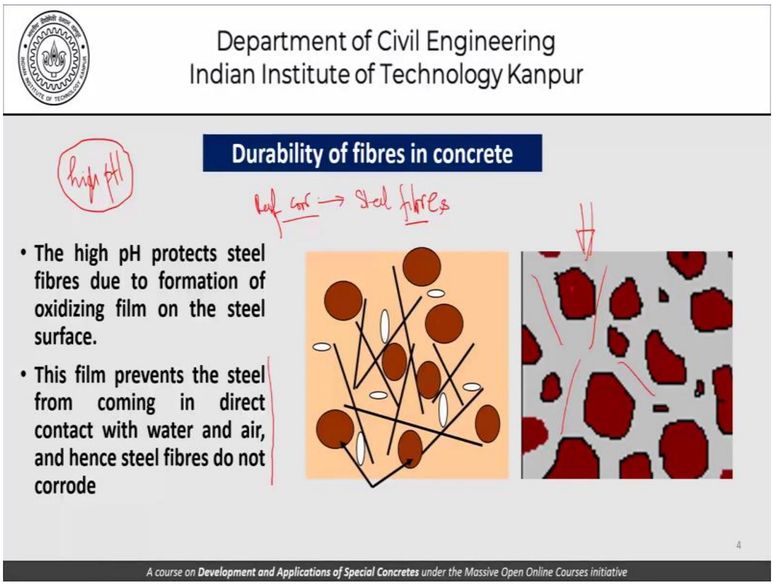
**Development and Applications of Special Concretes**
**Dr. Sudhir Misra**
**Department of Civil Engineering**
**Indian Institute of Science – Kanpur**

**Lecture 23**
**Fibre-Reinforced Concrete - II**

Hello and Welcome! We will continue our discussion on development and applications of special concretes. Last time we started a discussion on fibre reinforced concrete and we will continue with that in our lecture today. So, having talked about some basic principles and the types of fibres used in fibre reinforced concrete, today the discussion will focus on proportioning and handling of fibre reinforced concretes.

**(Refer Slide Time: 00:46)**

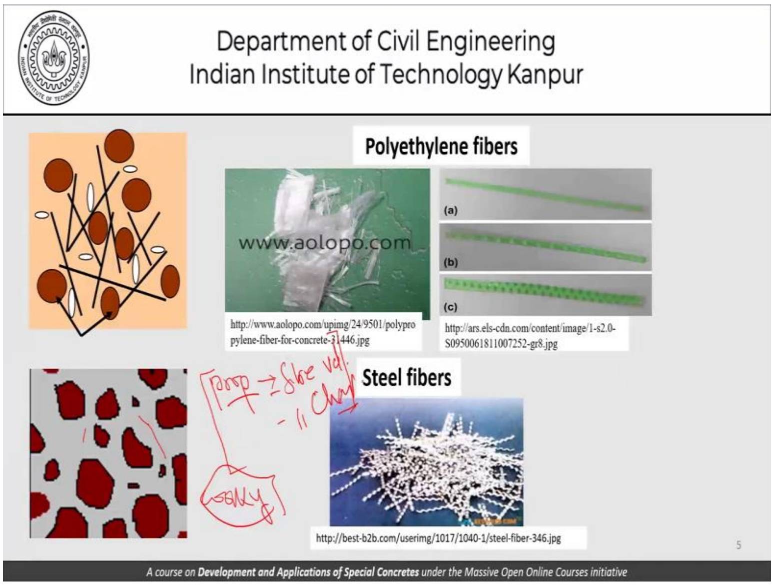



This is the picture which I had shared with you last time and I had left you with an assignment as to why steel fibres do not corrode or what is the kind of issues that we must be careful about as far as durability of the fibres within the concrete matrix is concerned. We had highlighted the fact that it is a high pH environment and therefore particularly glass fibres were mentioned to the extent that there could be durability issues with glass when it is exposed to high ph environment.

Now, one of the things with steel fibres which are a very common fibre to be used in concrete is that the high pH within the concrete protects the steel fibres due to the formation of oxidizing film on the steel surface. And this film prevents the steel from coming into direct contact with water and air and hence the steel fibres do not corrode. Now this simple mechanism of reinforcement corrosion is applicable even to the steel fibres.

At the end of it, the steel does not know whether it is part of the fibres or it is part of the main reinforcing steel. Now this picture we have been seeing regularly as far as our course is concerned and is a representation of the concrete itself with the coarse aggregates here and the mortar phase here. So, this will be a crucial picture as far as we are concerned today because we will be dealing with the proportioning of this material with the addition of fibres all over the place.

**(Refer Slide Time: 02:23)**

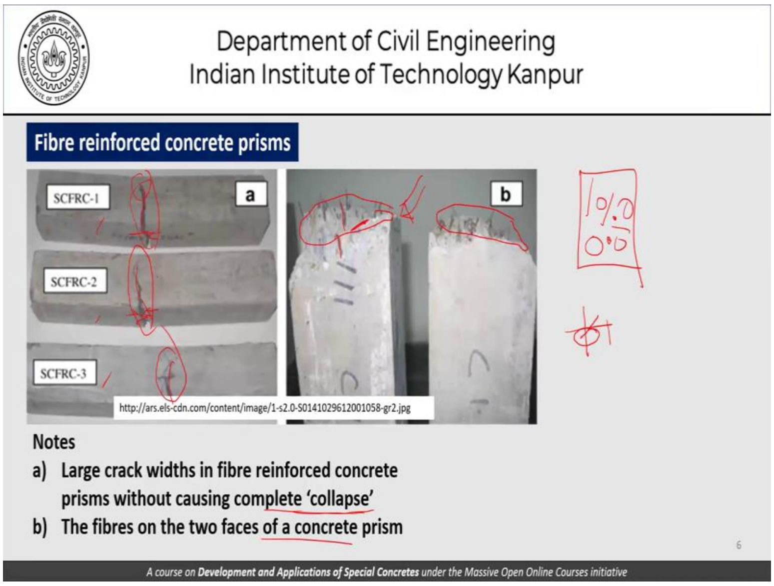



Now, this is again a reiteration of the type of fibres that we use steel, polyethylene, maybe aramid glass and so on. Now, the extent of modification in the properties of the concrete would depend on the fibre volume and the fibre characteristics. So, obviously whether it is the properties of fresh concrete or whether it is the properties of hardened concrete, this simple thumb rule will still operate.

So, if we are putting in steel fibres into this matrix versus, we are putting polyethylene fibres into this matrix. The effect of that on the workability of this matrix will be quite different. We need a different kind of an approach. We need to handle the demand that is placed upon the addition of these materials into this matrix differently because the demands are going to be quite different.

It will depend not only on the steel fibre versus polyethylene fibre, but also the size of the fibre. If the fibres are long that could be one story, if the fibres are short it could be a very different story. So, these are the kind of things that we will just briefly talk about as we go along in our lecture today.

**(Refer Slide Time: 03:43)**



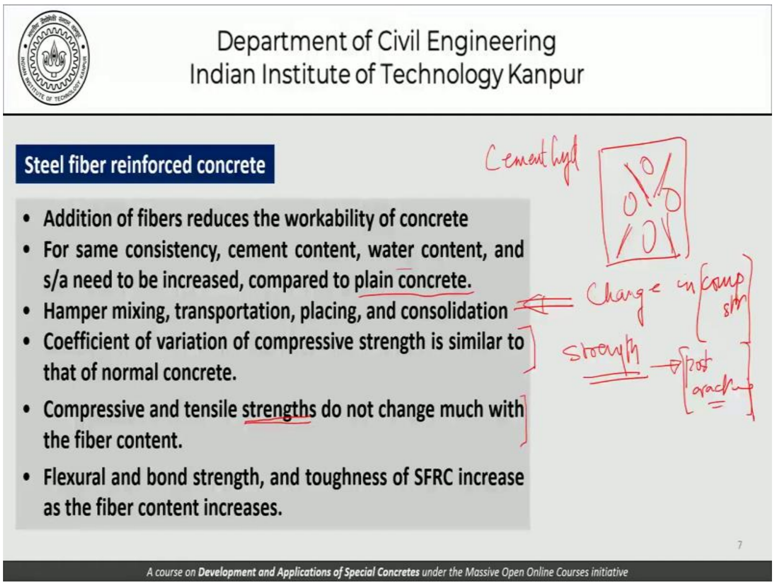

This picture here, before we get into properties of fresh concrete, a fresh fibre reinforced concrete, this picture here shows fibres is sticking out of the surface of concrete. So, this is something which we should visualize and connect to the previous discussion or the previous diagram where we try to show you, coarse aggregates here and mortar here and so this is the fibres that we are talking about.

Fibres are also sticking out of the surface after all they are distributed in three dimensions. So, some fibres are in plain here which have been removed obviously, which have fallen off and these fibres which are sticking out, are not necessarily sticking out normal to the surface. They could be sticking out something like this. They need not be embedded halfway into the matrix; they could be embedded more than half less than half and so on.

So, this is something which you should remember as an image in your mind. When we are talking of fibre reinforced concrete whether it is in the fresh state or it is in the hardened state. These pictures here tell us how these small beams or fibre reinforced prisms; this does not have any steel. These pictures do not have any steel reinforcement and we can see that the crack propagation is quite different depending upon different types of fibres and different fibre contents and so on.

But what is important to notice is that these beam none of them have really failed and broken into two. So, this large crack widths and fibre reinforced concrete prisms without causing complete collapse. So, we can see reasonably large crack fits and we can still see that the beam is holding on as far as not collapsing is concerned. So, the fibres in the two phases of a concrete prism is, what we are shown here and we have discussed this matter before.

**(Refer Slide Time: 05:42)**



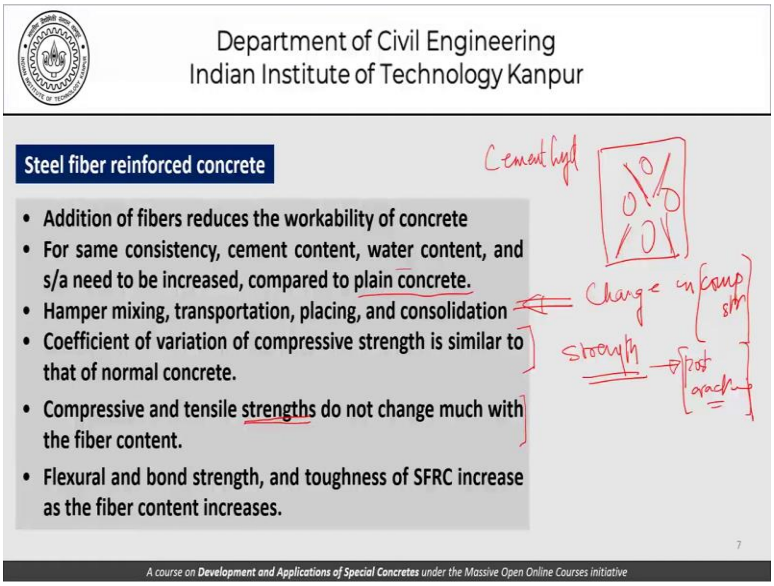

Now, as far as steel fibre reinforced concrete is concerned and this discussion is true with other fibres as well, the addition of fibres reduces the workability of concrete. So, you can very well imagine that if we have a matrix like we had, with coarse aggregate here, the rest of it being mortar, if I put fibres here, it will reduce the workability of the mortar phase and consequently of the concrete phase.

For the same consistency, the cement content, water content and the s/a need to be increased, compared to plain concrete. The presence of fibres in the concrete matrix would hamper mixing, transportation, placing and consolidation. All these operations will require more special attention more closer attention than they required in the case of plain concrete. The coefficient of variation of compressive strength of course is similar to that of normal concrete.

What we must remember is that by adding fibres to this matrix, we really do not do anything to the cement hydrates. And therefore there is no reason to believe or no reason to expect any change in the compressive strength or the variation in the compressive strength, on account of fibre addition.

Except in a situation that we do not pay enough attention to the fibre addition issue in mixing, transportation and placing in which case, the real culprit for observed changes in the compressive strength or its variation is our lack of attention to the mixing transportation placing issues rather than the fibre addition itself. So that is something which is very subtle and you must keep in mind all the time.

**(Refer Slide Time: 07:46)**

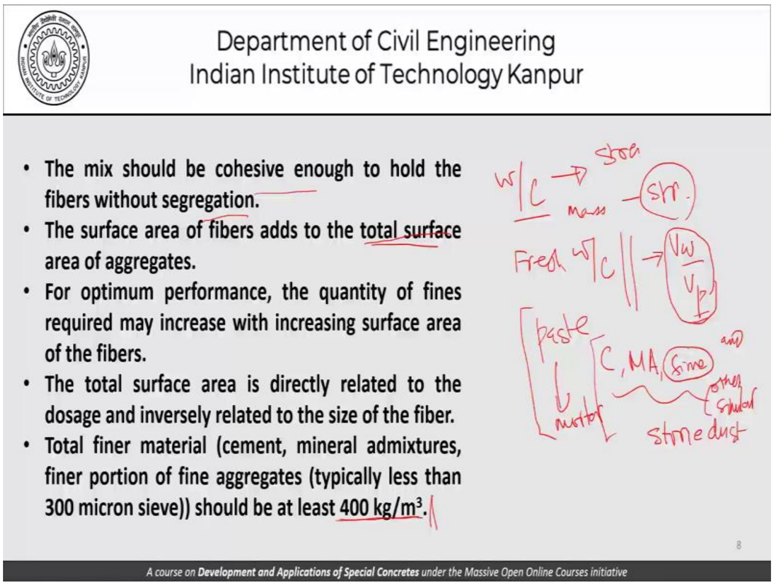



Moving forward the compressive and tensile strengths do not change with the fibre content this is especially true in low volume addition of fibres. So, long as the fibre addition does not exceed say two percent or one at least one and a half to two percent, we do not expect much change in the compressive or tensile strength as such. Strength means the maximum load that it can take.

The strengths may still be the same; we have talked about it before. The strength may still be the same but the post-cracking behaviour could be very different. So, the post-cracking behaviour is not represented by the parameter strength. So, the post cracking behaviour will be viewed separately and evaluated separately as far as fibre reinforced concretes are concerned. But the strength per se we do not expect much changes in the compressive and tensile strengths.

Flexural and bond strength and toughness of SFRC increases as the fibre content increases. This is something which we have been discussing in different ways throughout this slide.

**(Refer Slide Time: 08:56)**




Continuing with our discussion on the behaviour for fresh concrete with fibres, the mix should be cohesive enough, to hold the fibres without segregation. The surface area of fibres adds to the total surface area of the aggregates and the fibres have a reasonable surface area. They are long thin elements and therefore the surface area cannot be ignored. So, that gets added to aggregates.

And in fact, that could be one way you could understand or reconcile the fact that increasing fibres leads to an increase in the demand for mortar, in the demand for paste and finally the demand of water as far as fibre reinforced concrete is concerned. For optimum performance the quantity of fines may require to be increased, with an increasing surface area of fibres that is what we just mentioned.

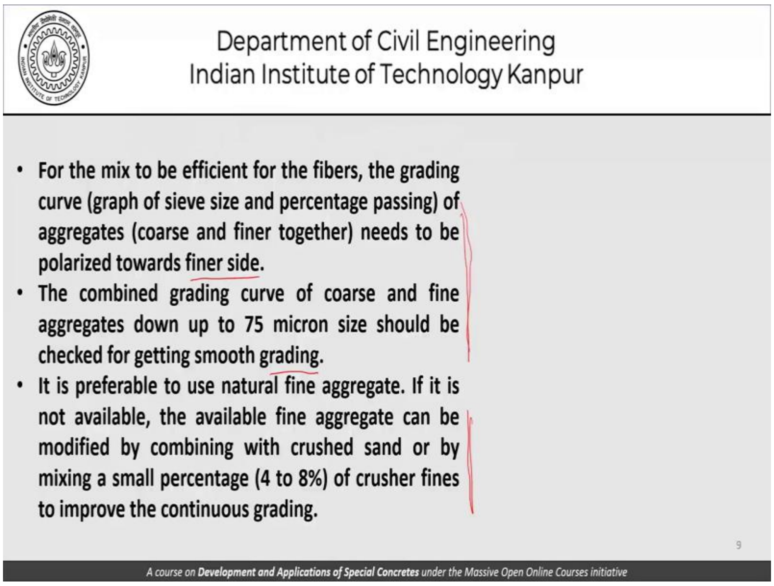
The total surface area is directly related to the dosage and inversely related to the size of the fibre. The total finer material that is cement, mineral admixtures and the finer portion of the fine aggregates typically less than 300 micron sieve level should be kept at, at least 400 kgs a cubic meter. Now, this tells us again the same story that we have been talking about in different parts of this course that we cannot only be interested in the water-cement ratio in the traditional understanding.

The water-cement ratio is important. It is given by mass and is important from the point of view of strength development. As far as the properties of fresh concrete are concerned, the water, cement ratio should be looked upon, in terms of the volume of water to volume of powder ratio and this powder content is coming from cement, mineral admixtures and also the finer component of sand or any other similar material that we may use.

For example, in some context, we talked of using stone dust. Now, all these components here which become finer material, they contribute to the paste phase and therefore of course to the mortar phase and that is something which important from the point of view of behaviour of fresh concrete rheological properties of fresh concrete and so on. Whether or not these finer materials play a part as far as the pozzolanic reaction is concerned that will be evaluated separately when we talk in terms of strength which was traditionally related only to the water cement ratio.

So, coming back to our story on fibre reinforced concrete, there is a limit or there is a lower limit, almost I should say, on how much the fines content be.

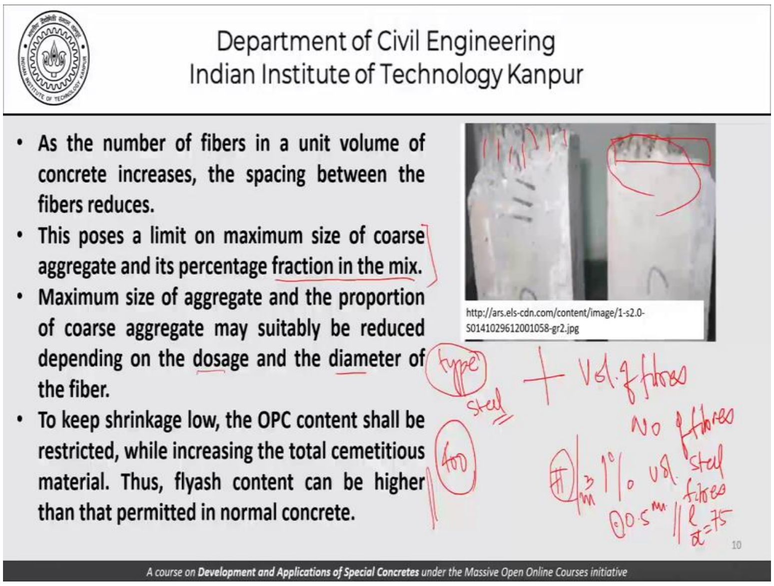
**(Refer Slide Time: 11:53)**




For the mix to be efficient for the fibres, the grading curve, the graph of the sieve size and percentage passing of aggregates, coarser and finer together, needs to be polarized towards the finer side. The combined grading curve of coarse and fine aggregates down up to 75 micron size should be checked for getting a smooth grading. Its suggesting is that as far as normal concrete is concerned or compared to what normal concrete demands are the grading of the coarse aggregate and the fine aggregate, the overall grading curve needs to be more closely watched, when we are talking of fibre reinforced concretes.

It is preferable to use natural fine aggregate and if it is not available, the available fine aggregate can be modified by combining with crushed sand or by mixing a small percentage of crusher fines to improve the continuous grading. So, this is just a suggestion that in case the grading curve, that we want is not being met, we can use alternatives ofcourse, with appropriate permissions and so on making sure that they do not adversely affect the properties of concrete in the short term or in the long term.

**(Refer Slide Time: 13:06)**




As the number of fibres in a unit volume of concrete increases, the spacing between them reduces and this poses a limit on the maximum size of coarse aggregate and its percentage fractions in the mix. What we have not done as far as this exercise is concerned here, is trying to relate the volume of fibres to the number of fibres, because at the end of it, when you look at a picture like this one obvious question that you will have in mind is that okay for a given cross sectional area here, because this could be a cross sectional area, for a given cross sectional area, how many fibres do we see sticking out.

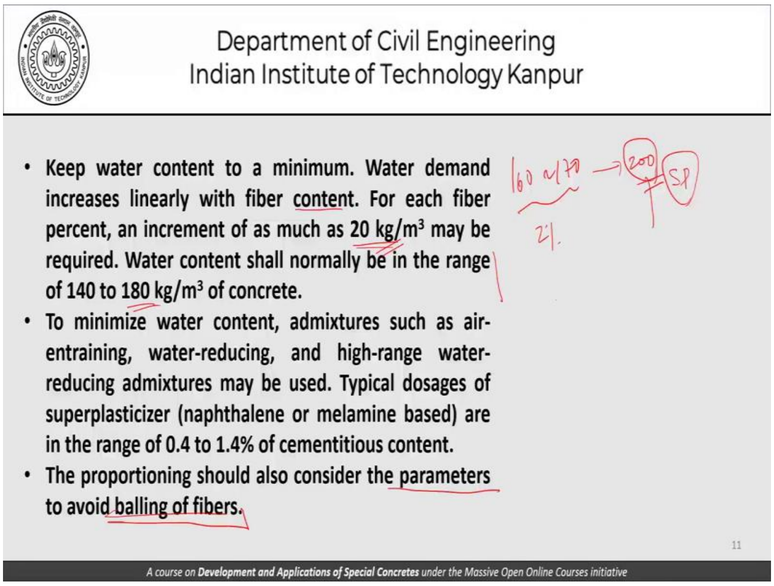
When we are doing that kind of an analysis so we are trying to do that kind of thought process, we should remember that whatever is sticking out is not necessarily sticking out normally. Normally means perpendicular to the surface so that is not happening. So, we must look at that kind of data with a pinch of salt. But I leave it to you to do an exercise on a one percent by volume of steel fibres.

Measuring 0.5 millimetres in diameter aspect ratio that is l/d of let us say 75 try to find out how many numbers, what will be the number of fibres present in a concrete mix, in terms of numbers per cubic meter. Or that will give you an idea on what to expect, or how many fibres to expect sticking out of this surface. The maximum size of coarse aggregate and the proportion of coarse aggregates may be suitably reduced depending upon the dosage and the diameter of the fibres.

Obviously, we have been talking about the dosage, diameter and also the type of fibres. Since all these slides are following the initial slide which said steel fibres of course, this is all true for steel fibres but it is also true for all the other kinds of fibres as well. So, to keep the shrinkage low, the OPC content shall be restricted while increasing the total cementitious materials. The fly ash content can be higher than that permitted in normal concrete because when we talked of that limit of 400 obviously we do not want to push in 400 kgs of cement alone into it.

We would like to have some fly ash and other powders so that our shrinkage and other problems that arise on account of high levels of cement are still kept in control.

**(Refer Slide Time: 15:53)**

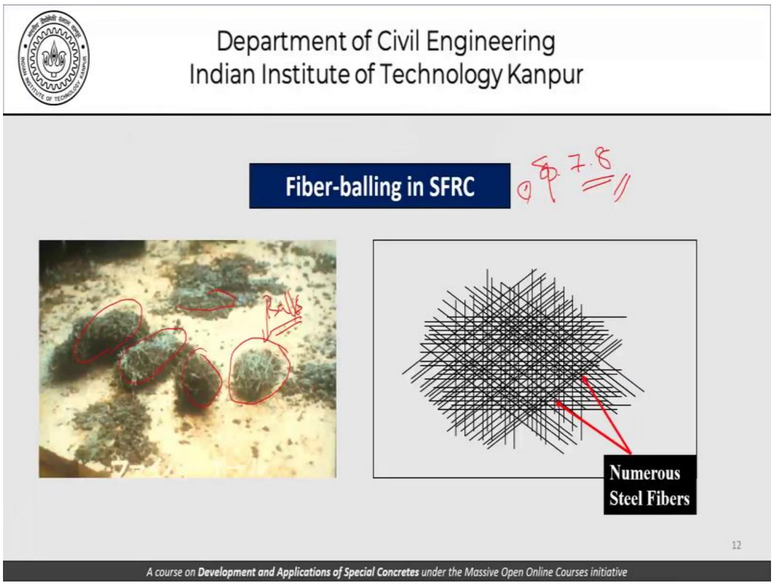



We need to keep the water content to minimum, yes but the water demand increases linearly with fibre content, so the more the fibre, more water you need for a given level of workability or consistency. And for each fibre percentage an increment of as much as 20 kgs may be required and water content shall normally be in the range of 140 to 180. This is just a range; this number is again just a indicative number.

The fact of it remains that yes we need a lot more water given that about 160 or 170 as the normal range of the water needed for getting concrete if we have say two percent of fibres in the system, we will probably need to push this to as much as about 200 now. If we go to 200 we will be tempted to use super plasticizers to keep this level back to 180. To minimize the water content, admixtures such as air entraining, water reducing and high range water reducing admixtures may be used.

And the typical dosage of super plasticizers which could be naphthalene based or melamine based is in the range of 0.4 to about 1.4 percent of the cementitious material content. The proportioning should also consider parameters to avoid the balling of fibres. Now, what is this balling of fibres? It is something which we need to have a quick look.

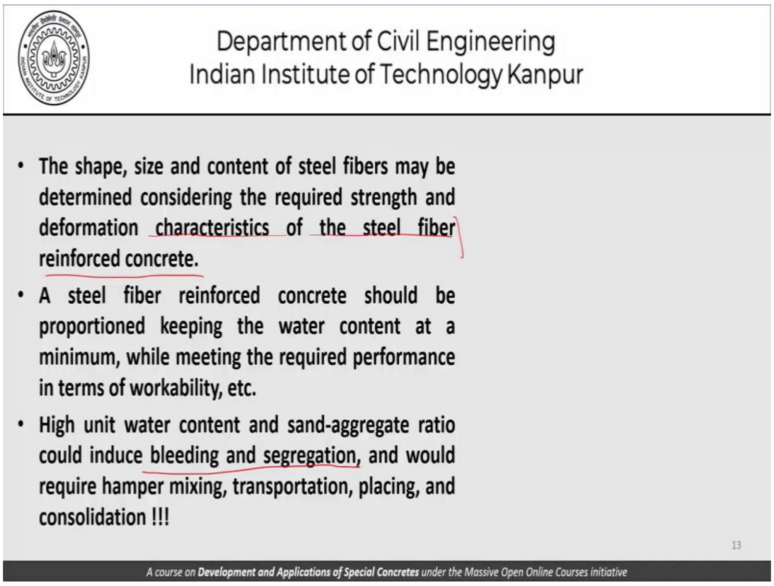
**(Refer Slide Time: 17:25)**




This is what is the concept of balling if we do not mix or disperse the fibres carefully they may tend to accumulate at one place and form balls. So, we should be very careful that the fibres do not form such kind of balls within the concrete. One should remember that the specific gravity of steel is 7.8 and this is much, much heavier than all the constituents as far as concrete is concerned.

And therefore there could be a tendency of these fibres to promote segregation of settling down in the concrete matrix. And not remain uniformly distributed throughout the matrix as we originally thought they should. Keep that in mind especially for steel fibres because they are heavy. The other fibres are not as heavy it's probably easier but if the fibres become very light. Then, again there is a problem because then they tend to float.

**(Refer Slide Time: 18:28)**

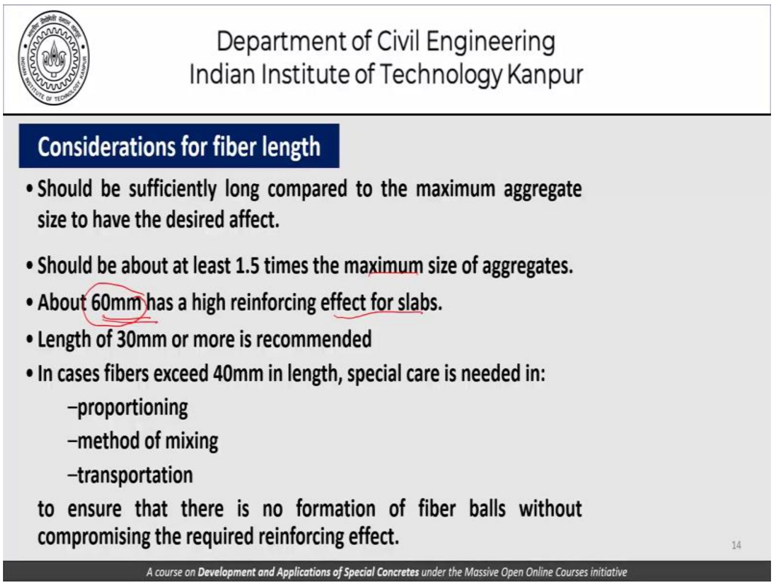



The shape size and content of the steel fibres may be determined considering the required strength and deformation characteristics of the steel fibre reinforced concrete. This is something which we will understand better perhaps after we have some understanding of the characteristics or the properties of the steel fibre reinforced concrete, or the fibre reinforced concrete in general, which will possibly do in the next class.

So, once we understand the properties then, obviously those properties depend on the characteristics of the fibre shape size and content. So, steel fibre reinforced concrete should be proportioned keeping the water content to a minimum still meeting the performance requirement in terms of workability. That is, given high unit water content and s/a could induce bleeding and segregation and would require special attention as far as mixing, transportation, placing and consolidation is concerned.

Remember that if we increase the water content and the sand aggregate ratio, we are making the concrete more prone to bleeding and segregation. That is what is being talked about here primarily.

**(Refer Slide Time: 19:43)**



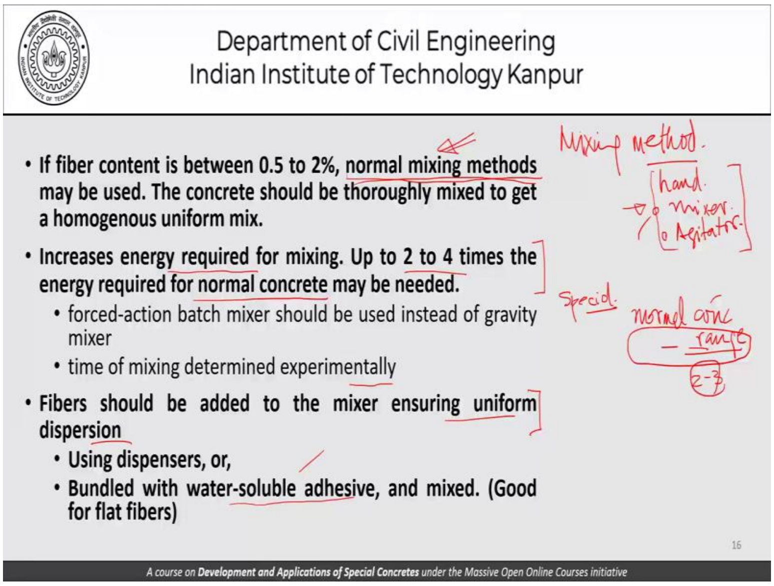

As far as considerations for the length of fibres is concerned, they should be sufficiently long compared to the maximum size of the aggregate to have the desired effect. Of course, there are applications in which shorter fibres are also used. They should be at least 1.5 times the maximum size of aggregates but I just mentioned that there are applications where this rule need not be followed. We could use shorter fibres about 60 mm fibre lengths has a high reinforcing effect for slabs.

Remember that, in order to accommodate 60 millimeter length of fibres, the workability and the placeability demand on the concrete would be fairly high. We can get away with it in slabs because the reinforcement is not very dense and the kind of concrete that we would have with 60 mm length fibres can be still used in slabs. But that may or may not be so easy or so simple to use if it were beams which has a much more normal reinforcement than slabs.

A length of 30 mm or around that number is more commonly used as far as steel fibres are concerned in cases when fibre exceeds 40 mm in length, special care is needed to proportion the concrete mix and not only proportion it, the method of mixing and transportation of concrete to ensure that there is no formation of fibre balls without compromising the required reinforcing effect.

So, these are some of the tips that you want to have when you are trying to use steel fibres or any other fibre as far as concrete is concerned.

**(Refer Slide Time: 21:32)**




Now, coming to some transportation and construction issues, relating to fibre reinforced concrete, if the fibre content is between 0.5 and 2 percent, normal mixing methods may be used, Concrete should be thoroughly mixed to get a homogeneous uniform mix. What is a normal mixing method? Now only when you are starting to use special concretes and we are getting into the discussion here, for example, with fibre reinforced concrete, this idea of normal mixing method has been invoked.

How will you characterize a mixing method? I am leaving it to you to think about it. What is the difference between mixing it by hand and mixing it in a mixer or an electrical mixer? Will that be the same if we were to use an agitator truck to mix it? What is the difference between these three ways of mixing concrete? Think about it and possibly we will answer this question in a couple of lectures.

Increased energy requirement is there and this increased energy requirement could be as much as two to four times compared to normal concrete. So, the first answer which I said will come in a couple of lectures, the first part of the answer is already here. This still remains an assignment for you to do some deeper studies. It is obvious that if you are putting in fibres into the concrete system, it will require more energy as far as mixing is concerned to ensure that the fibres are thoroughly mixed throughout the matrix.

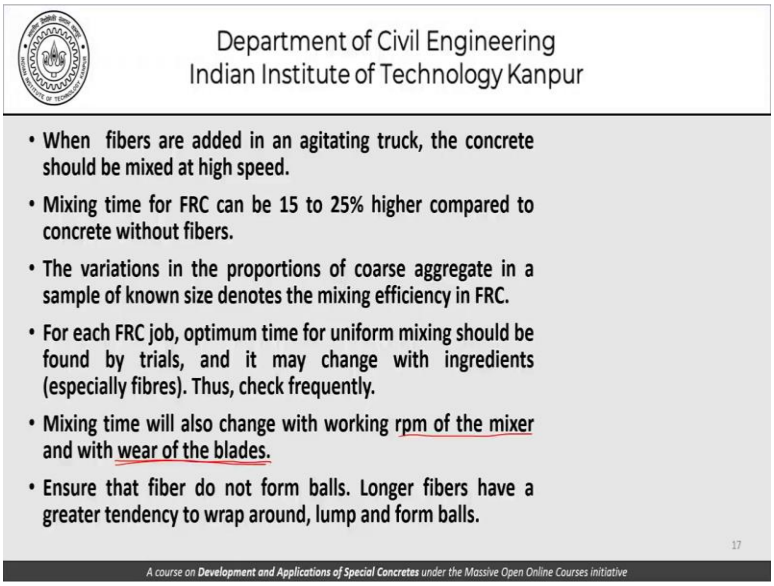
We could use forced action batch mixers instead of gravity mixers. We could increase the time of mixing, which can be determined experimentally, the kind of guidelines of two minutes or three minutes, which is there for normal concrete, should not be taken with a pinch of salt. The normal guidelines of two to three minutes should be taken with a pinch of salt in fact, that is what is the; essence of our discussion in special concretes that for all considerations there is a normal concrete.

And we have a normal range associated with each process. So, mixing is no exception for the mixing of normal range concrete or mixing of normal concrete, the normal range let us say is about two to three minutes if we are using a mechanical mixer. Now that is for normal concrete, if we are going to use fibre reinforced concrete, we need to either determine it experimentally or there has to be a different guideline for that.

Fibres should be added to the mixer ensuring uniform dispersion. Now, this is also very important because you cannot just dump the fibres at one place and hope that the mixing process will take care of the uniform distribution. We have to make sure that fibre disbursement happens in the right way. We can use either dispensers or we can use bundled fibres in water soluble adhesives and mixed.

This is good for flat fibres and we should be careful that the chemical that we use for bundling these fibres is not deleterious from the point of view of hydration of cement.

**(Refer Slide Time: 24:55)**

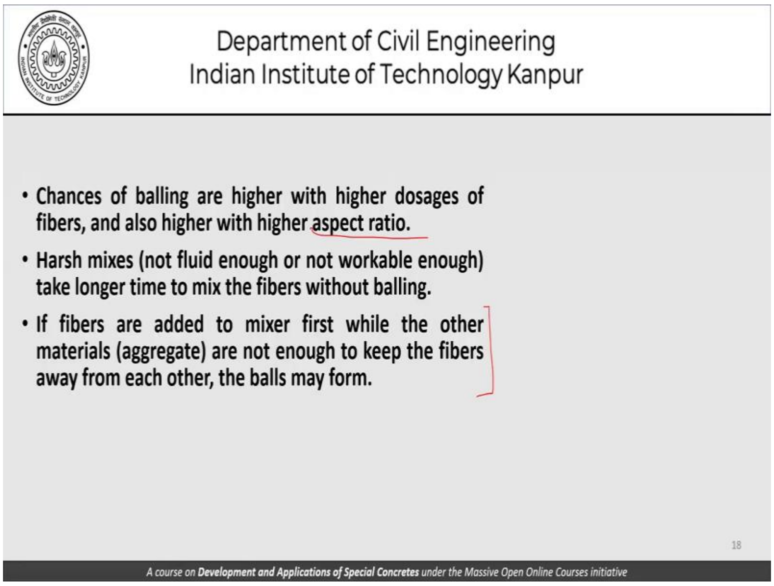



When fibres are added in an agitating truck, the concrete should be mixed at high speed. Mixing time for fibre reinforced concrete can be 15 to 25% higher compared to concrete without fibres. The variation in the proportions of coarse aggregate in a sample of known size denotes the mixing efficiency of fibre reinforced concrete. For each fibre reinforced concrete job, the optimum time for uniform mixing should be found by trials.

And it may change, when the ingredients especially fibres are changed that needs to be constantly and frequently checked. Mixing time will also change with the working rpm of the mixer and the wear and tear in the blades. In fact, the wear and tear in the mixer and the blades that could be another parameter that we should be careful about, when we are trying to use fibre reinforced concretes especially steel fibre reinforced concretes.

Ensure that the fibres do not form balls; longer fibres have a greater tendency to wrap around lump and form such balls.

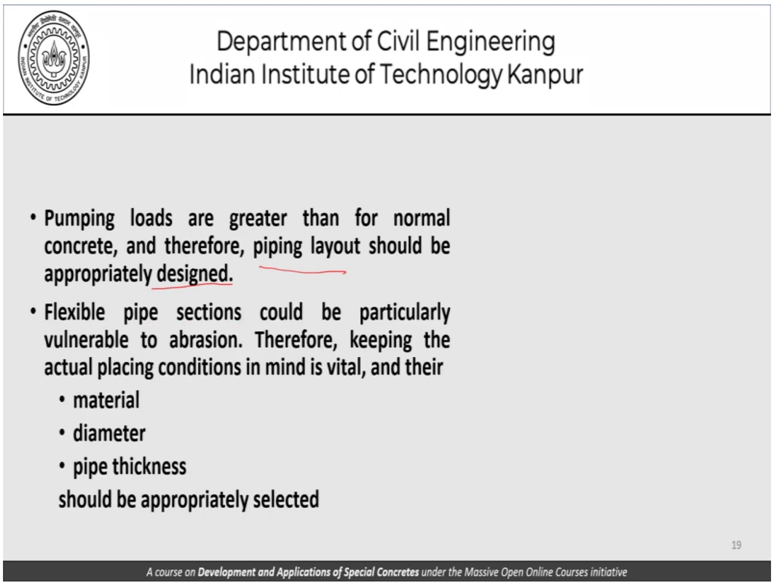
**(Refer Slide Time: 26:03)**




Chances of balling are higher with higher dosages of fibres are also higher with a higher aspect ratio. The aspect ratio means the length to diameter ratio of the fibres. Harsh mixes not fluid enough, not workable enough, take longer time to mix the fibres, without balling. If fibres are added to the mixer first, while the other materials are not enough to keep the fibres away from each other, again balls may form.

So, the order of adding the kind of ingredients is also a crucial parameter when we are trying to ensure proper distribution of fibres throughout the concrete matrix.

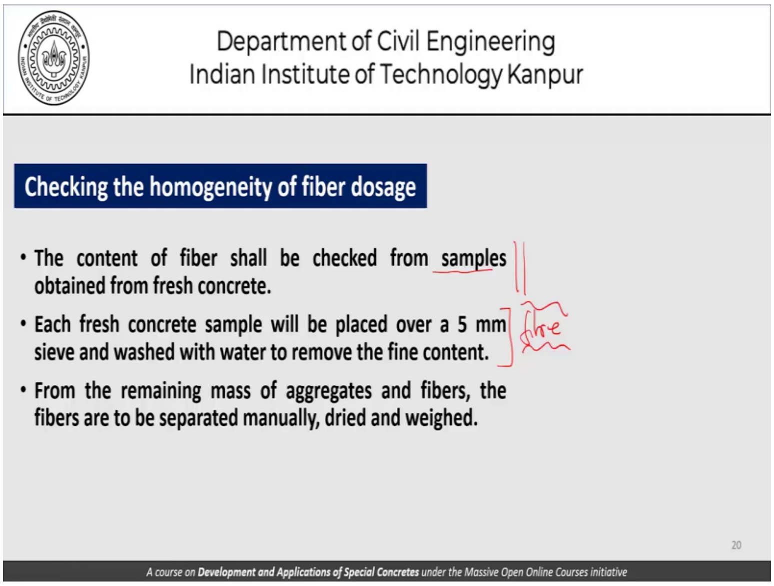
**(Refer Slide Time: 26:45)**




Now, when it comes to placing the pumping loads are greater than for normal concretes. And therefore, the piping layout should be appropriately designed for the same pumping power; we may or may not be able to pump the fibre reinforced concrete to the same distance. And therefore, we have to change our piping layout our power of the pumps and so on. Flexible pipe sections could be particularly vulnerable to abrasion because when the concrete is flowing through these pipes the fibres here will abrade the pipes or the surface of the pipes internally.

And that needs to be borne in mind and this is important to keep in mind and check the material of the pipes, the diameter and the pipe thickness. These things are also critical to keep in mind when we are talking of using fibre reinforced concrete in construction. So, if you are using fibre reinforced concrete. It is not only your concrete equipment in fact also the pipes that are used to carry the concrete from the agitator truck to the site of placement, they should also be properly accounted for.

**(Refer Slide Time: 27:58)**

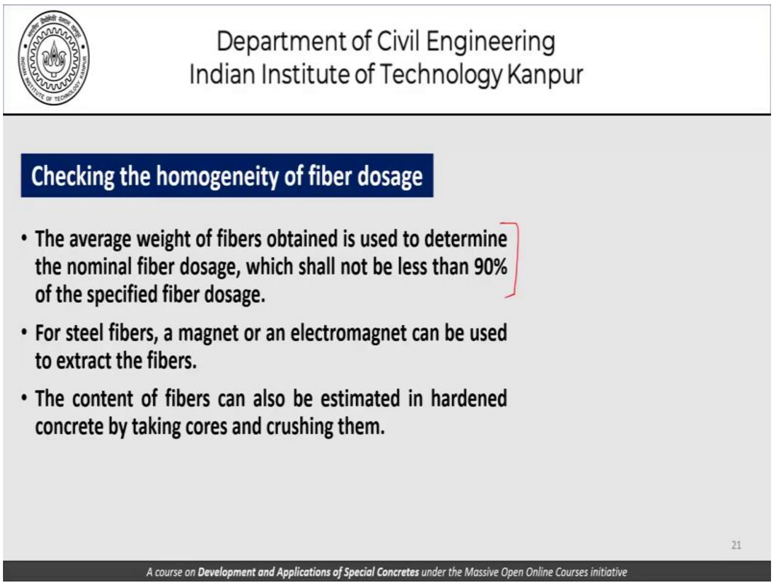



When it comes to checking the homogeneity of fibre dosage, it is very important to ensure the fibre dosage that we have added is indeed, uniformly spread across the entire concrete and for that the content of fibre shall be checked from samples obtained from fresh concrete. So, unlike coarse aggregates, where we do not do such tests unless we are looking for segregation for fibres it is important that such a test is carried out to ensure that the concrete has fibres in each location.

Each fresh concrete sample will be placed over 5 millimeter seam and washed with water to remove the fines content and obtain the fibre content. So, there is an additional test that is getting added to our tests for quality control as far as fresh concrete is concerned and that is a test to determine uniformity in fibre distribution across the concrete. From the remaining mass of aggregates and fibres, the fibres are to be separated manually, dried and weighed.

This is only a matter of procedure what we know is that we have the concrete, wet wash it and try to determine the amount of fibres. And we will have data on how uniformly the fibres are actually distributed throughout the concrete.

**(Refer Slide Time: 29:20)**



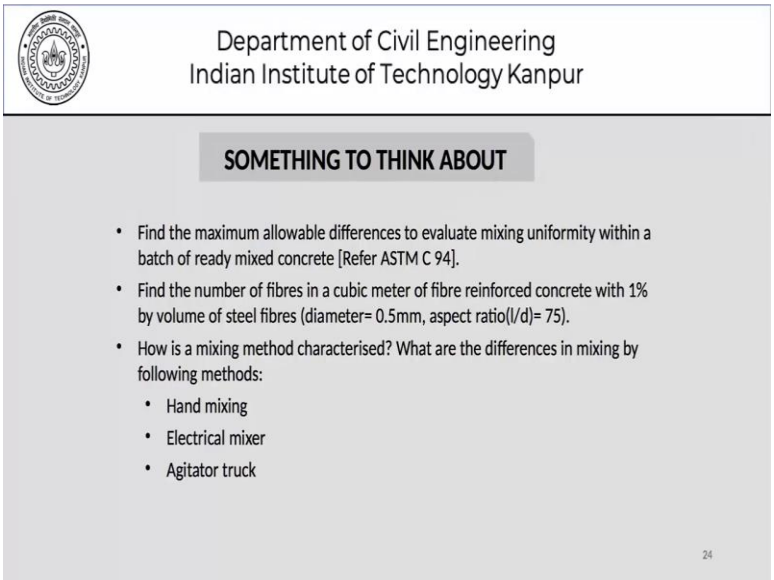

The average weight of fibres obtained is used to determine the nominal fibre dosage which should be not less than 90 percent of the specified fibre dosage. So, obviously once we do this kind of sampling, it need not meet the exact number that we had thought of. So, if we had put in two percent in a given sample it can be plus or minus a little bit and that is what the codes will tell us that it should not be less than ninety percent of the specified dosage.

For steel fibres, a magnet or an electromagnetic method could also be used for extraction and measurement, the content of fibres can also be estimated in hardened concrete by taking cores and crushing them. So, there are different ways of handling it. But the fact remains that it needs to be handled. We need to determine the amount of fibres actually present in the concrete.

**(Refer Slide Time: 30:11)**

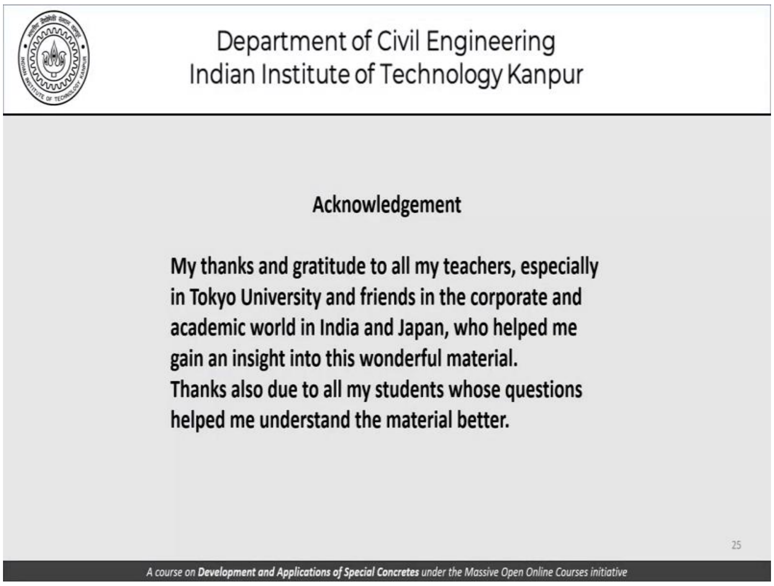
With this, we come to an end of our discussion today; in terms of the properties of fresh concrete in fibre reinforced concrete is concerned. So, this is one slide which tells you some reading material that I can suggest for you. There is some more suggested reading and references and as usual the list is incomplete. Do not think that if you have read all these documents and that is not an easy task anyway, do not think that if you have read all of these, you still will have more to read and more to learn as far as fibre reinforced concrete is concerned.

**(Refer Slide Time: 30:48)**




These are some things for you to think about. I have given you some assignments as far as our discussion is concerned. Some of those are listed here.

**(Refer Slide Time: 30:57)**



And with that we come to an end of our discussion. I must thank all my teachers, friends and colleagues, students who have helped me understand concrete better. And I hope I have contributed to your understanding of this subject, thank you once again and we look forward to another lecture now, on fibre reinforced concrete. As we continue our discussions on special concretes, their development and their applications. Thank you.