Development and Applications of Special Concretes
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Lecture 22
Fibre-Reinforced Concrete- I

Namaskar and welcome back; to another lecture in our continuing series development and applications of special concretes. Today we will start a discussion on another special concrete the fibre reinforced concrete. Getting started with fibre reinforced concrete Let us talk a little bit about why they are needed? What kind of fibres are used and the basic issues involved.

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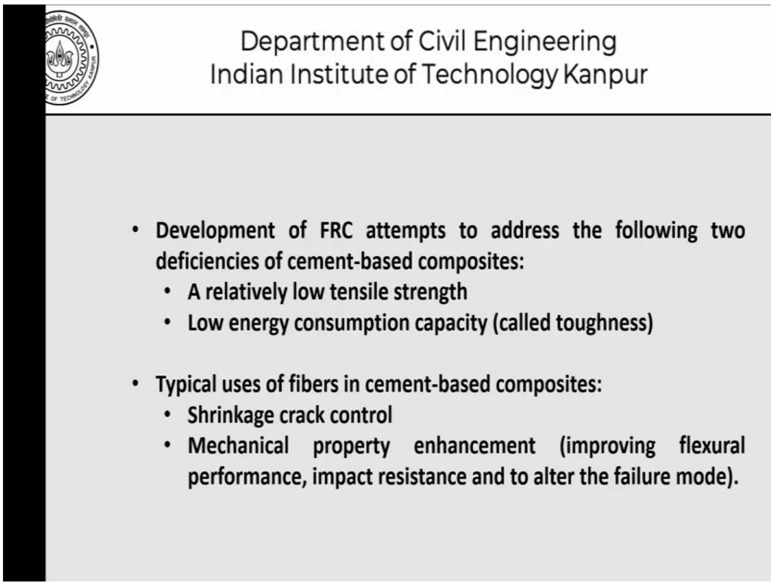

So the development of Fibre reinforced concrete attempts to address the following two deficiencies in cement based composites. One is a relatively low tensile strength and the second thing is low energy consumption capacity, which is called toughness. Now this toughness parameter is something which is used to characterize material from construction engineering point of view this is useful when you are talking of performance of structures in earthquake, loading where we expect the structures to show a lot of energy absorption capacity.

Typical uses of fibres in cement based composites could be for shrinkage cracks control and mechanical property enhancement. Now these mechanical properties could include flexural properties, impact resistance and to alter the failure mode as we will see.

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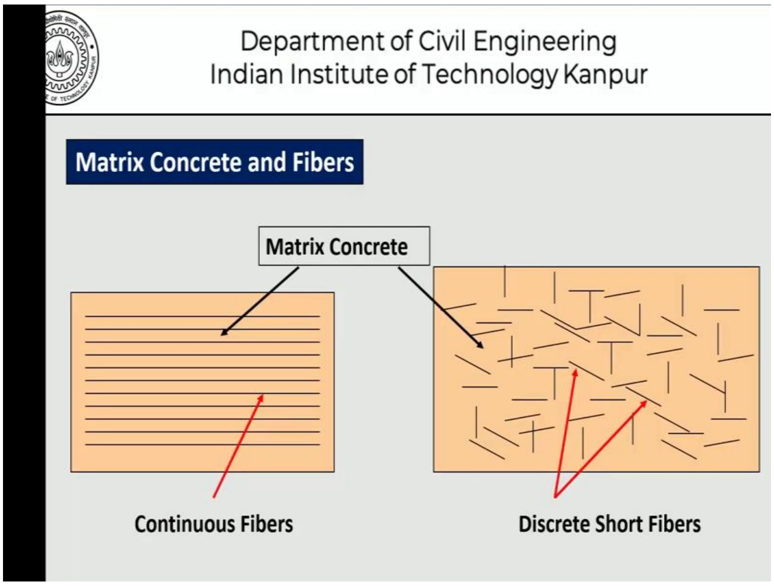

This here is a diagrammatic representation of how fibres are incorporated into the concrete matrix. Remember that as far as concrete is concerned we know that it is a composite made of cement, water, sand and aggregate. Aggregate here refers to coarse aggregates are not using the word coarse I just simply write it as aggregate. No in this normal concrete we add fibres. Now this picture here shows two types of fibres being used. This is the matrix of concrete one is continuous fibres and the other is discrete short fibres.

So these long fibres are continuous. So this could be again reiterated as long continuous fibres. And here we have short discrete fibres which are oriented in random directions and distributed throughout the matrix.

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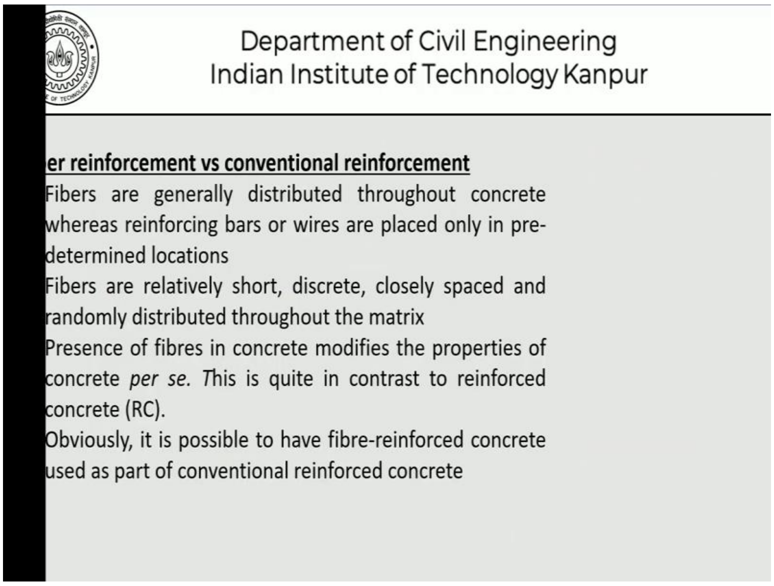

Fibre reinforcement versus conventional reinforcement now that something which often comes to our mind that how is fibre reinforcement different from conventional reinforcement, we know from our discussion of reinforced concrete members that if we have a beam which is simply supported let say and we subject it to a loading. Here this portion of the beam will develop flexural stress in excess of the tensile strength of concrete and we will have flexural cracks.

Now once this flexural cracks of formed in order to arrest them in order to make sure that they do not propagate through the section. We put reinforcing bars. So this is our understanding of reinforced concrete. From this understanding how is the fibre reinforcement different? Not this slide seeks to explain precisely that. Fibres are generally distributed throughout the concrete whereas reinforcing bars or wires are placed only in predetermined locations.

So as we can see in this slide here or this picture. Reinforcing bars are placed at tensile phase of the member. We put some reinforcing bars in the compression phase itself also but it is all at predetermined locations whereas fibres are distributed throughout the matrix that is if I was to use a different colour here. Fibres will be all over the place as far as the matrix is concerned. So it is not at a predetermined location as in the case of reinforcing bars.

Fibres are collectively short, discrete, closely spaced and randomly distributed throughout the matrix. These reinforcing bars are long bars. We run throughout the length of the member. How much of it runs through how much of it is not running through and there may be some curtailment and so on but by and large the principle is that these are long bars they will run throughout the section.

Whereas in the case of fibres that is not the case, they are short, discrete and randomly distributed throughout the matrix. Presence of fibres in concrete modifies the properties of the concrete per se. So remember that we had a picture which we use all the time. That we have concrete and we have these coarse aggregates and we have this as my mortar matrix. These are the coarse aggregates. So this is the properties of this picture.

We used to explain the properties of concrete and you would recall that we use some kind of three phase material model where we said that concrete could be modelled as made up of the mortar phase, the coarse aggregate phase and transition zone. So based on this we have explained the properties of concrete. Now the presence of fibres in concrete modifies the properties of this concrete that is because these fibres.

Let me use another colour here. Now the fibres here are all over the place. Of course they will not enter the coarse aggregate as shown here but they are all distributed in the mortar and it is in three-dimension throughout the concrete or throughout the mortar. So this presence of fibres modifies the properties of the concrete itself, this does not happen in reinforced concrete. In reinforced concrete we have concrete and we have reinforcement.

Whereas in fibre reinforced concrete obviously as it stated here. Fibre reinforced concrete could very well be used as the concrete to be used in reinforced concrete structure that is then we will have fibre reinforced concrete being used as part of the conventional reinforced concrete. That is then we will have a section here which will have reinforcement. And as far as this is concerned instead of concrete, we will have fibre reinforced concrete.

So there is nothing wrong with that. So fibre presence or the presence of fibres in the concrete matrix modifies the properties of concrete in different ways whether it affects the compressive strength or not whether it affects the tensile strength or not whether it affects the modulus of elasticity, whether it increases the toughness and so on. So those are all questions that we will answer as we go along when we deal with the impact or effect of fibre addition on the properties of concrete.

And that would become the properties of the fibre reinforced concrete. Having said that it is a different composite, it is not conventional reinforced concrete. Conventional reinforced concrete the way the images is normal concrete with reinforcing bars placed at predetermined locations in order to primarily control or augment the properties of concrete in tension.

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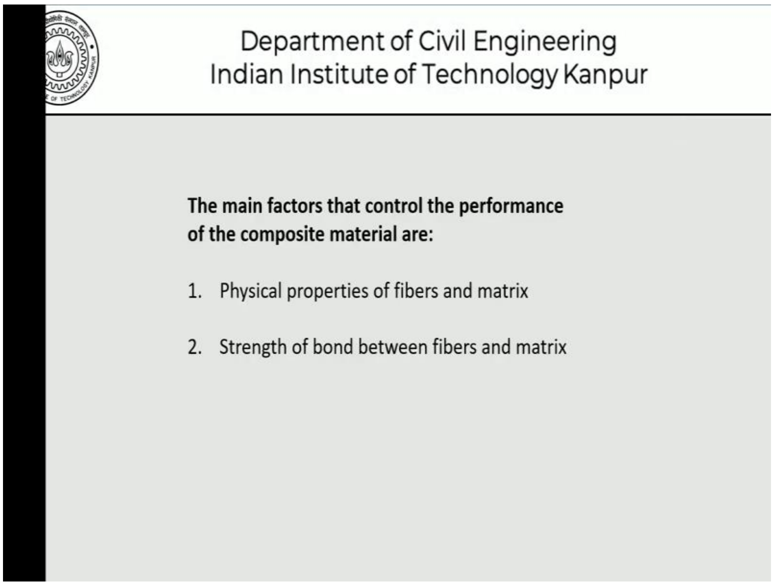

Moving forward the main factors that controls the performance of the composite material are the physical properties of the fibre and the matrix. So, obviously when we are talking of the matrix which is in this case, the way I have shown here this my concrete and we have some fibres. So the properties of this composite obviously would depend on the properties of the fibre. And the amounts of fibre that we use and of course the properties of the composite that is the properties of the concrete.

The strength of bond between the fibres and the matrix this is something which we will shortly see as to what happens. If we want to create a model of how this fibre participates in modifying the properties of this concrete. So the bond becomes important characteristic and that something which needs to be investigated it needs to be studied in greater detail. So the long and short of it is the performance of this composite called fibre reinforced concrete will depend upon the properties of the matrix, which in this case is concrete.

And the properties and the amount of course, you cannot just add one fibre to concrete and say that you made fibre reinforced concrete or for that matter if you put too much of fibre, that there are other issues. So there again has to be a balanced how much fibre you can put in? What kind of fibre you put in such amount and the properties of the fibre that is involved and of course the properties of the matrix and the bond between the fibres in the matrix.

So this is pretty much similar to the discussion that we had between the role of the coarse aggregate versus the mortar phase and ITZ. These three were the pillars on the basis of which we discuss the properties of concrete. Now with the addition of fibres in the concrete we are talking of properties of fibres the properties of matrix and bond between the fibres and the matrix.

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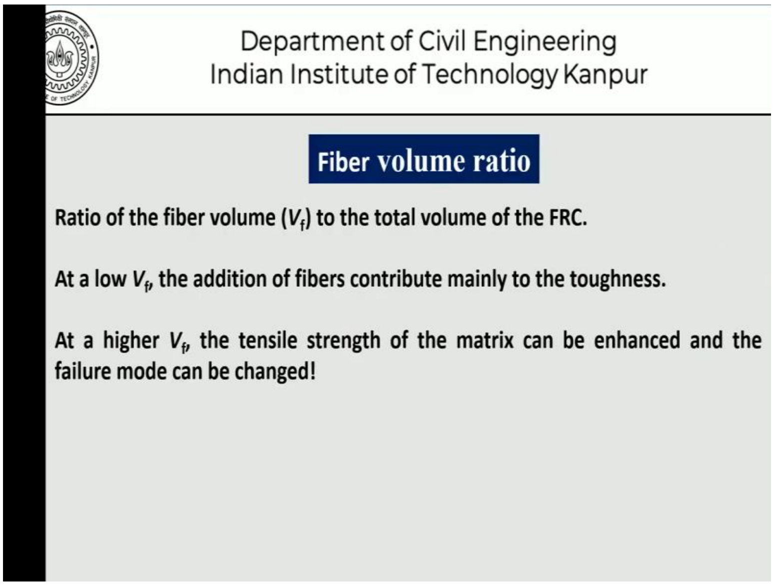

So as far as the fibre volume ratio is concerned this picture here just gives you very rough, very simple schematic representation or a discussion of how the properties of a composite are determined. If the ratio of the fibre volume is Vf to the total volume of the fibre reinforced concrete at a low Vf that is if the volume of fibres is low. The addition of fibres contributes mainly to toughness alone.

There is not so much of a contribution to the strength. At the higher volume fraction however, the tensile strength of the matrix can also be enhanced and failure mode can be changed. Now we will see it later that I can have a material. Let us not bother about fibre reinforced concrete. Let us talk of a simple material. We can have a material here, which is going to fail somewhere here. So this becomes the strength of this material. We can have another material which will not fail here but will sustain some more loads.

Sustain some more deformation I should say. We can have another material which has the same strength that is it cannot take any more load than this but does not fail here in a brittle manner but sustains the larger deformation before it fails. So, this is a very different characteristic. This is what we would refer to toughness and probably define it in a much more rigours manner. And then there is always a possibility for third situation where the material strength is also enhanced.

So from here the strength goes up to this point whether or not it leads to any substantial change in the strain capacities or so on is a different story. But here we have three models, this strength enhancement, the toughness enhancement, strength enhancement and toughness enhancement. So as for as fibre reinforced concrete is concerned what happens is that at low volume fractions of fibre addition, we typically get only this.

At higher fibre additions, of course, we also try to get something here. We have an increase tensile strength. And also the corresponding increases in the toughness values.

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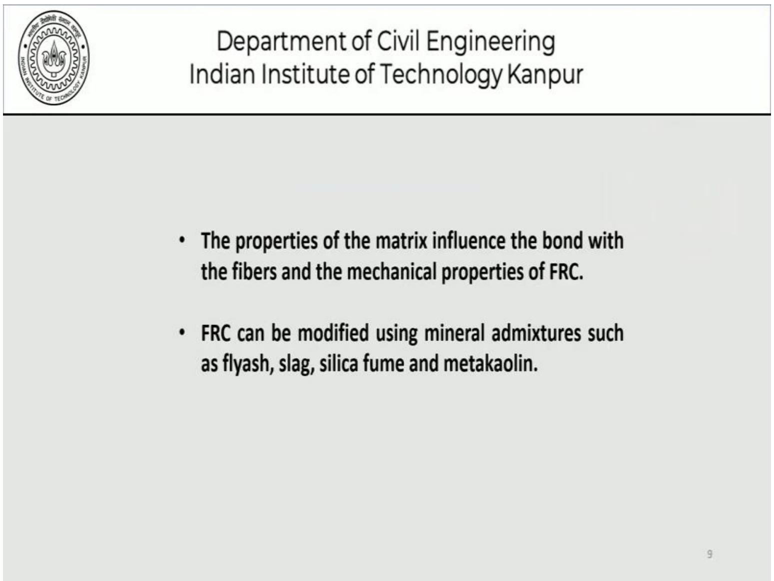

The properties of the matrix influence the bond with the fibres and the mechanical properties of fibre reinforced concrete and fibre reinforced concrete can be modified using mineral admixtures such as fly ash, slags, silica fume and metakaolin . So this modification here is for the modification of the matrix properties. Of course if you change the matrix properties that properties of the fibre reinforced concrete which is the composite will obviously change.

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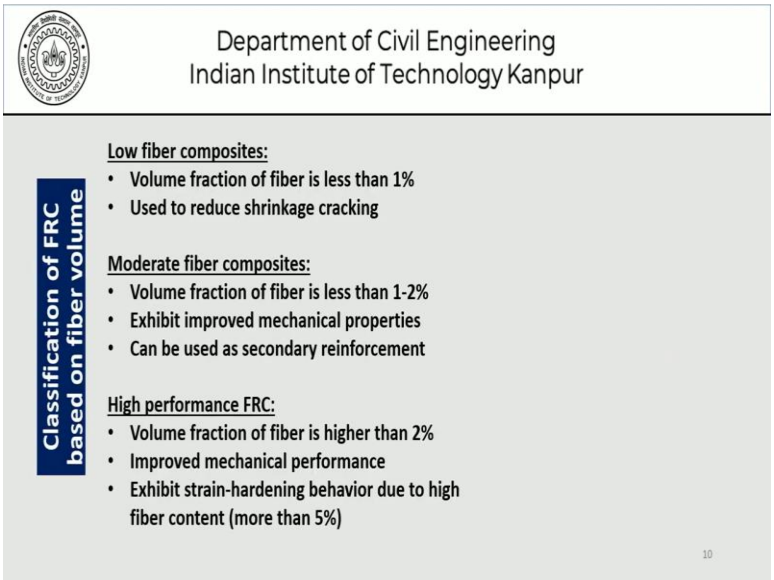

Now as far as the classification of fibre reinforced concrete based fibre volume is concerned if the volume fraction is less than 1% we often called low fibre composites and that application is largely for shrinkage cracking when it comes to moderate fibre composites typically we are talking volume fractions which are 1 to 2% and there we can exhibit or expect certain improvement in the mechanical properties.

This can also be used as secondary reinforcement, but only when it exceeds about 2% can we expect high performance fibre reinforced concrete and there we can have improved mechanical performance and exhibits some kind of strain hardening behaviour due to the high fibre content if it is more than 5%. Now these numbers cannot be hard and fast rules or cannot be prescribed with too much of rigger for the simple reason that the change in property also depends on the nature of fibres being used.

So if you are using steel fibres, if you are using glass fibres or aramid fibres these numbers could be quite different. So the principle involved is that what you achieve would depend on how much of fibres you put in. We could be looking for shrinkage cracking control. We could be looking at marginal improvement in mechanical properties. We could be looking at high improvement in mechanical properties and therefore we need to add the adequate amount of fibres into the system.

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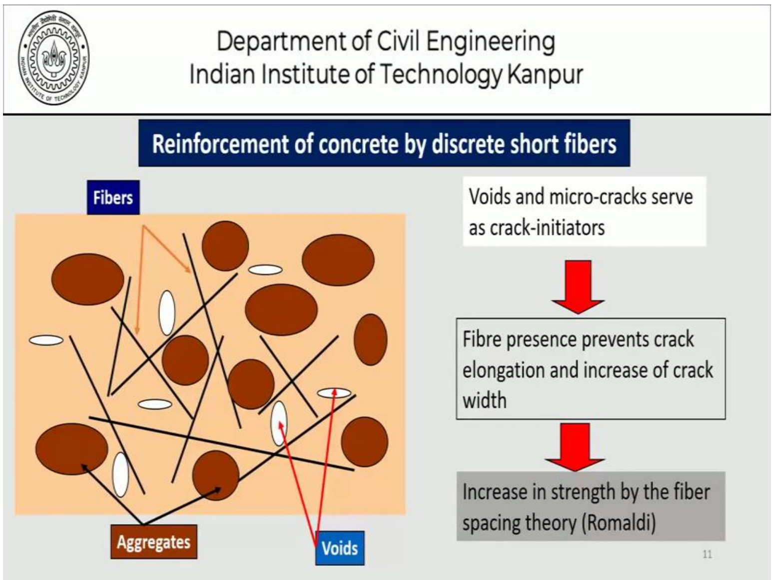

So, the reinforcement of concrete by discrete fibres is shown here once again. So as I try to show you in a more rough manner, of course, this is equally rough you can imagine this my coarse aggregates. These are the fibres that you are talking about. These are some kind of voids which are there within the concrete there always present and this is my mortar matrix. So voids and micro cracks, crack initiators as far as concrete is concerned.

The presence of fibres prevents the crack elongation and propagation and increase in crack width and that leads to an increase in strength of the fibre reinforced matrix by the fibre spacing theory. So now what is being said is suppose there is a void here. Now if this void was to try to progress. If crack is initiated at this end of the void it will soon hit the fibre. It cannot go through the fibre very easily and therefore it will get arrested.

Similarly if the crack propagation was to happen at this end of the void or this end of the void then these fibres would arrest further growth and that also tends to hold on or reduce the cracks width that we see. However, having said that I am leaving it you just think as to what will happen the kind of qualitative explanation which I have given what will happen if the crack propagation happens at this location A of the void or this location B of this void. Will this fibre be able to resist the crack propagation?

The answer obviously is no. And that is why we need to ensure that there is a certain amount of fibres which are present we cannot control all the cracking but we can arrest some of them. Here the fibre will fail it will not be very effective. Yet another question for you, the presence of these fibres also would alter the properties of my mortar from a fresh concrete point of view. And now as far as the discussion of the placeability of fibre concrete is concerned.

It is not simply the placeability of mortar and concrete that we are talking about but that modified because of the presence of mortar. I think it is intuitively clear to you or it should be intuitively clear to you after all the discussion that we been having for different types of concrete so far. That if I have too much of coarse aggregate here. Or the amount of mortar here is very less then can we add a lot of fibres to it?

Conversely speaking in order to add a certain amount of fibres, suppose we have a concrete to begin with which has 60% mortar and 40% coarse aggregates. Now in this if I want to add let's say 2% fibres. Can I manage with the same 60% mortar and 40% coarse aggregate. Let us not bother about the 2% where it comes from. I can make it 38, I can make it 68, 58 whatever I want to do. Will this property will this concrete with 38% coarse aggregate 60% mortar and 2% fibre have the same properties as one which had 60% mortar 40% coarse aggregates.

The answer obviously is no, it will not. So we need to reduce the amount of coarse aggregates. In other words increase the amount of mortar content as far as fibre reinforced concrete is concerned to maintain, placeability. Now this is something which will discuss when we talk about proportions, but I thought with this picture it should be intuitively clear that we cannot just add fibres to a concrete matrix and hope that the fresh concrete properties will not change.

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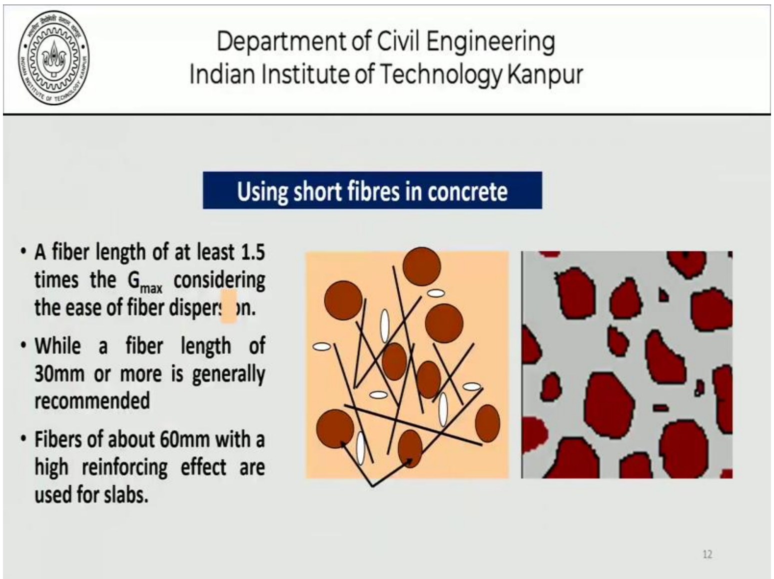

Using short fibres in concrete the fibre length of at least 1.5 times the maximum size of aggregate considering the ease of fibre dispersion is what is generally recommended. So, obviously concrete like this and this in the picture which we have been using all along. So consider a concrete like this if this is the size of my coarse aggregates here if I have fibres which are very small it may not be very effective.

In order of fibres to become effective it should be at least about 1.5 times the length or the size of the coarse aggregate. While the fibre length of 30mm or more is generally recommended. Now th is 30mm is coming from 1.5 times 20mm generally used are nominal maximum size of aggregate of 20mm as far as reinforced concrete is concerned. And therefore fibre length of 30 millimeter is often considered a benchmark as far as using the fibres is concerned in concrete.

Fibres of 60 mm have a high reinforcing effect used for slabs the kind of fibres that we use, what should be the length? What should be the diameter all that also depends on the member that you use to get it in? It would be a slab it could be beam. It could be a column. Therefore in slabs typically the reinforcements is less. So placing the concrete is easier. So we can use slightly larger fibres.

So those are the kind of operational issues that we will probably discuss it otherwise you have to learn it on your own. So, the size of fibres ranges from about 30 mm to 60 mm. When we say fibres that they are short, discrete randomly distributed fibres. How short is short? This question is answered here short means 1.5 times the size of the coarse aggregate that is a benchmark number as far as lengths of fibres are concerned.

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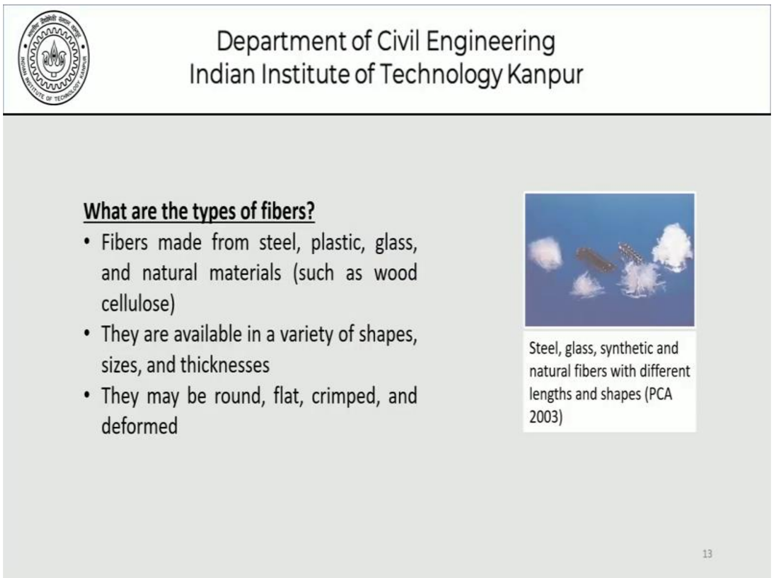

What types of fibres are used in the industry as far as concrete is concerned. Fibres made from steel, plastic, glass and natural materials such as wood or cellulose they are available in a variety of shapes, sizes and thicknesses. And they may be round, flat, crimped and deformed. So there are different types of fibres which are available to us in this picture here gives you the different types of fibres, steel, plastic, glass and so on.

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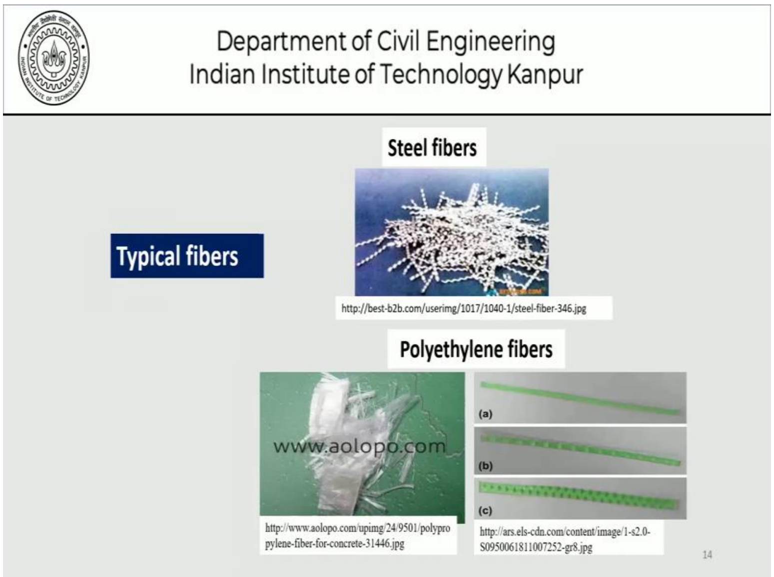

This picture again is typical fibres, steel, fibres, polyethylene fibres. And you will notice that as given in the previous slide. The fibres are not necessarily straight sometimes crimped, they are sometimes bent like this. The way your staples are after they are bent the staple if you recall something like this and this entirely goes back in when you stable your document. So we have fibres which are in this shape hooked fibres, straight fibres.

As far as the cross-section of the fibres is concerned it could be round it could be flat and so on. So these are different types of fibres, depending on the manufacturing method, depending on the kind of material that you use different types of fibres are available to us for use in concrete.

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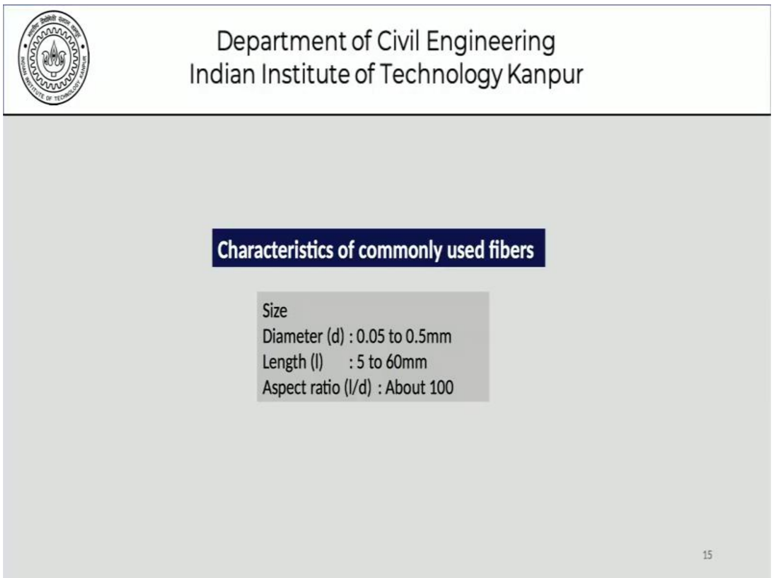

As far as the characteristics of common fibres is concerned. The diameter ranges from 0.05 to 0.5 millimeters and the length ranges from 5 to about 60 millimetres. The aspect ratio, which is the length to diameter ratio, is kept at about 100. In the previous discussion I said that in order to be effective the fibre should be about 1.5 times the size of the coarse aggregate. So there are particular applications where fibres shorter than the coarse aggregate size or smaller than the coarse aggregate size also have a role to play.

And there is no reason why we should not use them. As for the diameter is concerned is 0.05 to 0.5mm so you can see that they are not very large. When it comes to reinforcing bars we do not talk in terms of 4.5 millimetre kind of bars we talk about 16mm, 22mm, 25mm maybe 40 mm kind of bars. So that is what is the basic difference; very important difference between reinforcing bars and fibre reinforcement, never confuse between the two.

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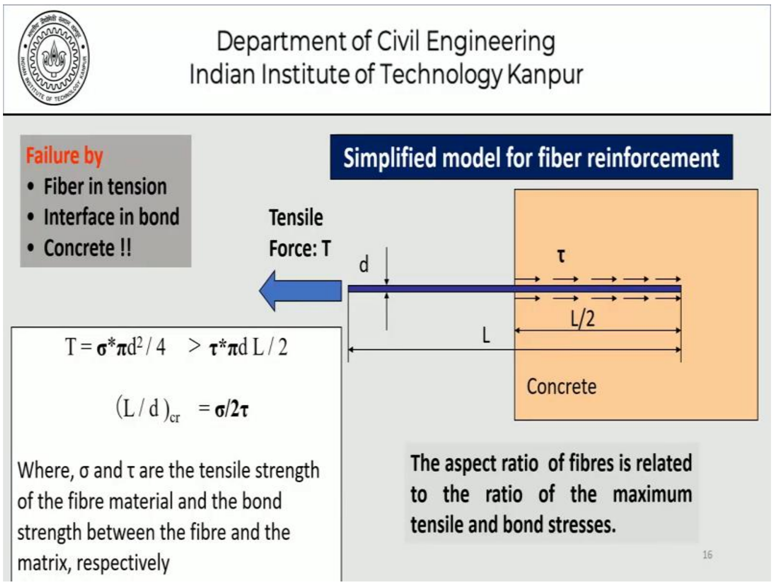

So, moving forward here is a typical illustration of failure of a fibre when it is embedded in a matrix. So, what we talking of here is Fibre of length L embedded in the matrix to the extent of half that is L/2 is buried and if we try to pull it out by applying a tensile force t here. How is the tensile force going to be resisted? It will be resisted by mobilization of a bond stress between the fibre and the matrix over this L/2, length and if d was the diameter of the fibre.

Then πdL/2 would be the area over which this bond stress will develop and if there was a limiting value called τ then this would become more or less the load carrying capacity of the fibre as far as failure in bond is concerned. If this was very large then the failure of fibre could occur by the breaking of the fibre which is governed by tensile strength of the fibre multiplied by $\pi.d^2/4$ which is the area of cross section.

So, basically if these 2 were equal then we will have a equal probability of the fibre failing in tension or by bond. So that is the kind of thumb rule that is kind of simple back-of-the-envelope rule which says that L/d that is length to diameter ratio of the fibre this is what is called the aspect ratio as far as the fibre is concerned. This is related to tensile strength and the bond strength mobilized between the fibre and the matrix.

So the aspect ratio of fibres is related to the ratio of the maximum tensile and bond stresses. The third possibility which I have not discussed here is that if both these are very strong fibre is very strong here in terms of tensile load carrying capacity and the material here is very strong as far as the bond is concerned. Then there is a failure which can happen by the failure of concrete. So this is something which I am not covering here and you to think about and reason for yourself as to what will happen if the fibre was very strong and very strongly embedded in this matrix. And we still continue to apply this force t what is the third likely mode of failure.

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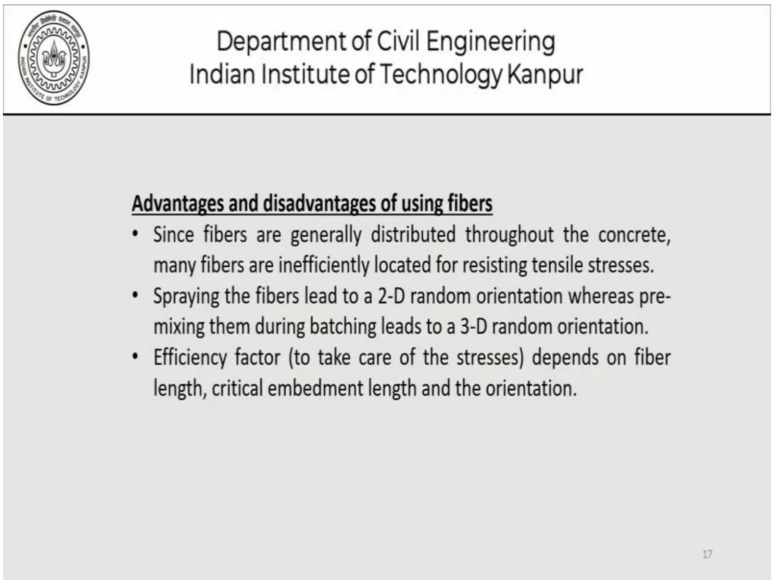

So the advantages and disadvantages of using fibres: Since fibres are generally distributed throughout the concrete many fibres are inefficiently located for resisting tensile strength. This is one of the very important disadvantages that they are inefficiently located for resisting tensile stresses because they are randomly distributed throughout the concrete. And the stresses do not act uniformly across different parts of the concrete.

So, therefore only at those places where these stresses are acting and the fibres are being effectively used. Spraying the fibre leads to a 2D random orientation whereas pre-mixing them during the batching leads to a 3D random orientation. Now depending on how the fibres are added to the concrete mix. The fibres could be oriented in a 2D and orientation or a 3D random orientation which also has implications in terms of effective utilisation of fibre addition for resisting stresses in the different directions.

In efficiency factor to take care of the stresses depends on the fibre length critical embedment length and the orientation so these are something which you will study if you want to study fibre reinforced concrete in greater detail. Recall that I have always said that is for this particular course is concerned. We will possibly not be able to create experts in all different special concrete that we are talking about.

We will probably be able to just highlight to use some of the issues involved and then if an opportunity arises to use the material then of course, you know, what kind of material to look for as far as literature is concerned and what are the issues involved in using that particular type of concrete or that construction method and so on.

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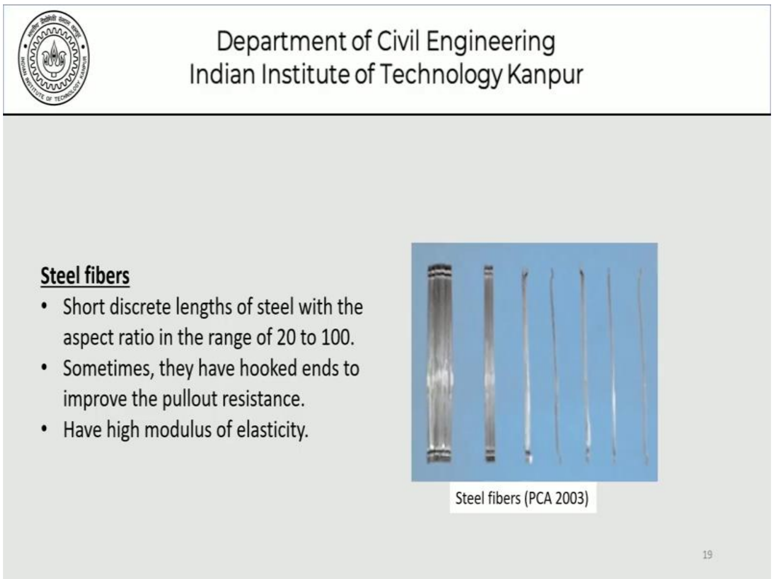

Now; quickly going through the types and properties of fibres that we normally use. This here is steel fibres, short discrete length of Steel with aspect ratios ranging from 20 to 100. Aspect ratio as I told you is the length to diameter ratio. Sometimes they have hooked ends to improve the pull out resistance. And of course, they have the high modulus of elasticity.

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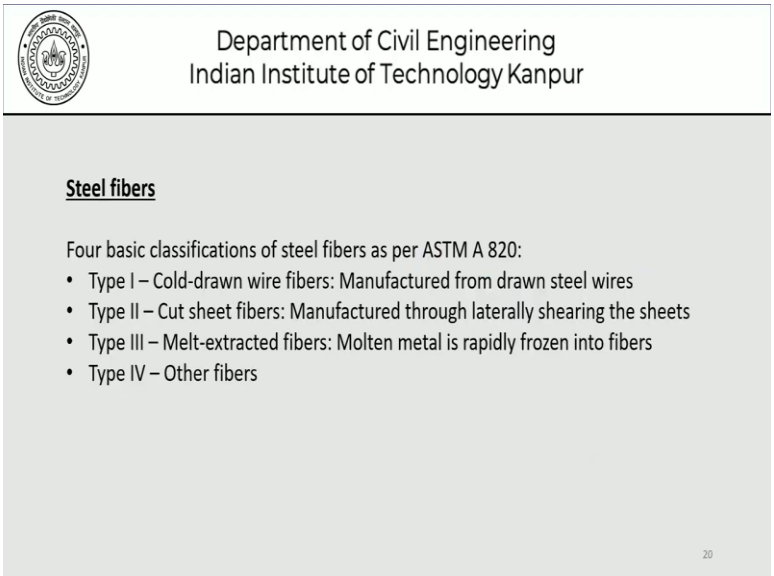

Steel fibres according to ASTM A 820 have been divided into four types of classified as Type 1, 2, 3 and 4 depending on what they are all about. Type 1 fibres are cold-drawn wire fibres manufactured from drawn steel wires. Cut fibres or cut sheet fibres are those manufactured from laterally shearing the sheets. Melt extracted fibres are molten metal is rapidly frozen into fibre. And then of course there can be any other type of method of manufacture which would give you the type 4 steel fibres as for as ASTM A 820 is concerned.

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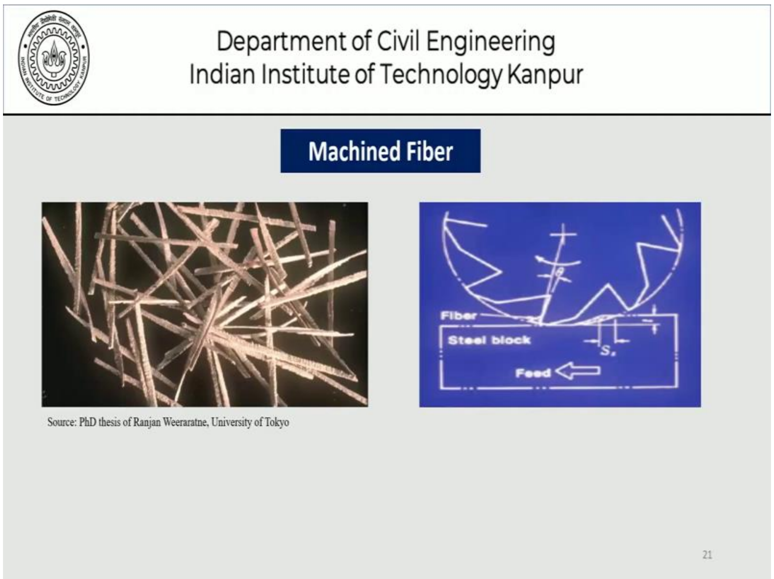

This here shows your picture of machine fibres. This one here is a picture of cut wire fibres and then shared fibres. These are some of pictures I showed you for steel fibres.

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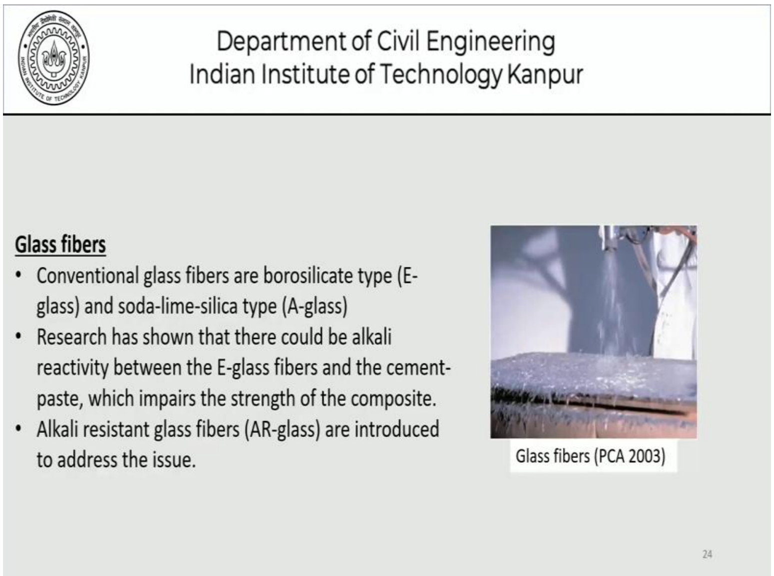

Then we have of course glass fibres; you can see this picture here. Glass fibres means conventional glass fibres are borosilicate type, E glass and soda lime silica type which is A glass. Research has shown that there could be alkali reactivity between E glass fibres and the cement paste which impairs the strength of the composite. And alkali resistant glass fibres that are A glass alkali resistant are introduced to address the issue.

We call that the concrete that we talked about the aggregates and the cement paste and mortar and so on this is a high pH environment. This is something which we have already talked about this high pH coming largely from the calcium hydroxide generated during the hydration process. This high pH here means that any fibres or any material that we introduce in this matrix should also be durable in the high pH environment.

This is typically or this could be sometimes not true for normal glass and that is why when we are trying to assess the applicability or assess or evaluate a particular type of fibre for use in concrete. We should be careful that it should be able to sustain the high pH and it should not deteriorate because of exposure to high pH environment. Corollary; to you why do we not have such worries with steel fibres?

Think about it and possibly at this onset of the next class. I will give you the answer for it and sure you already know about it.

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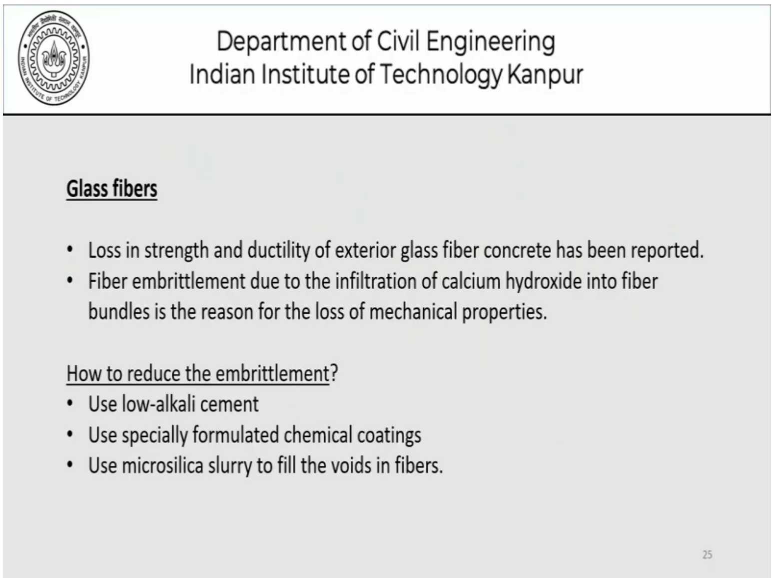

Continuing with glass fibres loss and strength and ductility of the exterior glass fibre concrete has been reported. Fibre improvement due to infiltration of calcium hydroxide into the fibre bundles is the reason for this mechanical properties loss. And we can reduce this embrittlement by using low alkali cement use specially formulated chemical coatings and use microsilica slurry to fill the voids in the fibres.

There are problems and solutions to these problems if we are really trying to use one type of the fibre or the other. So in the case of Glass fibres if there is an issue arising out of the exposure to high pH obviously the first Strategy could be use low alkali cement. The second strategy would be coating of fibres. The third strategy could be filling up the voids in fibres. So that something which as engineers we have to always understand what we want to achieve? What are the hurdles in achieving it and then how do we go about removing those hurdles?

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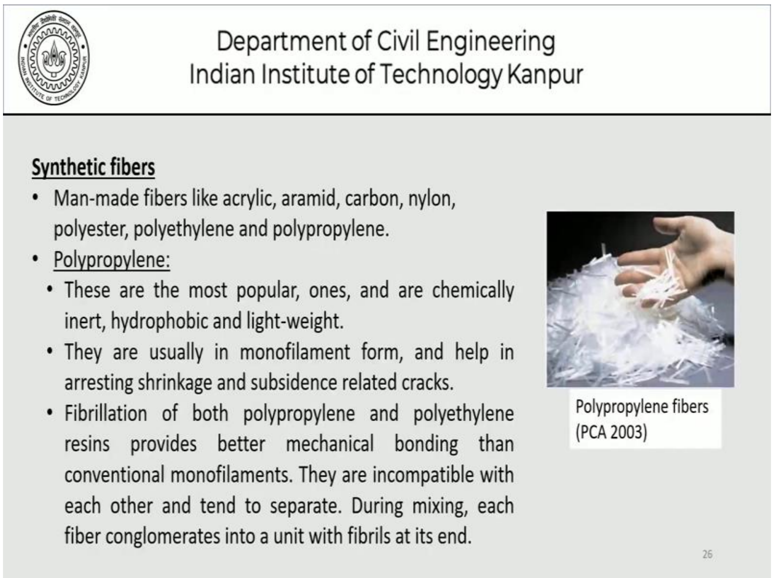

Continuing with synthetic fibres: Now synthetic fibres are manmade fibres like acrylic, aramid carbon, nylon, polyester, polyethylene or polypropylene. As far as polypropylene is concerned these are most popular fibres and are chemically inert hydrophobic and lightweight. There will be a slide at the end of the discussion today where we talk about this weight part a little bit. They are usually in monofilament form and help in arresting shrinkage and subsidence related cracks.

Fibrillation of both polypropylene and polyethylene, resin provides better mechanical bonding than conventional monofilaments and they are incompatible with each other and tend to separate. During mixing; each fibre conglomerates into a unit with fibrils at its end. So, these are some of the details that we can be looking at if you are trying to really use polypropylene or polyethylene fibres.

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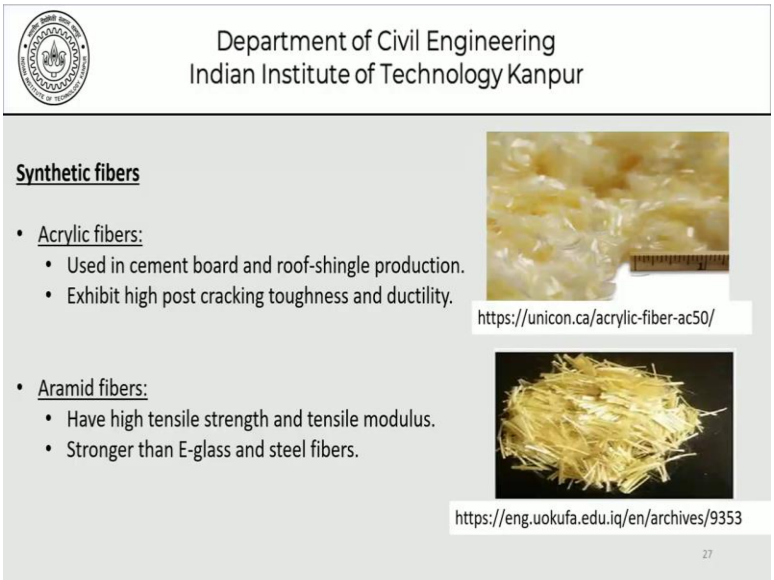

Continuing with synthetic fibres this picture here shows you acrylic fibres and this picture here shows you aramid fibres. So acrylic fibres used in cement boards in roof shingle production exhibit high post cracking toughness and ductility. As far as aramid is concerned high tensile strength and tensile modulus, they are stronger than the E glass and steel fibres. The strength sometimes has different connotation when you talk in terms of fibres and fibre reinforced concrete and so on.

One is the strength per se that is load carrying capacity. The other thing which we talk about in strength could be strength per unit weight. For example material such as steel has a certain specific gravity maybe 7.8. What is the specific gravity of acrylic or aramid or glass and with relation to the weight that we use what is the kind of strength that we get? That is the strength to weight ratio that we often use to compare the performance.

So the strength per unit weight could be one of the performance parameters that we used to evaluate whether one type of fibre or other type of fibre is useful to us. Apart from weight of course, we can use cost.

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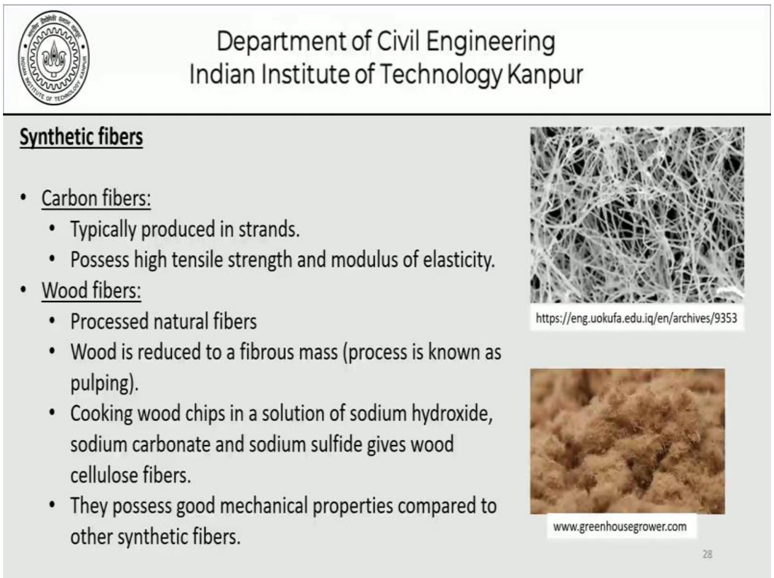

Continuing our discussion on synthetic fibres this picture here shows you carbon fibres and this shows you wood fibres. Carbon fibres are typically produced in strands causes high tensile strength and modulus of elasticity. Wood fibres are natural fibres. Wood is reduced to a fibrous mass through a process called pulping, cooking wood chips in a solution of sodium hydroxide, sodium carbonate and sodium sulphide gives wood cellulose fibres.

And they possesses, good mechanical properties compared to other fibres. I must warn you when we are choosing to use fibres in concrete like we talked about the durability in high pH environment. We should also talk about the durability of these fibres themselves due to exposure to water, exposure to oxygen and so on. Because it should not happen that the concrete initially has a lot of good characteristic.

But in 10 years the fibres lose their strength. Oxidize or something likes that and then the fibre reinforced concrete has been reduced to simple concrete. So we must study not only the durability of fibres in the initial high pH environment or high pH environment alone, but also its exposure within concrete over a long period of time. So whether it is wood fibres or steel fibres or aramid fibres this is something which we must take note of and make sure in the early stage itself at the planning or whatever stage itself, when we try to evaluate different fibres here.

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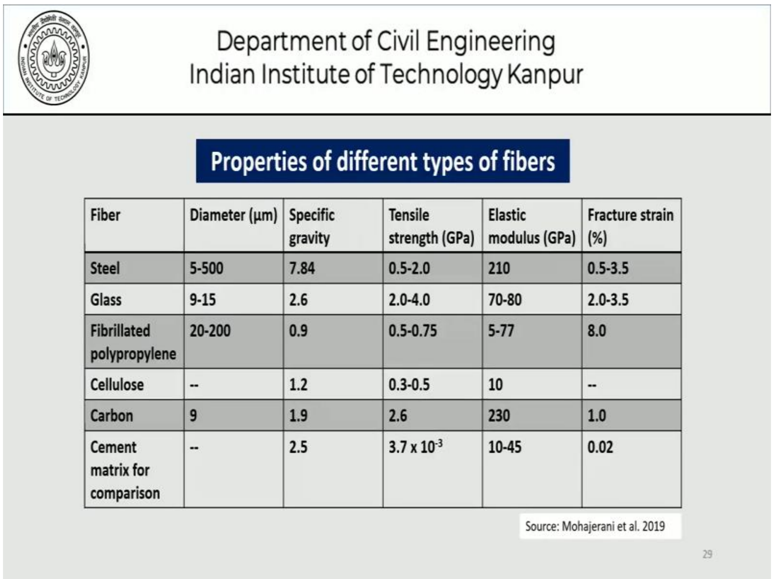

Fiber	Diameter (µm)	Specific gravity	Tensile strength (GPa)	Elastic modulus (GPa)	Fracture strain (%)
Steel	5-500	7.84	0.5-2.0	210	0.5-3.5
Glass	9-15	2.6	2.0-4.0	70-80	2.0-3.5
Fibrillated polypropylene	20-200	0.9	0.5-0.75	5-77	8.0
Cellulose	--	1.2	0.3-0.5	10	--
Carbon	9	1.9	2.6	230	1.0
Cement matrix for comparison	--	2.5	3.7×10^{-3}	10-45	0.02

Here is a picture which compares the properties of different fibre materials steel, glass, and fibrillated polypropylene, cellulose, carbon. And of course cement matrix is there only for comparison. So if you talk in terms of diameter in micro metres steel is 5 to 500, glass, polypropylene. Specific gravity is listed here tensile strength is listed here. And the elastic modulus is listed in this column here along with the fracture strain somewhere here.

If you look at these properties these are the facts. Now, we need to understand evaluate these facts on the basis of strength per unit weight. We have not listed cost which could be in tonnes or rupees per tonne or dollars per tonne. Now if you want to compare the performance in terms of cost, in terms of weight, we are very much free to do that. So I am leaving it to you as an assignment to find out the cost of these fibres in your neighborhood.

And try to then understand and evaluate how we can go ahead of whether as an engineer, we should go ahead and use fibres in concrete.

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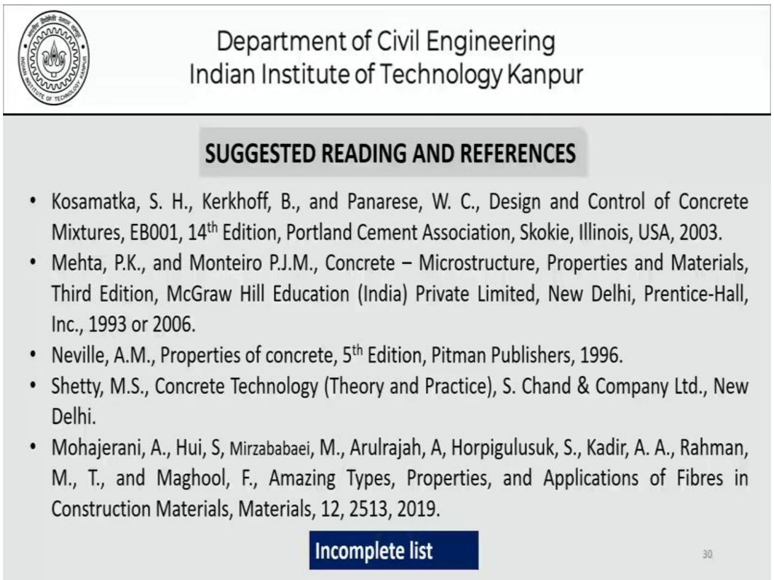

This slide here shows you some of the references which you could probably go through in order to have better understanding of fibre reinforced concrete. And of course as usual the list is incomplete and there is such a lot more material available on the Internet which will help you understand fibre reinforced concrete better. Of course the discussion today has been limited towards the type of fibres that used their characteristics and a simple discussion of how fibre reinforcement actually works.

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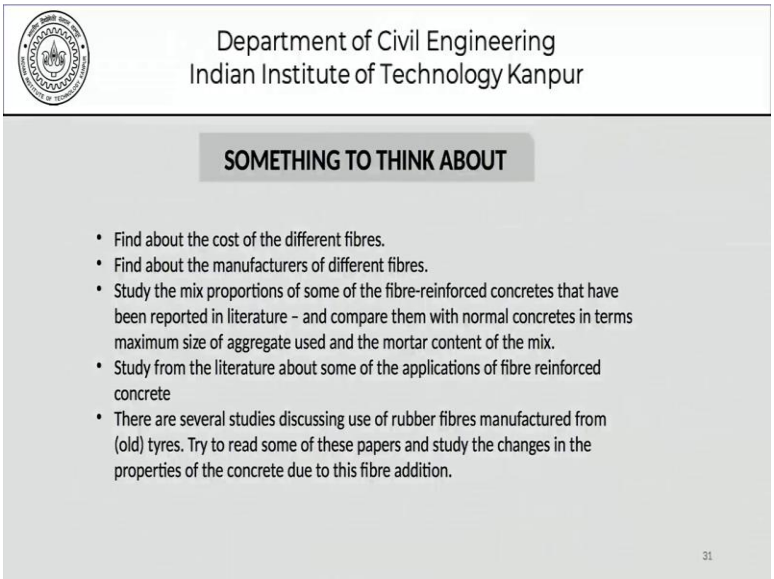

These are some of the things that I have already pointed out to you and that would be so many other things that you can think for yourself in order to understand the different dimensions that are involved as far as development for use of fibre reinforced concrete is concerned.

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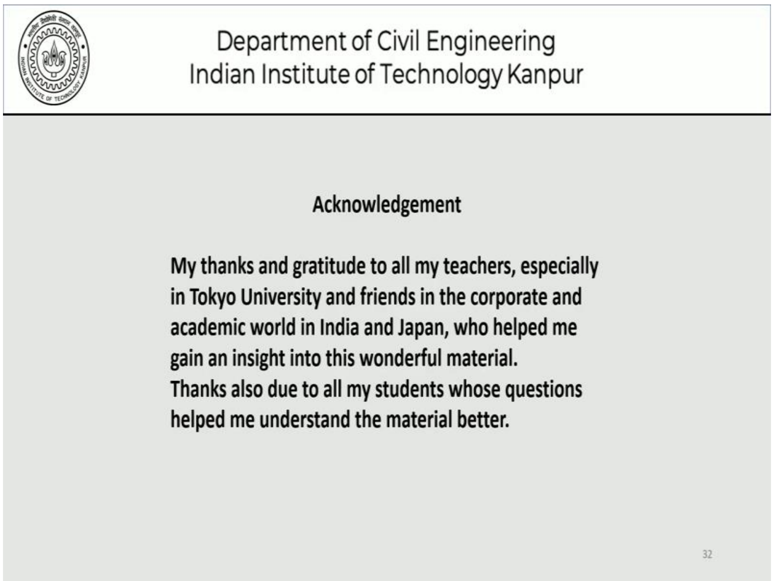

And with this thank all of you especially my teachers, friends and colleagues students who helped me understand this material better and put forward. Thank you once again and I look forward to another discussion with you next time on fibre reinforced concrete.