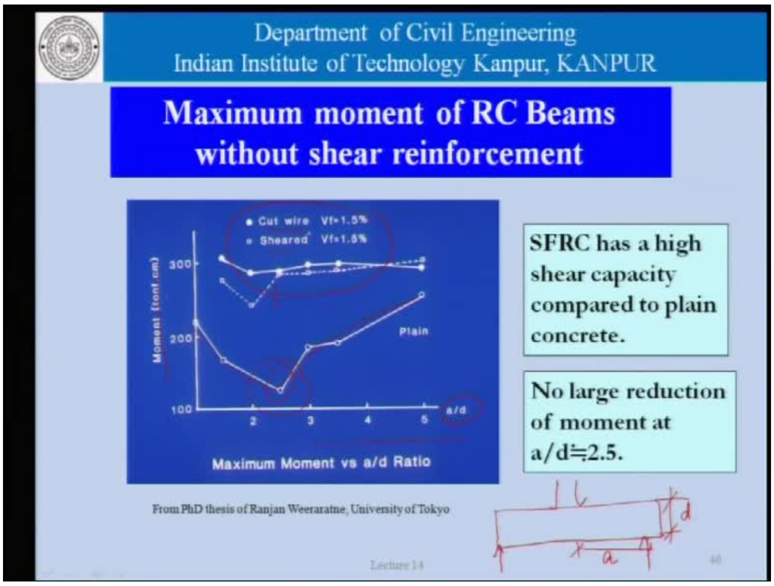

This picture, here is an extension from what we saw, if we look at the moment carrying capacity versus the a by d ratio, now the a by d ratio is the ratio, which defines the span to the depth; the depth of the beam and the span, that we are testing. So, as this span is as the a by d is increased. We know from our understanding of reinforced concrete structures, that there is a certain dip, here where the shear is really predominating and therefore, very often the a by d is as far as normal reinforced concrete beams are concerned or required to be higher than a certain number. So that, we can ensure proper flexural behavior and we do not expect shear failures.

Now, when it comes to steel fiber reinforced concrete beams, where it is cut wire or sheared fibers this dip ,that we have at an a by d or say 2.5 or something is not really seen. So the moment carrying capacity really remains the same, that is the concrete is not failing and it is only really the mean reinforcement, which is governing the capacity of the beam and that is the way, it should be as far as reinforced concrete beams are concerned.

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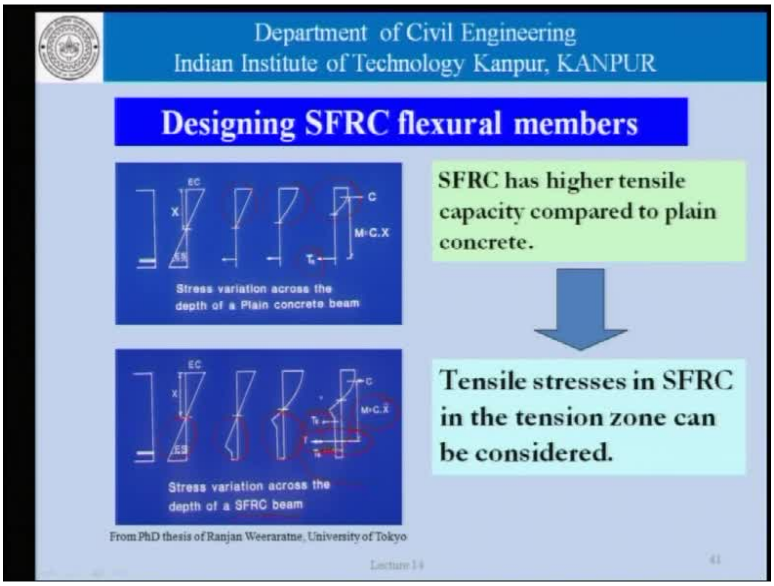

Now, this picture here shows the, elements of design of a steel fiber reinforce concrete flexural member, where the top part is concrete and we have a variation of strain stress and so on. And on the tensile side, we have the force been taken only by the mean reinforcement. Now, in the case of a steel fiber reinforced concrete beam, this part here is definitely not 0, that is the capacity in concrete as far as its ability to carry tensile loads is concerned is not 0 and that is what changes but behaviour of the SFRC been completely, as we have seen in a example in the previous slides, and that is something, which the designer needs know, when we calculates the capacity is in designs those needs.

So, the net tensile force for example, in this case in the case of a steel fiber reinforced concrete beam is acting at a level, which is slightly higher than the location of the reinforce in powers and by how much higher would depend on, what is the total tensile load, that the concrete is carrying? so these two together decide, what the, so called momentum will be for those of you, who have a better understanding of the design of normal concrete structures of the design of concrete structures using normal concrete and hands are it the flexural design or techniques design are used, would appreciated some of these points a little better.

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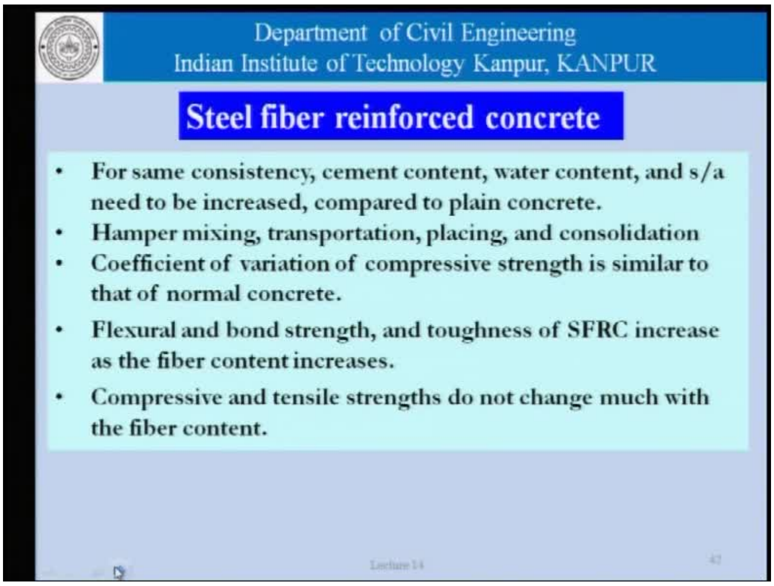

Now, let us come to some of the engineering properties of concrete and how they change? as far as the presence of fiber is concerned, so for the same consistency in cement content, water content and s by a; they need to be increased, the water needs to be increased, the cement content therefore, goes up and the s by a goes up, now s by a going up, we know basically means the mortar content goes up and that is something, which we need to have in order for the mortar space to be able to support the additional burden of the presence of fibers information is the presence of fibers tends of hamper, the missing transportation placing in consolidation and that something, which we need to taking to account, when we designing the concrete itself.

And also the concrete structures so coefficients of variation of compressive strength may be taken to the same, because that really does not change the flexural bond strength and toughness of the steel fiber reinforced concrete, increase as the fiber content increases, and there is not much change, which needs to be taken into account as far as the designer is concerned in terms of the compressive and tensile strengths.

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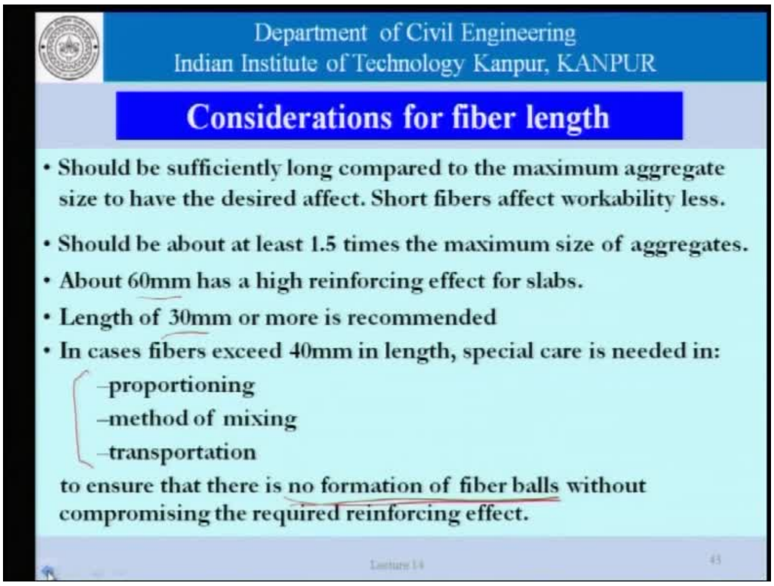

As far as, the considerations for fiber length is concerned, we have already gone through that and we know that, they should be sufficiently long compared to the maximum aggregate size, to have the desired effect. If the fibers as short their effect on the workability is smaller and that is something, which we would individually know. We already said that, the fiber should be 1.5 times, the maximum already aggregates and 6 30 to 60 mm size, as far as length is concerned and in case the fibers exceed 30 to 40 mm.

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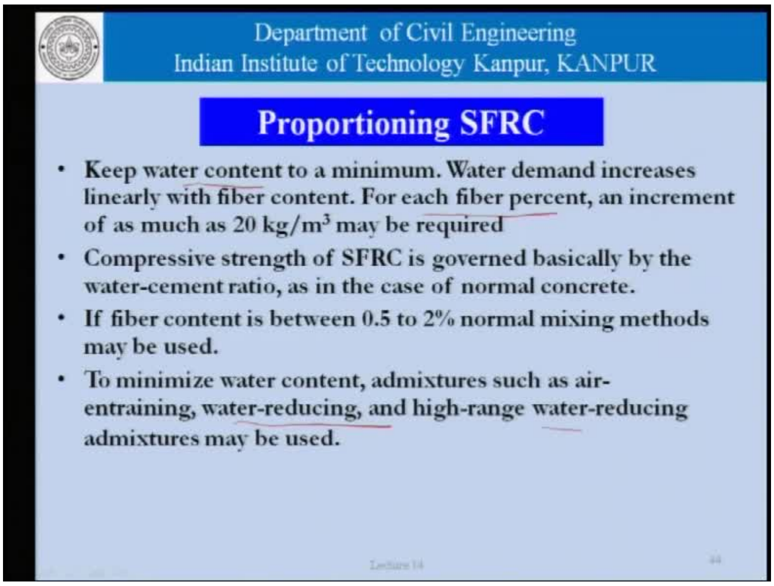

A special care need to be taken in terms of proportioning, the method of mixing transportation and so on, is concerned to ensure that, there is no formation of fiber balls and that something, which we will see in later slide.

As far as proportioning of fiber reinforced concrete, as far as steel fiber reinforced concrete is concerned, we should keep the water content to a minimum. But, we should remember that, each fiber content entrains are requires, that the water being increase by about 20 kgs per cubic meters. So, if we are working with a water content of about say 100 and 65 or 100 and 70 kgs per cubic meter of water, if we add some fiber to it, it might go up by about 20 kgs and we might land up with water content of 185 and 90 for a 1 percent fiber in the concrete matrix.

So far as, the fibers are between 0.5 and 2 percent, we need not bother about any special mixing method and since, the addition of fibers increases, the water content it is proved and try to use water reducing admixtures or high range water reducing admixtures in order to control that, increase in the water content. We might like to increase, the super plasticizer dosage, so that we do not have to increase, the water content and yet get the same amount of workability in a fiber reinforced concrete.

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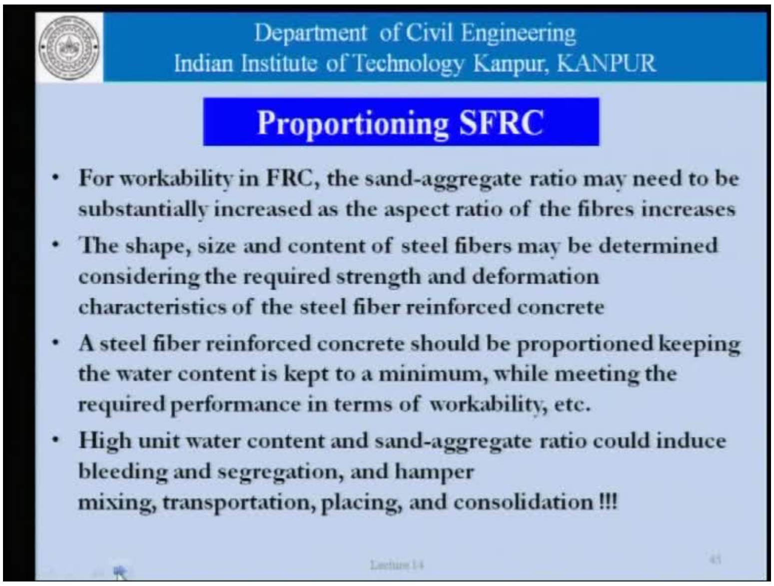

I have already mentioned, that for the workability in fiber reinforced concrete, the sand aggregates ratio needs to be increase, that is we need of basically higher amount of mortar in the system. The shape, size and content of steel fiber contents may be determined considering, the strength and deformation, that is required a steel fiber reinforced concrete can be proportion much in the same manner, as we did with normal concretes and keeping in view, that is there is keeping in view things like workability and strength and seeing, how much is that initial water demand but we must remember that high unit water content and the sand aggregate ratio could induce bleeding, and segregation in a concrete and also hamper. The mixing transportation placing and consolidation and these are thing, which we need to address, when we tried to talk in terms of proportioning of steel fiber reinforce concrete or a fiber reinforced concrete in general.

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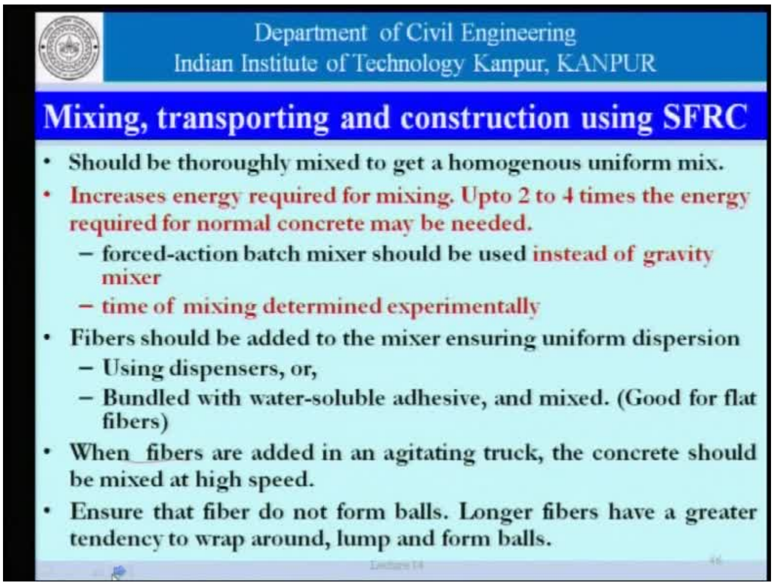

As far as, mixing and transportation is concerned of course, the first thing to remember is that the mix should be thoroughly homogeneous, a mixing process is such that we do not have fibers just in one place or the other. However, we need an increased energy to mix the fiber reinforced concrete, because the fibers add to the extent of energy; that is required. So, the energy demand as far as the mixing is concerned increases, in fact it could be 2 to 4 times the energy required for normal concrete and therefore we may need to have forced action batch mixers, instead of gravity mixers, the time of mixing may have to be increased and so on.

And that is needs to be determine experimentally depending on, the type of fiber; that we are using and we have already talked in terms of addition of fibers through dispensers and so on. We should also make sure that, when fibers are added in an agitating truck, the concrete should be mixed at high speeds to ensure proper dispersion of the fiber and its distribution throughout the concrete mass, and as far as the balling is concerned, we have already talked about it and we will see later on.

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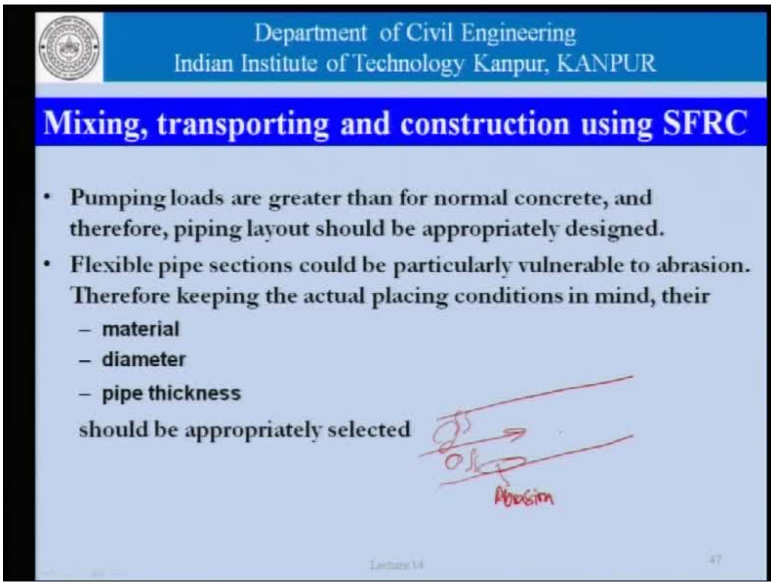

It may also be remembered that, the pumping loads are greater than those for normal concretes and therefore, the pipe layout, that we used, when we were pumping concrete from one place to another needs to be appropriately design, the bends and so on, need to take into account, that the fact that concrete may not flow that easily or it will require additional pumping effort.

Flexible pipe section, could be particularly vulnerable to abrasion, because of the presence of fibers within the concrete, what we are saying is that, if we have a pipe and if concrete is flowing through this, if fibers are present in the concrete, then they could cause abrasion, then they could cause abrasion in the lining of the flexible pipe and therefore, what something and therefore, that something which the engineer needs to keep in mind the diameter, the material, the pipe thickness and so on of the pipes used in the pumping operation should be carefully chosen.

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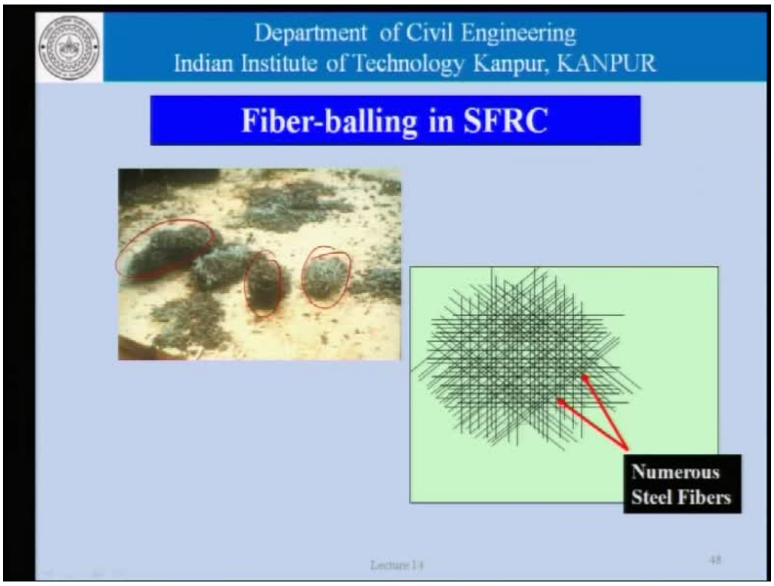

This here is the picture of the fiber balling in the case of steel fiber concretes. So, we see that these are the kind of balls, that the fibers may form unless precautions have taken to disperse the fibers throughout the concrete matrix.

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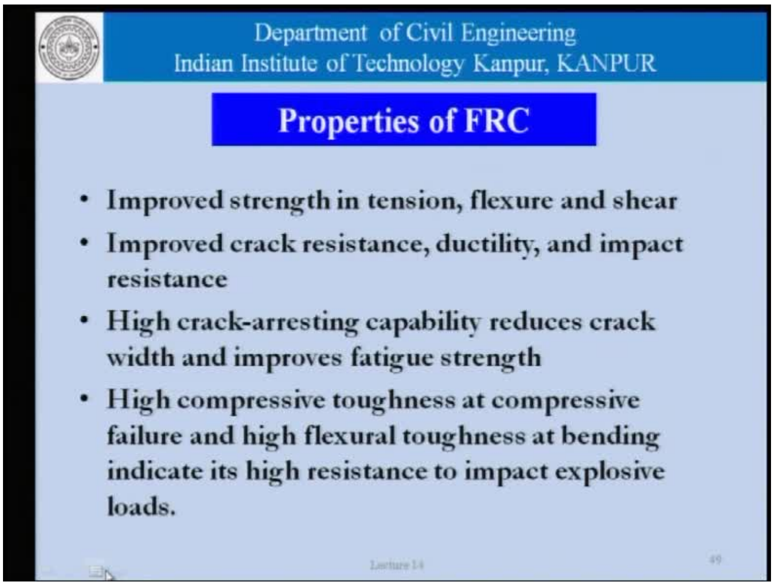

So, reviewing the properties towards the closure of the discussion, improve properties in terms of tension flexure and shear improved crack resistance ductility and impact high crack arresting capability, reduces the crack width and improves fatigue strength of the concrete higher compressive toughness at compressive failure and high flexural toughness at bending indicates, its high resistance to impact in explosive loads.

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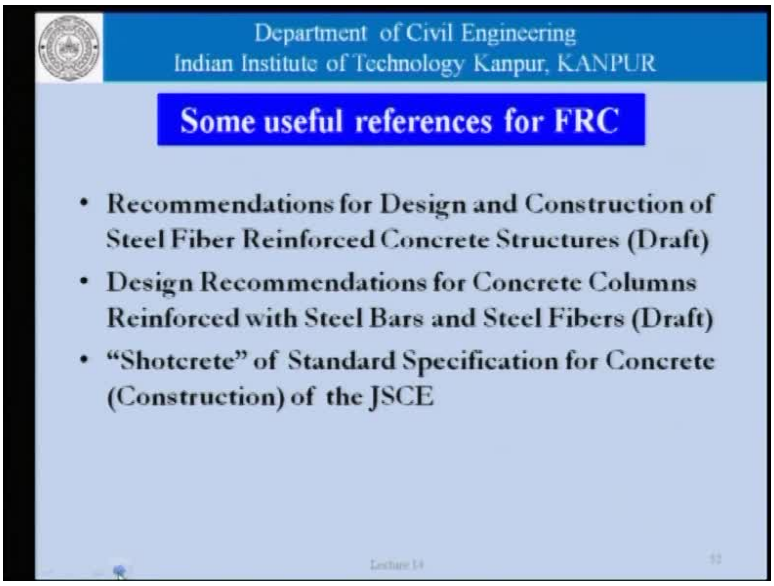

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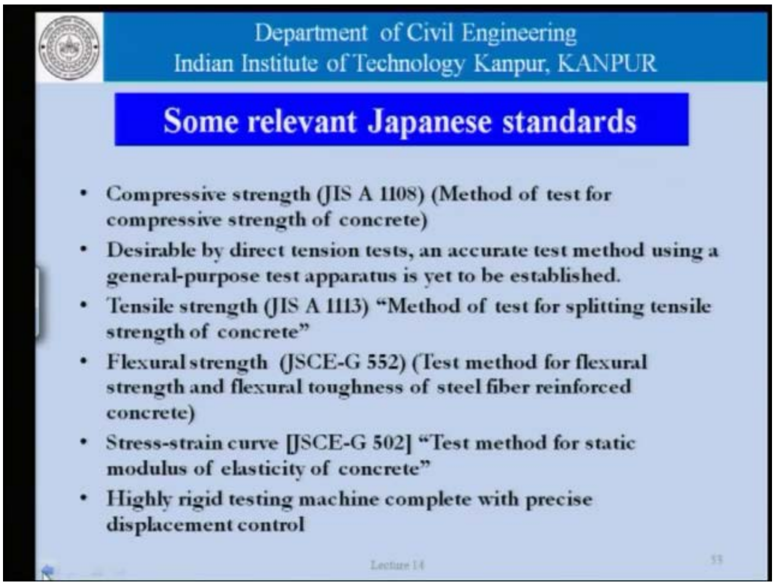

These here are some of the useful references for fiber reinforce concrete. And of course, we can continue our discussion, this list is binomial exhaustive and the lot of publish literature is available.

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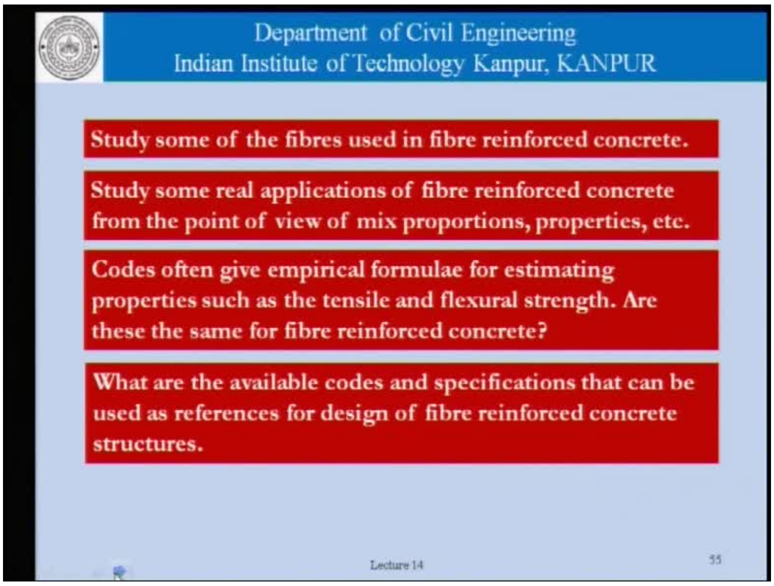

As far as, fiber reinforced concretes are concerned and before we close the discussion for the day, let us try to see, what we need to do additionally in order to understand some of the concepts in fiber reinforced concrete systems, that we studied today first thing obviously is to study, some of the fiber is used in fiber reinforced concrete even though, we some of the fibers today, that is not exhaustive there are different companies, which manufactures the fibers the fiber vary in their length the diameter, the material itself and so on.

We could study some real applications of fiber reinforced concrete, from the point of view of mix proportions properties etcetera. If talked in terms of the effect of fiber addition in terms of workability, toughness and so on. As a lot of published information, which tells us quantitative details is to, how much fiber addition needs work kind of an improvement or, what is the quantitative scale of improvement in terms of toughness, increase in the cracking load and so on, when there of course, codes which often given empirical formulae for estimating properties such as the tensile and flexural strength what we could try to do is to see if the codes, what the codes say, about whether the same equations or the same estimating methods, can be used in the case of fiber reinforced concrete or there is a difference, for the case of fiber reinforced concretes.

And of course, what are the available codes and specifications, that can be used as references, some of them. We try to see as far as, the plan is concerned there are others in the US and Europe, which help us design for the reinforced concrete structures and the comparison of the provisions, there could be very helpful.

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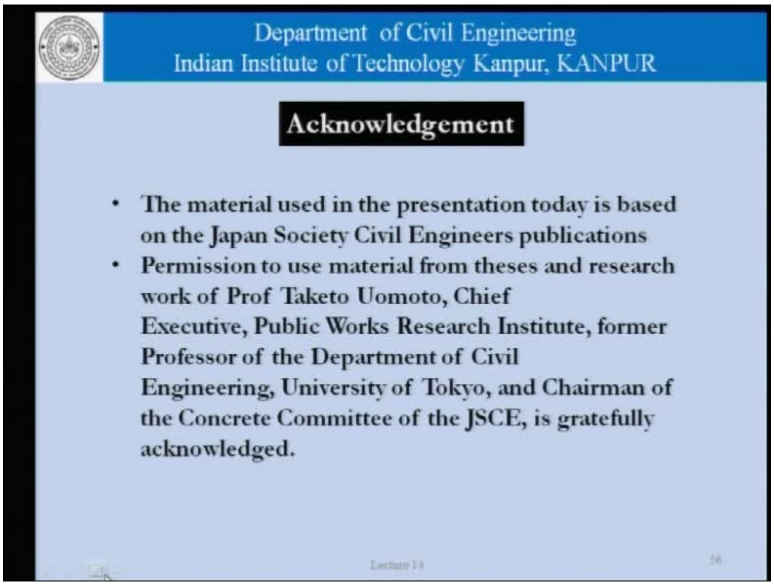

I would like to acknowledge my thanks, to the JSCE publications, which I have used in the public in my discussion today and of course, the permission that I have for using materials by Professor Uomoto of the public works research institute, to use that material in the discussion today with the course and with gut, we come to an end of the discussion today.

Thank you.