Hydration, Porosity and Strength of Cementitious Materials
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Lecture – 03
Basic Properties of Concrete

[FL] and welcome to the third lecture. In this course on hydration porosity and strength of cementitious materials with the title of this lecture being basic properties of concrete. The properties of concrete both in its fresh state and the hardened form are discussed in this lecture.

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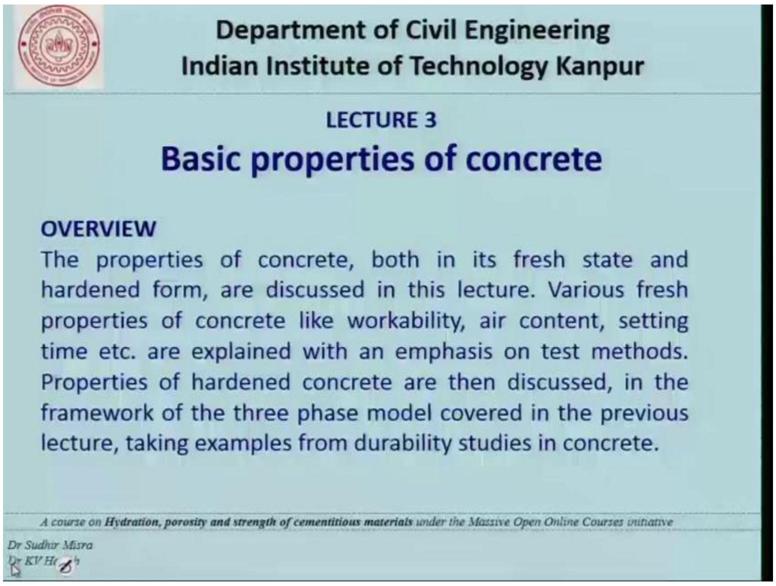

Various fresh properties of concrete like workability air content setting time or explained with an emphasis on the testing methods, and properties of hardened concrete are then discussed in the framework of the three phase model that we talked about in the last class, and we take examples from durability studies in concrete.

We must keep at the back of her mind that even though we are going through concrete properties in this lecture, but that has to be in the framework that it facilitates understanding of cement and cementitious material, hydration in the paste which is an integral part of properties of concrete.

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So, the topics that you will talk about today are the properties of fresh concrete and the properties of hardened concrete from the point of view of strength and durability.

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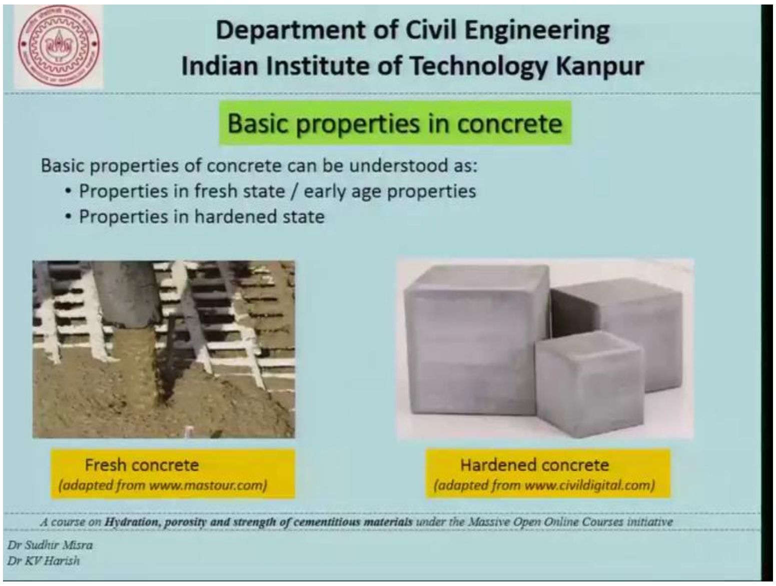

Now, when we talk of basic properties of concrete we saw that we can look up on that has the properties of fresh state where we expect the concrete to behave like a fluid, and in the hardened state where we expect the concrete to behave much like a rock which has taken the shape of the form work. Now how do we characterize the concrete in the fresh state and the hardened state is the discussion of the properties.

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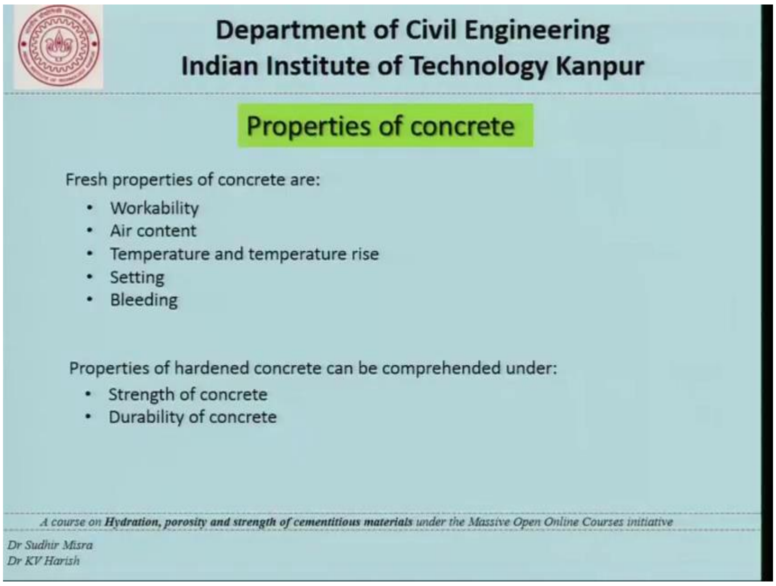

So, in the fresh state the properties that are of relevance and importance to us are workability, air content, temperature and temperature rise, setting and bleeding; in the hardened form we can talk of properties which could be related to strength and the durability of concrete.

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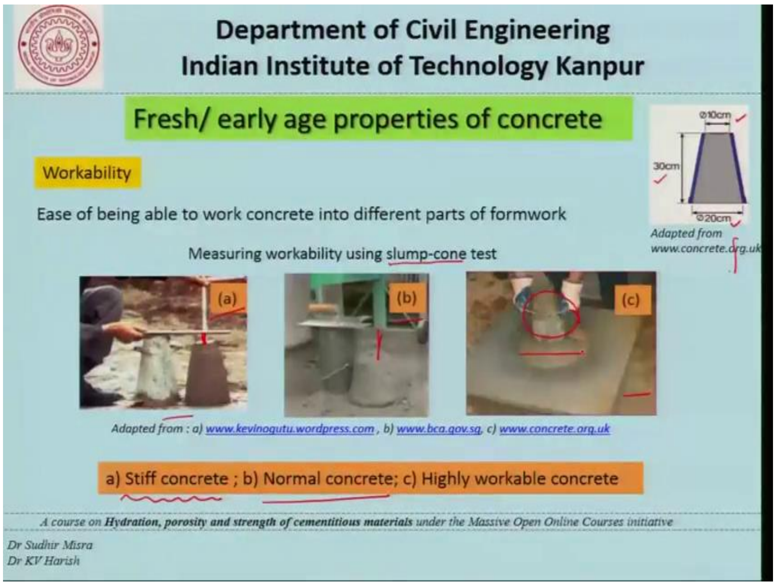

Now, let us look at some of these properties one by one; workability is basically the ease of being able to work concrete into different parts of the formwork. Essentially that means, that a concrete will be deemed to have a high workability if it is easier for the concrete to fill all the spices in the form work. In the extreme case concrete that behaves like a liquid is very highly workable, is workability the most commonly used test having a wide range of application is the slump cone test, that is shown here it is a cone having ten centimeters at top 20 centimeters at the bottom, at 30 centimeters height fill this cone with concrete and lift the cone and weight and watch as the concrete slumps.

So, in this picture here the extent of slump that we find is very small compared to this. And therefore, the concrete in this picture which is a stiff concrete is not a very workable concrete. In picture b we find what we can call a normal concrete, whereas an pictures see we find that upon lifting this slump cone the concretes the concrete cone has actually totally collapsed and has a spread in tomorrow lesser circle and that is what is the highly workable concrete. Where do we use this concretes this is stiff concrete finds a application in places like road construction, where there is not so much of an obstruction for the concrete to move. On the other extreme highly workable or a fluid consistency concrete is used in placing with structures having extremely then reinforcement or in situations where compaction is otherwise not possible.

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Other than the slump there are other methods which are available to measure the workability of concrete one of them being the compaction factor test, the Vee-Bee test and the flow table test as an assignment I would like you to read about these tests and the standard methods that have been prescribed in different standards of the world as to how these tests should exactly be carried out.

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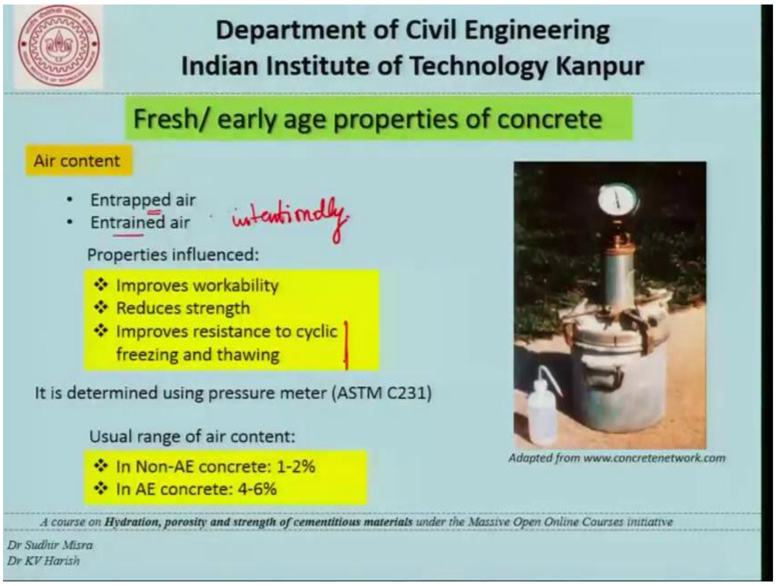

Now, let us comes to air content, air in fresh concrete exist in two forms one is entrapped air and the other is entrained air. As this classification suggests entrained air is one that is intentionally put in the concrete because that suits are purpose, it helps to enhance the performance of that concrete; where is entrapped air is unintentionally present in the concrete and with seek to remove that to the extent possible through compaction and so on. The properties that the air content influences or workability if we have more air content the concrete becomes more workable; because of basically the ball bearing action of air particles that facilitates the movement of particles one over the other it reduces the friction between particles.

However increased air content also has the danger of contributing to reduce the strength because at the end of it, air content is basically wides and we do not want the air content to reach levels, where those wides become a source of introducing a problem as for as strength of the concrete is concerned. Air content is prescribed in concretes which are used in environments with cyclic freezing and thawing, air content in concrete is determined using a pressure meter and the usual ranges of air content in non-air entrained concrete that is those concretes which have only trapped air, is about 1 to 2 percent by volume, whereas in air entrained concrete where we use chemical admixtures to entrained the air the percentage could be between 4 and 6.

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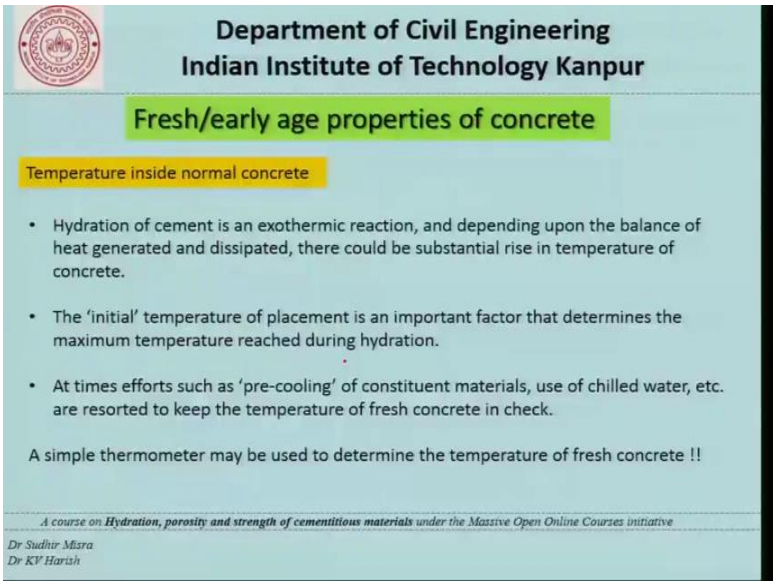

Now, let us talk about temperature; we must remember that hydration of cement is an exothermic reaction, and depending upon the balance of the heat generated within the concrete and the heat dissipated from the concrete, because of the atmosphere there could be a substantial rise of temperature in the concrete. The initial temperature of placement is an important factor the determine is the maximum temperature reached during hydration, and the times afford such as pre cooling the constituent materials use of chilled water etcetera are resorted to keep the temperature of fresh concrete, and the temperature rise in check.

As far as tools are concerned we use a simple thermometer to know or to determine the temperature of fresh concrete.

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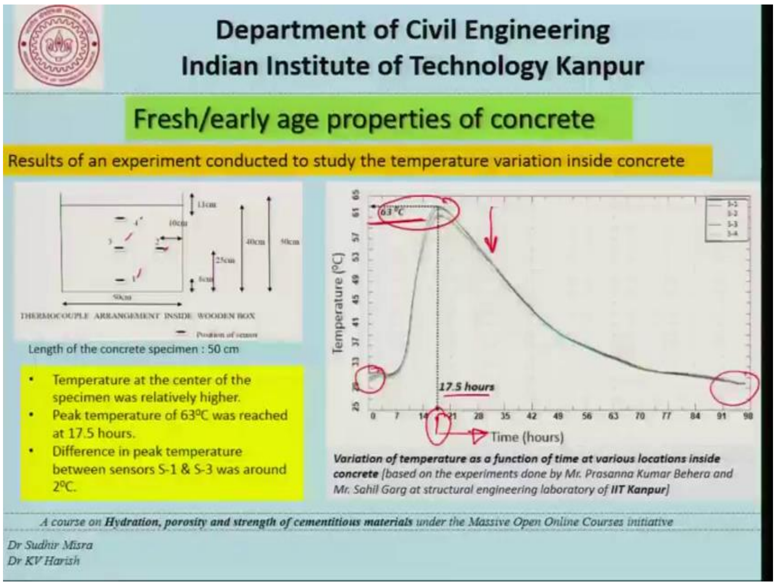

Here is an experiment here is data that was collected in the lab using a simple experiment where a block of concrete podcast, and the temperature at different locations in the block was measured and you can see their starting with the temperature of more 20 930 degree centigrade the peak temperature reached was 63 degrees and this happened at about 17 and half hours.

In fact, it took practically 4 days 96 hours for all these sensors that are shown here to record atmospheric temperatures. So, this graph shows how the temperature of concrete actually changes over period of time, and there could be applications where a client or where it would be demanded that this peak temperature be brought down or this peak occurring at a certain point of time we delayed. Now these are the kind of things to address which we need to understand hydration, the rates of hydration, the effect of having mineral admixtures and the system more clearly, and that is where this course is had it to works. So, well this is just a summary of what we just said the temperature at the center was relatively high the peak temperature about 63 degrees reached in about 17 hours.

Setting of concrete is also an important phenomenal and we much quantitatively determine the time of setting in concrete.

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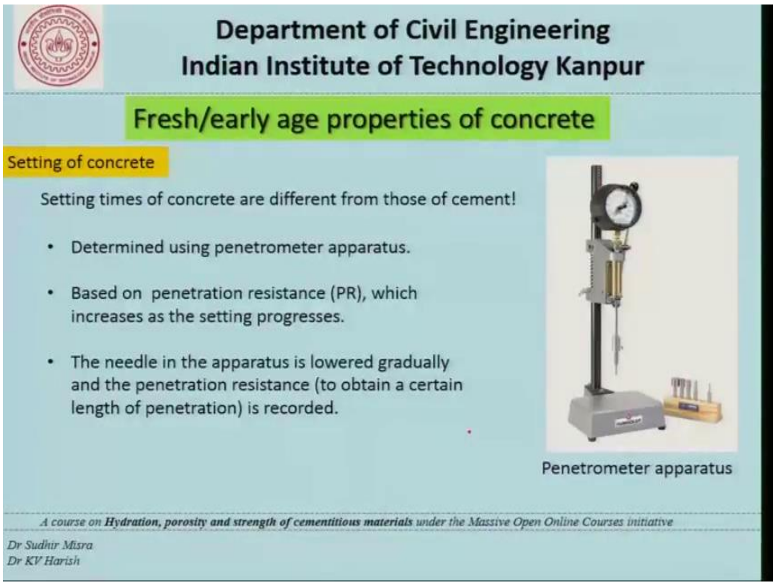

We must remember that the setting time of concrete is not the same is that of cement; cement setting time is a measure of the quality control of the cement those tests are carried out under standard and control laboratory conditions, whereas the setting of concrete in an actual site happens in the uncontrolled atmosphere, also when we are trying to determine the setting time of cement we are working only with cement paste where as a concrete is not only cement paste, but also as sand and coarse aggregate. So, indeed there is reason to believe if that if the setting time of cement is high or low the setting time to of concrete will also be high or low, but as far as quantitative treatment is concerned it is not fair at all to say that we will translate the setting times determined in the lab for cement to be the setting time of concrete in the site.

Therefore, we need an apparatus to determine the setting time of concrete, and here is this apparatus which is called the penetrometer apparatus which can be used to determine the penetration resistance which increases as the setting progresses. So, indeed as the hydration progresses in the cement, the concrete sets the penetration resistance increases and after a point in time it is no longer a matter of penetration resistance what we get into the strength development regime. The needle of this apparatus is lowered gradually and the penetration resistance to obtain a certain length of penetration is recorded.

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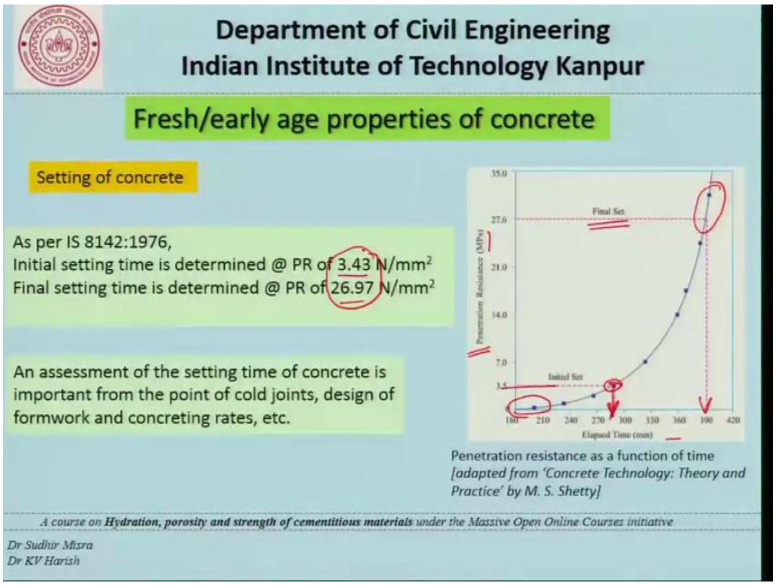

Now, here is this penetration resistance which is recorded in m p a which is plotted over a period of time, and as can be expected that initially the penetration resistance values are low, and finally they become very high.

So, arbitrarily standard suggest a certain value here to be taken as the initial setting time of concrete, and similarly the final setting time of concrete. As far as the Indian standards 8142 is concerned this penetration resistance values have been taken to be 3.43 and 26.97 Newton's per millimeter square, and I am giving it to you as a small assignment to find out the genesis of these very odd looking numbers, we probably address this question and later on why do we need this assessment we need an assessment of the setting time of concrete to better understand and better treat subjects such as cold joints, design of formwork, concreting rates and so on.

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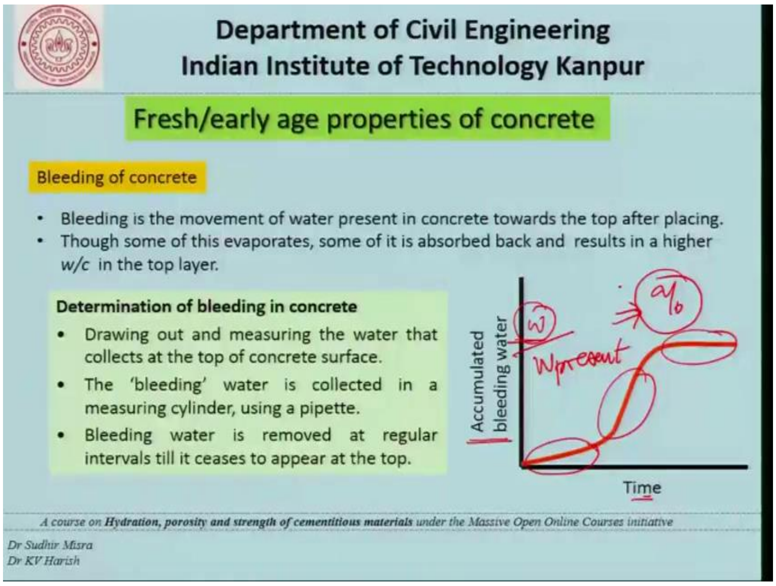

Now, let us look at bleeding. Bleeding is essentially the movement of water present in concrete towards the top after placing; we must remember that has for as concrete is concerned all the constituent materials or heavier then water and therefore, no wonder that when they are mixed with water at the end of it they try to settle down, in other words water collects at the top as a result of this segregation that happens between the materials and that is precisely what is bleeding.

We need to quantify bleeding because this water that collects at the top some of it evaporates, but some of it is absorbed back and results in a higher water cement ratio in the top layer. If the water that collects at the top of concrete on the surface of the concrete is removed and we try to plot this accumulated bleeding water with time we will get a graph which is something like this, that initially we have very little water that comes large amount water comes here. And finally, no more water comes out and then we get if a cap or their limit of the accumulated bleeding water and this amount of water that we get in relation to the water present in the concrete. This can be expressed as a percentage and we can talk in terms of percentage bleeding.

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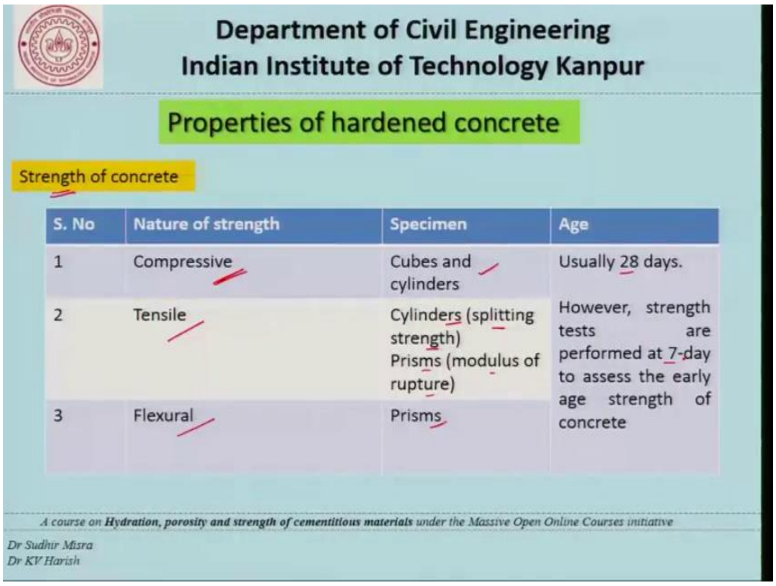

Now, coming to properties of hardened concrete, we have a strength indeed is strength could be compressive strength, but concrete is not all the time in all applications subject it only took compressive stresses and therefore, we often talk of the tensile strength of concrete or the flexural strength of concrete and we use different kinds of specimens which could be cubes or cylinders to determine the compressive strength, we often use cylinders for the splitting strength and prisms to determine the modulus of rupture, to get an idea of the tensile strength and for flexural strength is well we use prisms.

Usually, these tests are carried out a 28 days or 7 days as the case may be depending on the application that we have more importantly for us we would like to understand the implications and the relationship of durability of concrete to the hydration process, and how do we try to control or better understand the durability characteristics of hardened concrete.

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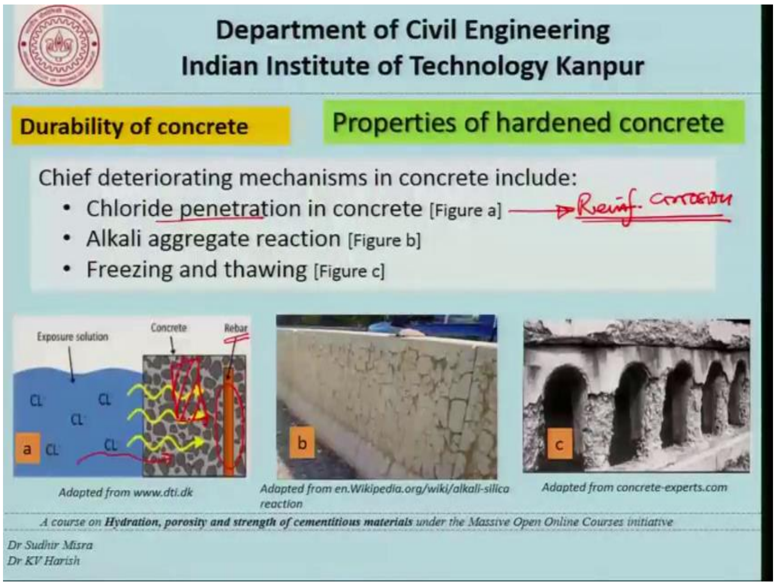

So, for that let us take some examples of deterioration mechanisms or what are the common deterioration mechanisms that we have in concrete. One of them is chloride penetration, and chloride penetration is important from the point of view that it leads to reinforcement corrosion and reinforcement corrosion is an absolutely undesirable phenomenon as for as in force concrete of pre stress concrete structures are concerned. And the chlorides that moving to the concrete structure the way that shown here and cause the corrosion of this reinforcing bar is a matter of concerned to us therefore, we need to have ways and means of finding out the chloride permeability of this concrete.

As I said in the first class strength durability and porosity are all interrelated and therefore, the traditional wisdom of say that if we have a concrete here which is stronger than the chloride permeability will be lower, that is absolutely true except that from a functional point of view or from the point of view of performance evaluation it is always better to directly get information about chloride permeability rather than measuring strength and hoping that it is somehow related to chloride permeability.

So, we need tests for chloride permeability of concrete; similarly this picture here is that of alkali aggregate reaction in concrete, now this is another undesirable situation we would expect and like the aggregates in a concrete to be inert. Now in certain cases they are not inert they are reactive aggregates and therefore, we can either simply not used reactive aggregates or try to understand the level of reactivity of those aggregates so that necessary measures can be taken to mitigate the damage on account of alkali aggregate reaction. The third picture here is that of concrete deterioration on account of freezing and thawing. So, therefore, in environment suggest this where concrete is likely to be subjected to cyclic freezing and thawing we would like to put in place a concrete which has a higher durability in that environment for which we need to understand the durability characteristics of concrete in freezing and thawing environment.

So, in the subsequent slides we will talk about tests which are available to quantitatively assess the chloride penetration resistance of the alkali aggregate reactivity or the resistance to freezing and thawing of concrete.

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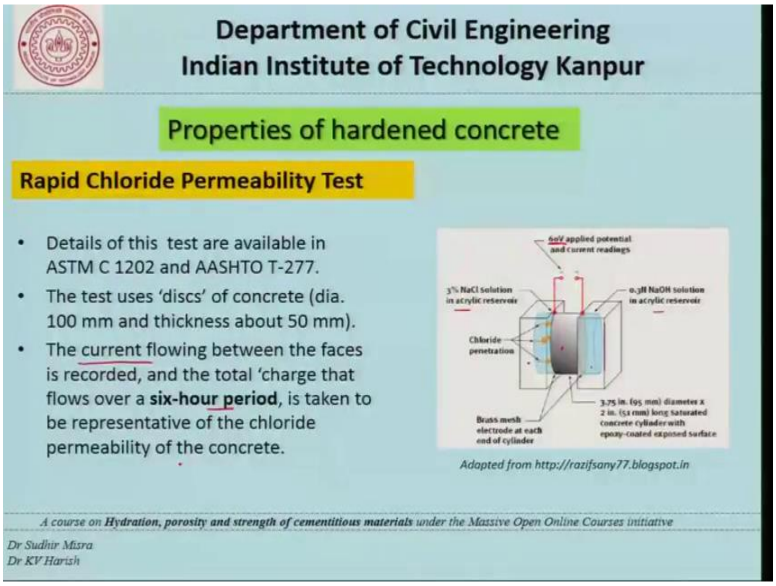

This is only one of the tests which is used to ascertain the chloride permeability of concrete and is the so called rapid chloride permeability test which essentially involves placing a disc of concrete here in the middle, on two sides you have chambers which are filled with 3 percent NACL solution and 0.3 and NAOH solution, and we apply a 60 volt potential difference across the two phases and we monitor the current that flows from one phase to the other and this recording is continued over a period of 6 hours, and we measure the total charge that passes which is an integration of the current and time.

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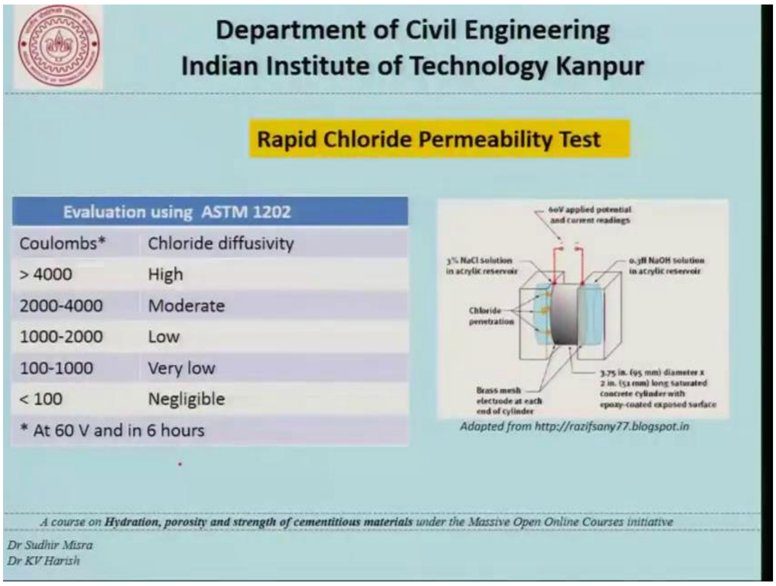

And here is the interpretation that is to be given in terms of the coulombs, and that is according to ASTM 1202, if the coulombs is greater than four thousand the chloride diffusivity is rated as high and if it is less than 100 it is rated as negligible with other values being evaluated the way to shown here of course, this is not the only test to determine the chloride permeability of concrete, but this is one of the tests and as an assignment I would like you to read literature and make a list of the other tests which are available to evaluate the concrete from the point of view of chloride permeability.

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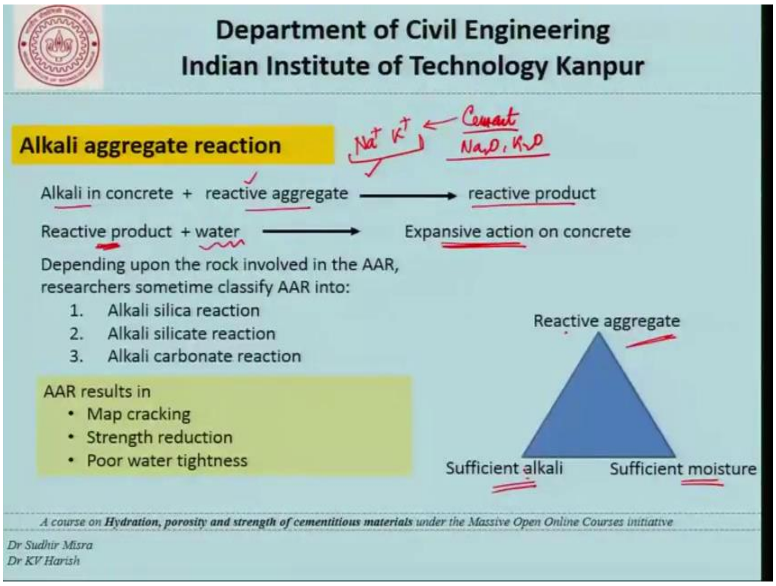

Now, let us come to alkali aggregate reaction; the real problem basically is that the aggregates are reactive and they react with the alkali in the concrete.

Now, where is the alkali in the concrete coming from? The alkaline the concrete refers to the presence of sodium and potassium ions and these are coming is cement these are impurities that are present in the cement, as NA2O and K2O. So, if you look at the chemical composition of cement you will find assert amount of sodium oxide and assert amount of potassium oxide present there, there are ways and means of expressing the equivalent alkali content of the cement and these alkali ions they react with the reactive aggregates to form a reaction product, and this reaction product upon absorption of water it absorbs water and this has an expansive nature and causes the concrete to crack. And depending on the classification that we have if you read an of literature you will find that people of try to talk of alkali aggregate reaction in two different forms alkali silica reaction, alkali silicate reaction, and alkali carbonate reaction.

What we basically need in order to study alkali aggregate reaction is the reactive aggregates sufficient alkyl should be there to have a reaction with the aggregates, and there should be sufficient moisture which will cause the expansion to happen because these reactive aggregates and alkali they form a reaction product which absorbs water to cause expansion; what are the results of the this alkali aggregate reaction map cracking, strength reduction and poor water tightness.

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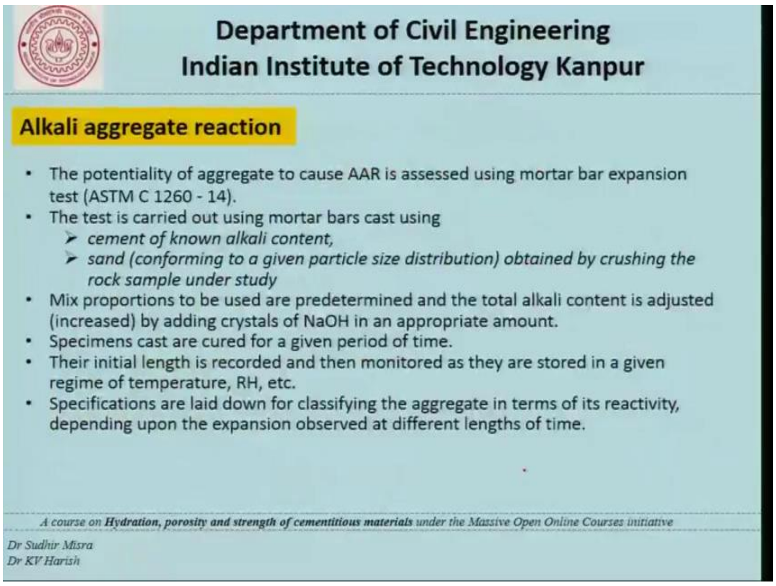

How do we evaluated we do this evaluation based on tests such as the mortar bar expansion test, and this test is carried out using mortar bars cast using cement of known alkali content, sand conforming to a given particle size distribution obtained by crushing the rock sample on the study, proportion the mix appropriately and adjust the total amount of alkali that is present in the system by adding crystals of sodium hydroxide, quite the specimens and measure the length.

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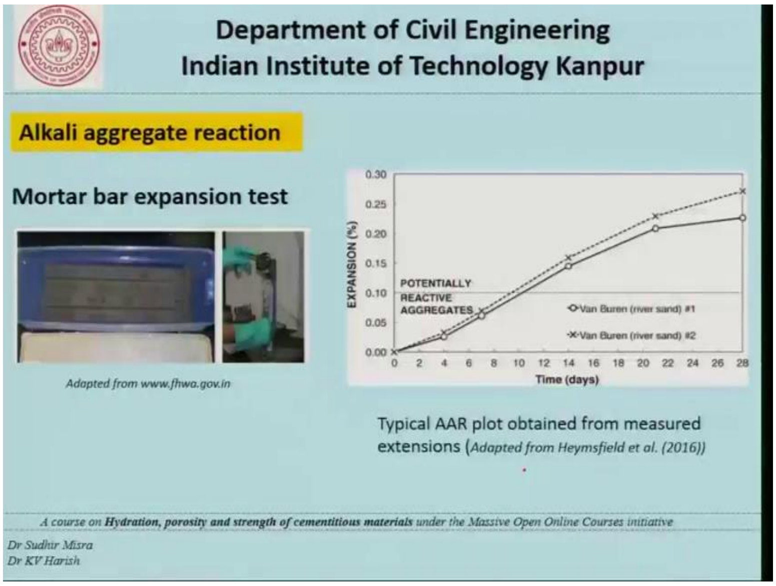

Now, this here is a typical example of how the length changes, how much expansion occurs over a period of time if the aggregates are reactive. Of course, depending on our application we can fix a line here which will separate the potentially reactive aggregates and the nokose aggregates, and as in the case of the chloride permeability this is not the only test to determine the alkali aggregate reactivity and again as an assignment please go through literature and the books to find out what are the other tests and how do we interpret those results.

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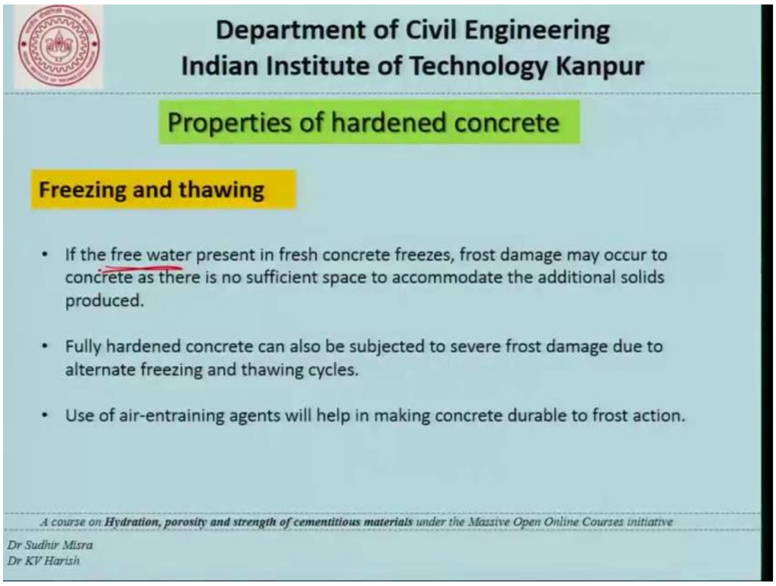

Now, coming to freezing and thawing if the free water present and fresh concrete freezes frost damage may occur to concrete as there is no sufficient space to accommodate the additional solids produced; fully hardened concrete can also be subjected to severe frost damage due to alternate freezing and thawing.

We must remember that we add more water to concrete than is required for hydration, now if this water remains in the concrete and the concrete is subjected to freezing and thawing that is the free water that you are talking about. The water which is free and has not been used in the hydration process apart from that in certain applications the concrete absorbs water if the structure is subjected to rain. For example, or it is subjected to any kind of water it could be a river it could a sea whatever it is the course in the concrete are saturated to different levels and if that water freezes it expands, and that cyclic phenomenon if the water expands and it thaws that causes deterioration and disintegration of the force and concrete, and that is this the genesis of the deterioration in concrete on account of freezing and thawing.

Use of air entraining agents has been found to be a very effective way of creating a durable concrete from the point of view of freezing and thawing.

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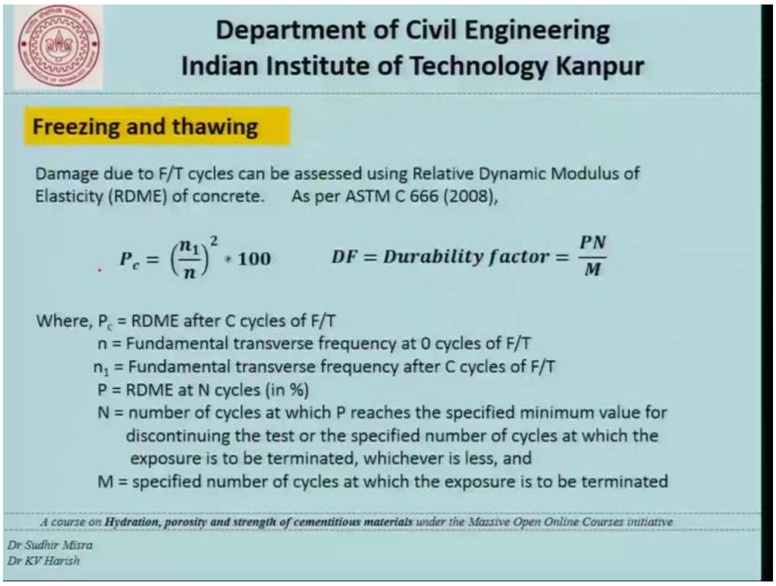

Now, how do we evaluate the durability of a concrete from the point of view freezing and thawing? That is done by the so called relative dynamic modulus of elasticity of concrete the test is carried out using the relative dynamic modulus of elasticity of concrete in as per ASTM C 666, there is a procedure given there is an equipment which I would like you to read from the web or the books and there is something called the durability factor which we finally calculate and as far as the durability of concrete to freezing and thawing is concerned we value it is based on the durability factor.

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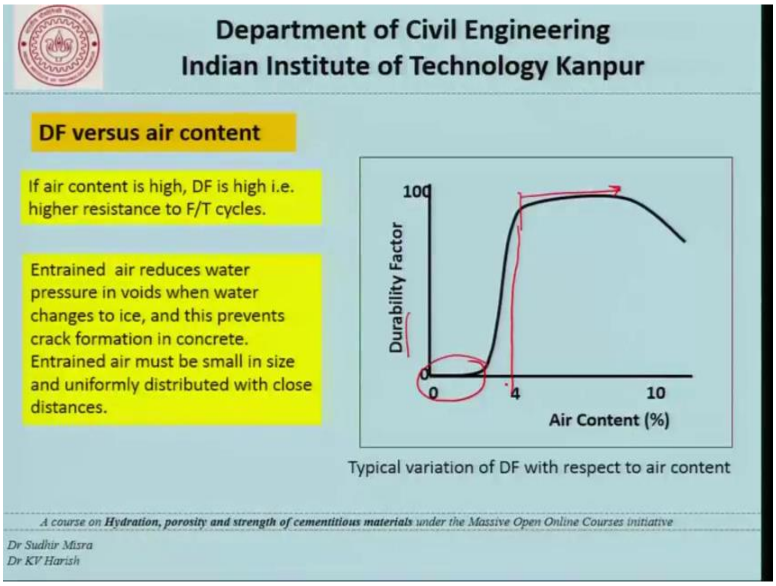

Now, if we plot the durability factor versus air content we get a graph which is typically like this, what this graph shows is that if the air content in the concrete is less than about 3 to 4 percent the durability factor is pretty close to zero; that means, the concrete is very highly vulnerable to freezing and thawing damage whereas, for all concretes having an air contain more than about 4 percent the durability factor is very high. So, what we would like to do as for as specifying the concrete is concerned, is to have concrete which has at least 4 percent air in order that the concrete is durable under freezing and thawing.

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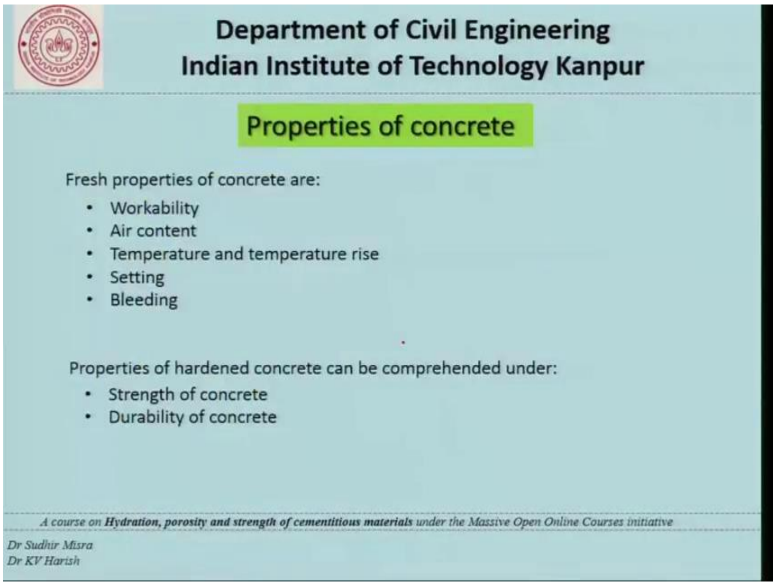

So, this determination of durability factor is at the root of our exercise to ensure durable construction. So, with this we are coming to a close to our discussion today we set out to discuss the properties of fresh concrete, and the properties of hardened concrete in terms of strength and durability, and that is what we have accomplished.

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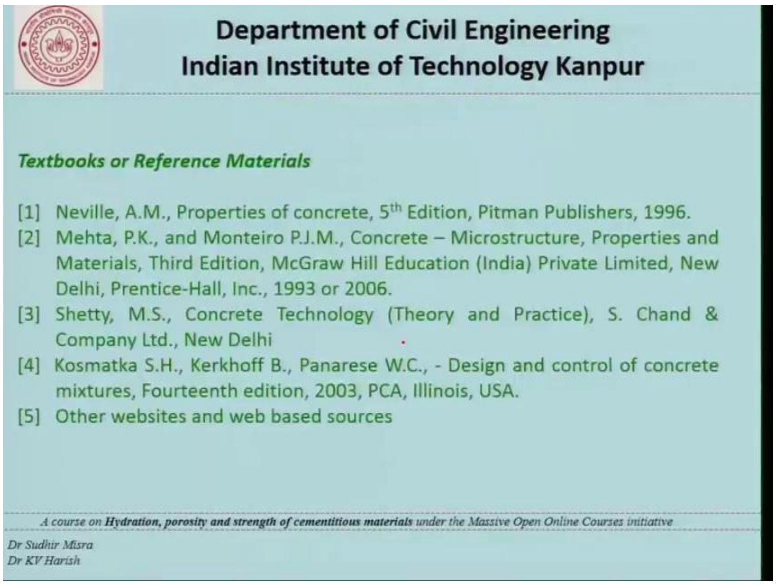

Here are some of the text books or reference materials which you could use to get information and also try to do the questions that we post in the lectures.

Thank you.