Hydration, Porosity and Strength of Cementitious Materials
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Lecture – 16-18 (Part-I)
Portland Cement Based Paste System

Hi. Good morning to one and all. I am K. V. Harish Assistance Professor, Department of Civil Engineering IIT Kanpur. You are watching MOOC lecture course on Hydration, Porosity and Strength of Cementitious Material. Today we will see lecture 16 to 18.

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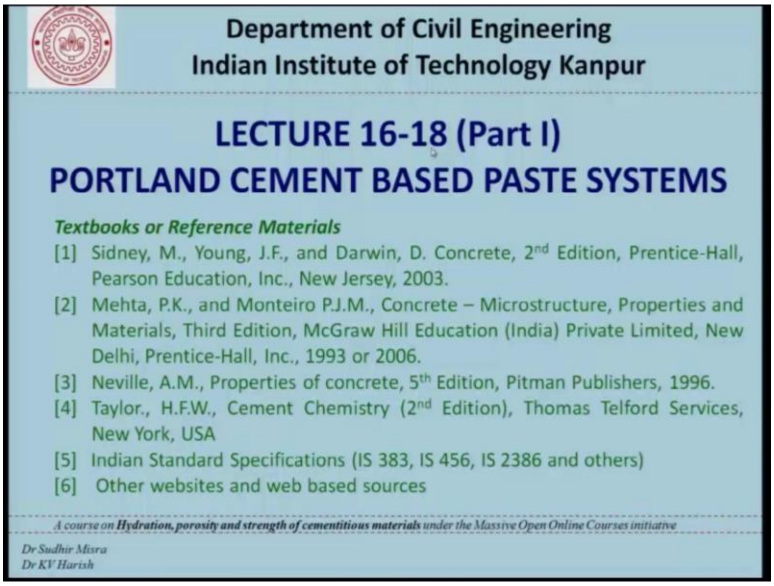

Remember that we have divided the lecture 16 to 18 into 2 parts. So, today we will see part one of lectures 16 to 18, and again under the broad heading Portland cement based paste systems and the text books and reference materials are shown.

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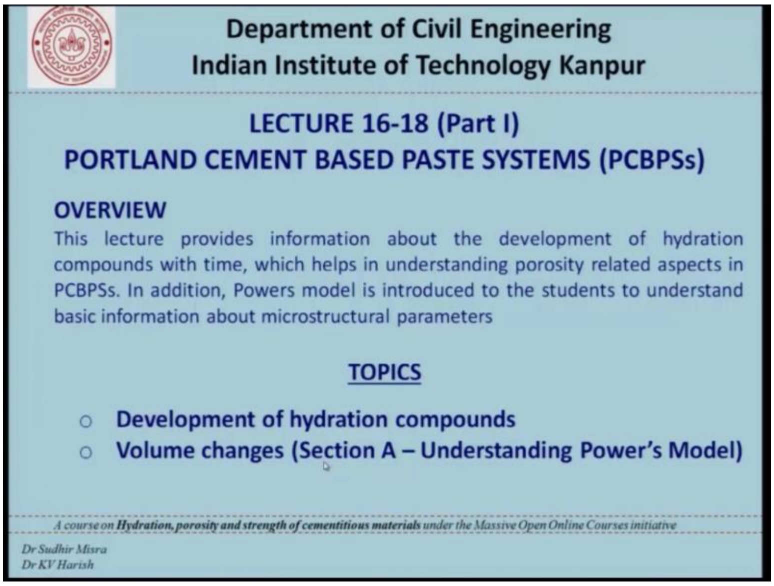

So in part one, we will see topic such as development of hydration compounds, volume changes. And again volume changes divided into 2 sections. We will see section which includes information from powers model for cement hydration. So, and overview of this lecture is as follows. This lecture provides information about the development of hydration compounds with time. If you recall in the previous lectures we have seen; what are the individual hydration compounds that are formed. Some are major compounds some are minor compounds. And individually what are the characteristics of these compounds. So, all these things have been dealt in the previous lecture.

So, in this lecture we will see information about development of hydration compounds with time. And this will help in understanding the porosity related aspects in Portland cement based paste systems. And remember that porosity is a very important microstructure property, and we have to understand the setting and hydration setting and hardening process of Portland cement based paste systems through microstructural parameter. So, that is one of the reasons why micro level strategies are required. So, for understanding porosity related aspects, we will see some of these topics in addition. The powers model is introduced to the students to understand basic information about microstructural parameter. So, here we will be introducing 1 or 2 important microstructural parameters which power created when he developed his model.

So, the first topic is development of hydration compounds in Portland cement based paste systems. Now what we have seen in the previous class previous lecture is that you have individual compounds that are formed.

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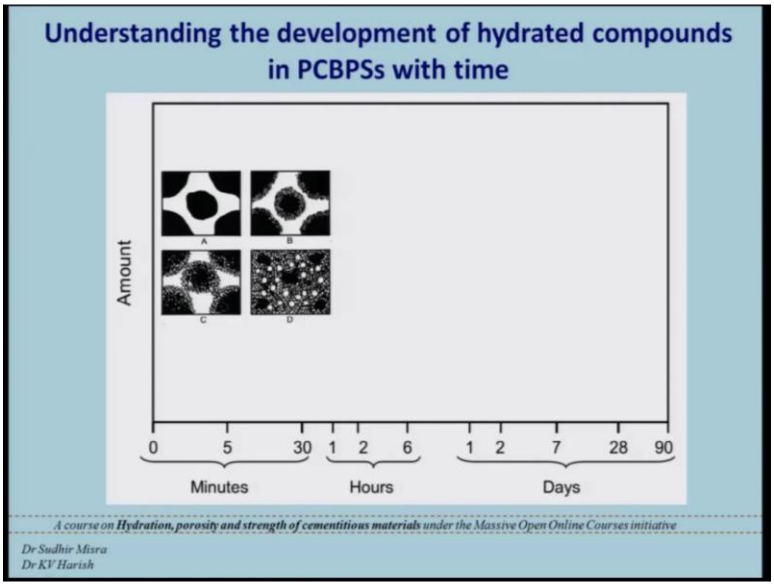

And if you recall you can remember this slide where you have 4 different stages a stages when water is just added to cement, you can see that the white color spots basically denote water and the black color spots denote cement grains. And slowly just after addition of water you basically see that, the surface of the cement grain hydration products is formed. And with time more and more hydration products are formed and finally, at a matured stage you see that the capillary pores are present and you also have hydration hydrated compounds in addition to some unhydrated cement.

Now, you also we will see that the area in which water was initially present, that is slowly filled with the hydration products. And finally, the hydration product is not completely able to fill all the pores or all the water area. So, you still finally, have some capillary pores. So, this diagram we will see at different slides just to help us to understand little more about the porosity related aspects. So, in this figure what you have is, you have x axis which indicates the amount of products that will be formed. The exact values are not given, but it is only a relative it only provides relative idea about different hydration compounds. And in the x axis what you have is the time scale and remember that here the time scale it is not to scale. So, so we have different parts here, one is what is happening during the first minutes and the next part is what is happening between say 30 minutes to about 6 hours. And in the third part we basically have what is happening between 6 hours to about say 90 days.

So, what we will see in the next few slides are that what are the compounds that are formed at different stages and what are the different compounds that are formed at the same stage. And finally, how is the amount changing in each of the hydrated compounds

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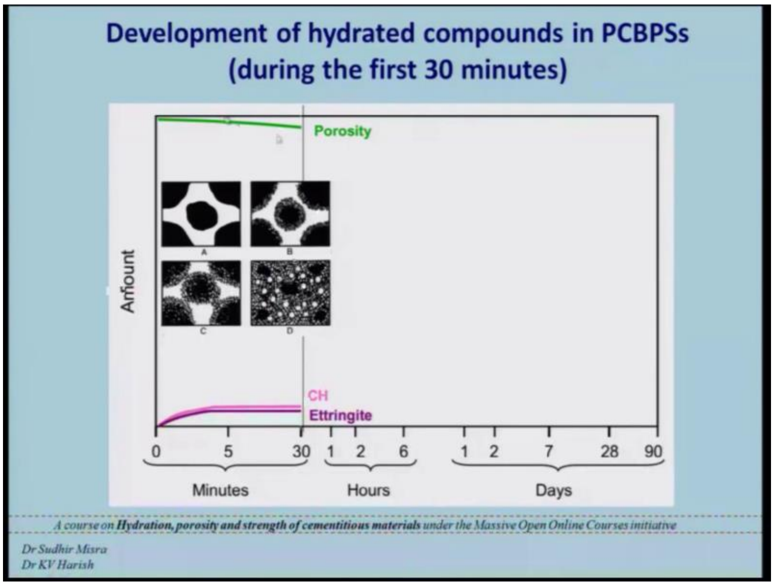

So, now if you just consider the first stage, where which discusses about what is happening during the first few minutes, that is between 0 to 30 minute. You find that the ettringite which is a hydrated product from tricalcium aluminate, that is getting formed. And you also see that when the mixture is very wet the porosity is extremely high. Remember that the pores the capillary pores that are present in the matured stage are generally formed in the in the region where water is present. So, at the first stage what you find is the porosity is extremely high.

And as soon as the hydration products are formed slowly the porosity will decrease. So, this figure what it shows is what is happening during the first 30 minutes. And what is happening to the porosity in relationship with the compounds. So, the first compound that forms in the hydration process is ettringite. And we have already seen the characteristics of ettringite and others. So, I will not get into that you also see that sometimes calcium hydroxide is also formed. That is primarily because the quantity of calcium oxide in the cement Portland cement is extremely high. So, sometimes a very little amount of calcium hydroxide is also possible during the first few minutes of hydration, but the primary compound is ettringite

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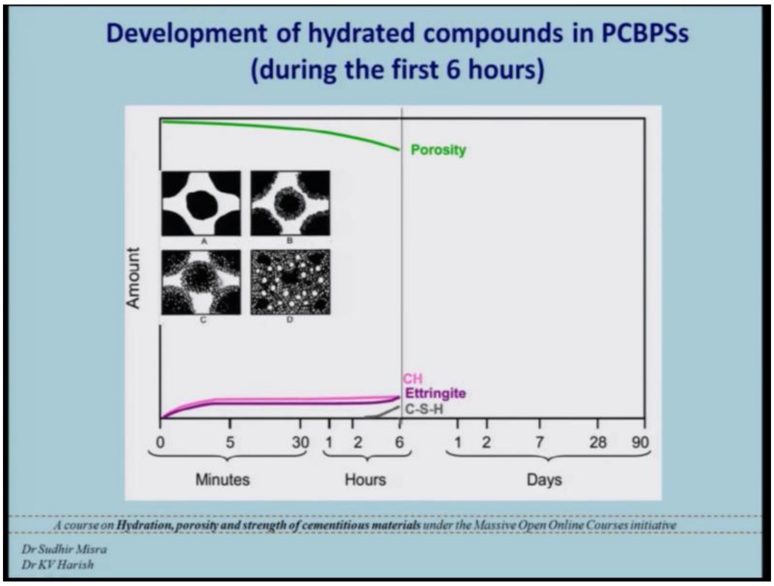

Now, in the second stage that is during the first 6 hours, what happens is that this ettringite that is formed is continues and probably you will have a little more increased quantity of ettringite, but say at a time between say 2 to say 4 or 5 hours, we see that calcium silicate hydrate gel which you can see around unhydrated cement grain slowly starts building up.

And you find that the calcium silicate hydrate gel also increases slightly and when you see that ettringite and calcium silicate hydrate gels are formed say at time of about 6 hours. The porosity also starts decreasing little steeply. In this case when you compare it with the previous figure the decrease is substantial, but not very steep, but it is steeper than the previous case from 0 to 30 minute, that is less steep compared to 30 minute to 6 hours.

So, let us go to the next stage and see how the hydration products grow with time.

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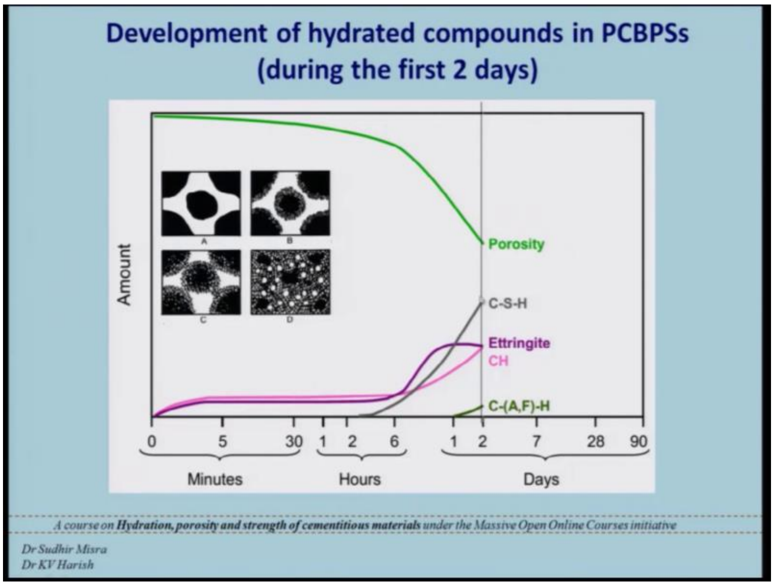

So, if you take up to say 0 to 2 days, you see that after 6 hours the calcium silicate hydrate gel typically starts increasing primarily because of hydration of tricalcium silicate. At the same time, you also see that the ettringite also increases because of the continued hydration of tricalcium aluminate. And this goes up to a stage up to say one or 2 days. Likewise, in silicates also produce calcium hydroxide. The quantities of calcium hydroxide is also increasing, but remember that the quantity of calcium silicate hydrate is much higher compare to calcium hydroxide, if you actually refer to the hydration of silicates which was discussed some lectures before, you will find that the quantity of calcium silicate hydrate gel is much higher than calcium hydroxide.

So, this steep increase of calcium silicate hydrate gel at one end also decreases the porosity of the mixture very steeply. This is what we have we have seen just a while before. The start of the calcium silicate hydrate gel is actually the starting point of reduction of porosity. And likewise if you see the first 2 days once the calcium silicate hydrate gel increases in quantity the porosity is steeply reduces. So, there is some correlation that researcher tend to admit that the porosity is largely decreased because of the presence of calcium silicate hydrate, but also remember that the other products like ettringite and calcium hydroxide also increases, but not to the level of calcium silicate hydrate gel

Now, let us take the next figure which goes up to 90 days.

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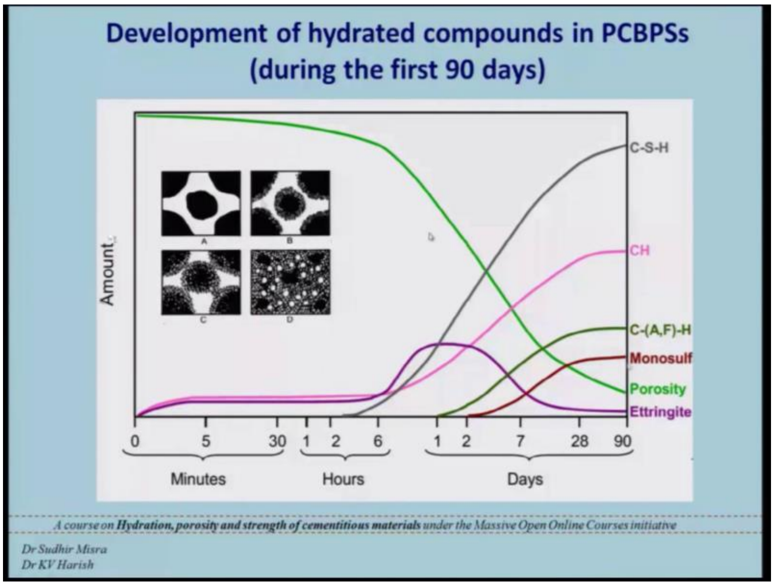

Now, what you find is that the calcium silicate hydrate gel grows substantially. And you also see that the porosity decreases steeply decrease steeply and finally, it reaches a low value. Remember that in this figure the amount is not clearly specified, how much and all those things that is primarily because you do not know the water to cement ratio that is originally taken. If the water cement ratio changes then these values also change, but remember that the trend will essentially be the same in the sense that if the porosity is decreasing the calcium silicate hydrate gel well increase. And calcium silicate hydrate gel will always be the maximum quantity in the within the hydrated compounds compared to the others. And what you also see until 90 days is that the calcium hydroxide also tends to increase very steeply.

And closure look into the ettringite quantity, you see that suddenly after 2 days the ettringite quantity decreases. And the 2 days decreases steeply and goes to a minimum quantity say at around 90 days. What is happening is that sometimes if ettringite is available and tricalcium aluminate is available in excess, they both react together and form monosulfoaluminates. So, if you again get back to some of the hydration equations which were discussed in the previous lecture especially the hydration of aluminates and specific case is where monosulfoaluminates is formed, you will you will see that the reduction that in ettringite that you have in this figure is compensated by the formation of monosulfoaluminates.

So, basically the ettringite that is formed from the initial hydration, it may react with tricalcium aluminate and form monosulfoaluminates. So, basically the monosulfoaluminate curves starts from 2 days, slowly it picks up and at 90 days you will have quite substantial amount of monosulfoaluminates. Likewise, the ettringite reduces, but remember that in many Portland cement based paste systems this this may not happen also. So, because ettringite only when you have substantial amount of tricalcium aluminate, it will react and form monosulfoaluminates otherwise it will remain as ettringite in the system itself. In that case this curve will be flatter and this will be approximately equal to the quantity of monosulfoaluminate indicated here.

So, if ettringite is getting converted to monosulfoaluminates then this curve will come down. And likewise the monosulfoaluminates will increase. And the other curve which we did not see is the ettringite like compounds which is a formed because of the hydration of tetra calcium aluminoferrite. So, here what you see is that say about one to 2 day the ettringite like compound from the from the hydration of tetra calcium aluminoferrite starts increasing, and slowly it reaches to some substantial amounts depending upon the percentage of tetra calcium aluminoferrite present in the Portland cement based system. So, all these figures which we have seen previously give some approximate idea about how the porosity is changing with the development of hydrated compounds.

And this is the very extreme and this is a very important part in the Portland cement based paste systems and also from the width stand point. So, it is suggested that the audience paste more attention to which compounds are formed at a later stage and which compounds are formed at the early stage. So, that they get a representative idea of the entire hydrated compounds say up to 90 days.

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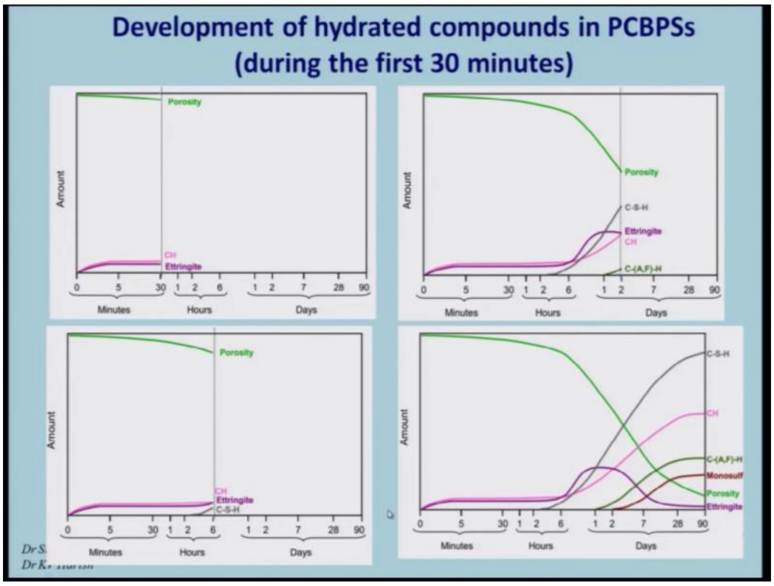

Now, figure which contains all these 4 figures together is shown. So, people can go through this simultaneously.

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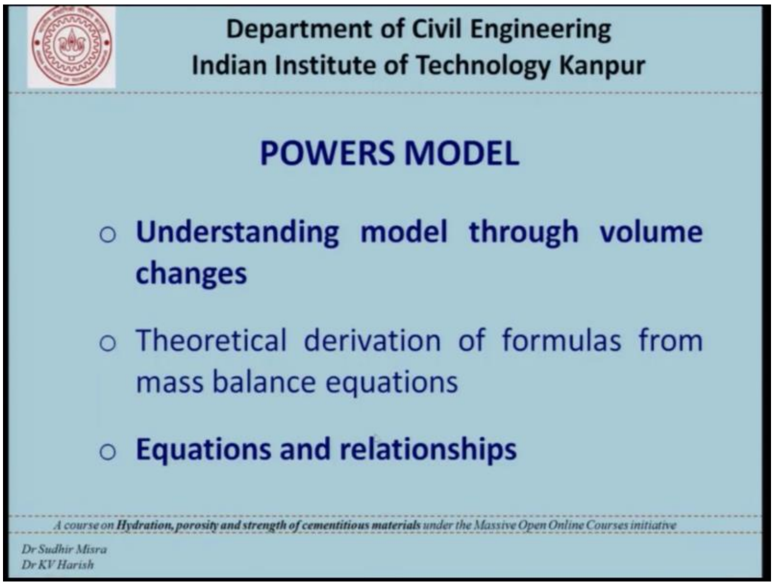

Now, coming on to the second topic, which is volume changes in Portland cement based paste systems. We are in this lecture I am covering a section a which is understanding powers model. What we will do in this powers model is that it is basically divided into 3 parts. One; is understanding of the model through volume changes. The other one is the theoretical derivation or formulas which are developed from mass balance equations.

And the third one is actually the final equations and how they relate to other properties. So, of the 3 part in this lecture we will cover only the first part. In the second lecture we will cover the third part.

So, the second part will not be covered and it is generally not required for this course so, but the final set of equations and relationships are extremely important. This theoretical derivation is found in different text books which are already mentioned in the first slide. So, people who are interested in knowing; what is the derivation can go through those text books for more information. For this particular course it is important to know the volume changes suggested in the model as well as the final equations that derived from the model. And how it relates to the properties of the Portland cement based paste systems.

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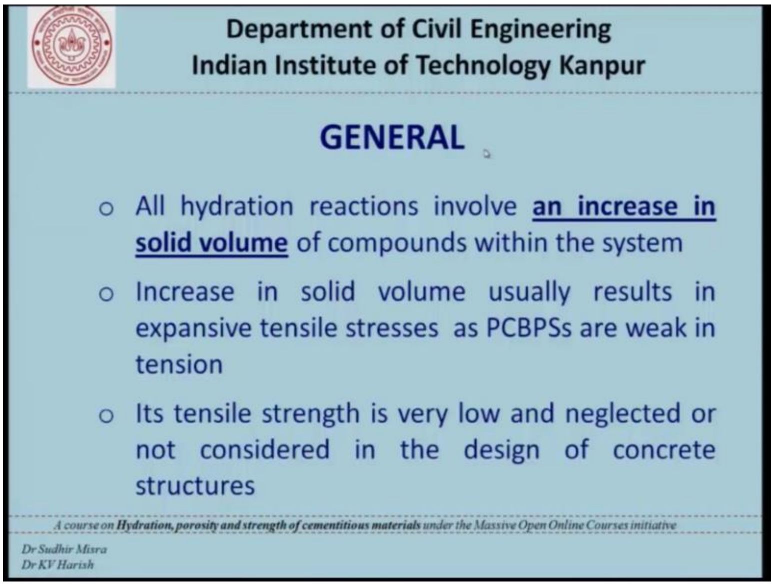

Now, before heading on to the model some important information all hydration reactions involve an increase in solid volume of compounds within the system. So, if you actually get back to this figure what you find is that you have this water you have this cement grain and then the hydrated compounds from around the cement grain, slowly the volume increases. So, that is what is the meaning of the first line all hydration reactions, involved and increase in solid volume of compounds within the system.

So, the increase in solid volume usually results in expansive stresses as Portland cement based paste system; so weak in tension. So, the meaning is that when these hydration compounds are formed with time usually they try to occupy the available space.

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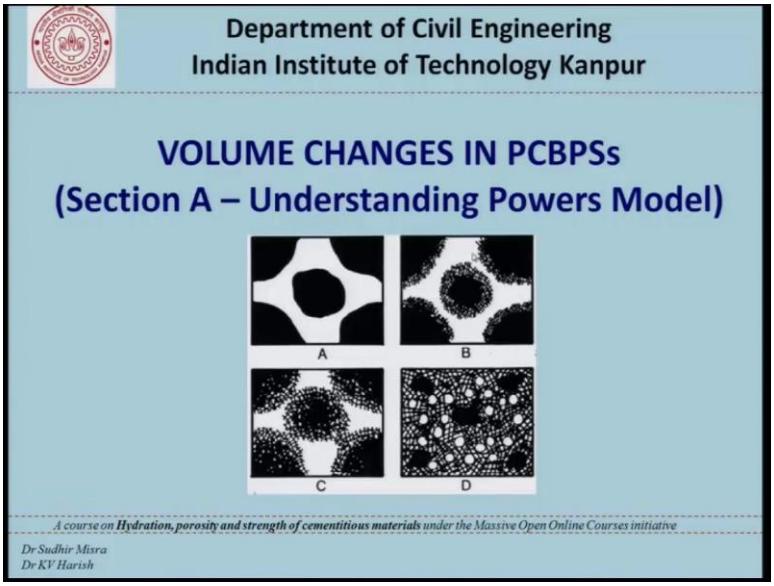

But many times it so happens for certain compounds you may not have enough space within this system. So, in that case sometimes they may create some stresses. And those stresses are generally tensile and natures there are many times referred as crystal pressures. So, we will go through some of the slides at a later stage about which compounds create crystal pressure and which compounds do not create crystal pressure.

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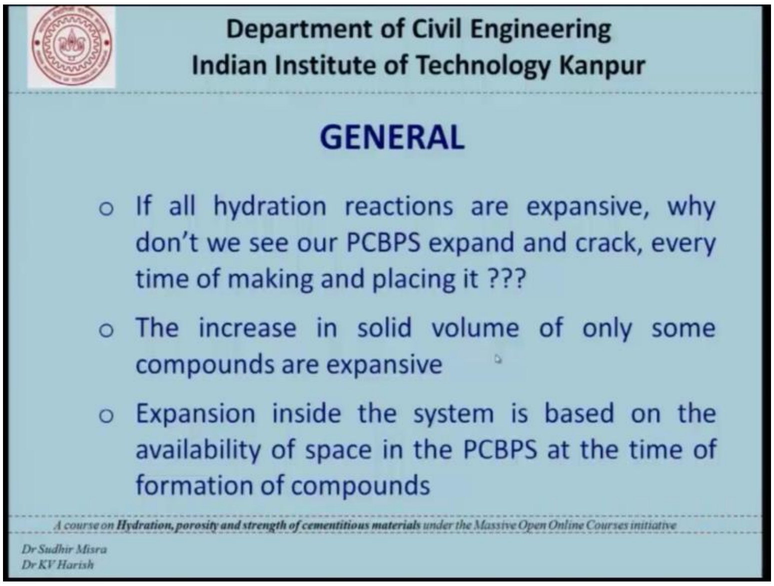

So, it is tensile strength is very low and many times it is neglected or not considered in the design of concrete. If all hydration reaction or expensive and nature then the assumed thing is that Portland cement based paste system should expand and crack, but it does not happen it does not happen every time we make concrete or place concrete; that means, that certain compounds may create crystal pressure and certain compounds may not create crystal pressure, when the solids or when the hydration products are formed around this surface of the cement grain. So, the increases in solid volume of only some compounds are expensive in nature. So, expansion inside the system is based on the availability of space in the Portland cement based paste systems at the time of formation of compounds.

So, what is the meaning of this line is that when a particular compound is forming, at that point whether do you have enough space for the compound to grow. So, if you have enough space, then the compound basically forms without creating in any tensile stresses, but if you do not have enough space, because some other compounds are formed around them. In that case certain compounds create crystal pressure and certain compounds do not this is very important let us go to the next couple of slides to understand why it is important.

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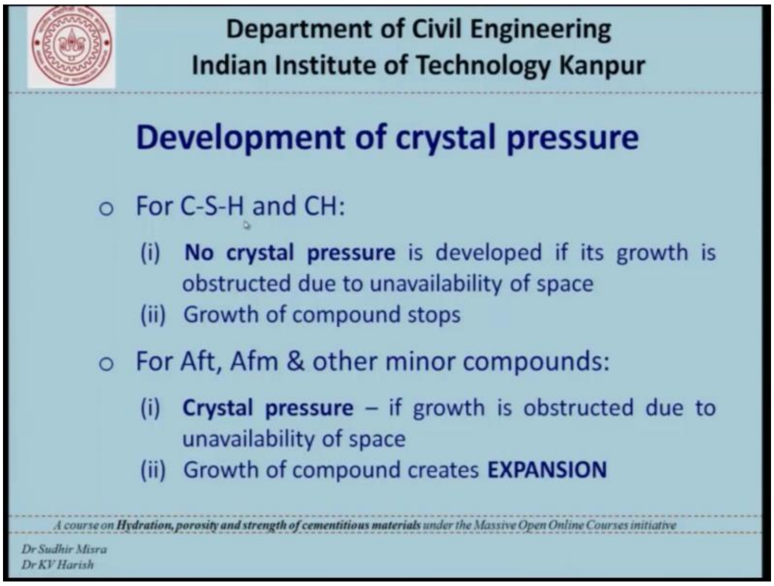

Now, the title here is development of crystal pressure. So, if you take the characteristics of calcium silicate hydrate gel and calcium hydroxide they usually do not create crystal pressure irrespective of whether space is available or not.

So, when calcium silicate hydrate gel or calcium hydroxide is formed because of the hydration of silicates, even if it is growth is stopped it does not create crystal pressure, but if you have enough space then there is no issue. If you do not have enough space basically this the growth of these crystals stops, but in the case of ettringite monosulfoaluminates and other minor compounds. They develop crystal pressure. They do not develop crystal pressure if sufficient space is available. If sufficient space is not available they create a lot of crystal pressure, and this could lead to tensile stresses developed in concrete.

And hence you will have expensive stress is leading to cracking. So, if you actually recall what we discussed in sulphate attack we see that the formation of monosulfoaluminates from the reactions between ettringite and available tricalcium aluminate remains in the system after remains in the system for longer time. When they come in react with external sulphate, and then they try to react with those sulfates and form ettringite. So, when ettringite is getting formed at a later stage where you do not have enough space because the all the hydration compounds are already form in such cases the formation of ettringite create creates crystal pressure and causes expensive stresses and cracks concrete which we have already dealt in sulphate attack.

So, the same usually does not happen, if the compounds like calcium silicate hydrate or calcium hydroxide are stopped. So, now, moving on to the next one what is the significance of powers model why do we have to study it and what is the special thing about studying powers model.

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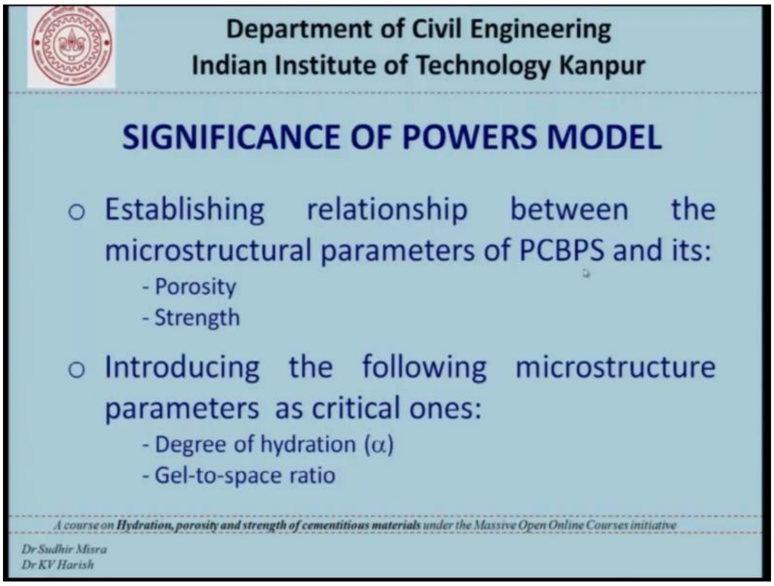

Powers model provides relationship between the micro structural parameters of Portland cement based paste systems, and it is porosity and strength. Remember in the macro level strategies that we discussed under mixed design and strategies, we see that strength is a very important performance parameter, like workability and durability and we typically do not know how to correlate strength and porosity from the strategies that we have seen under mix design.

So, the micro structural parameters in Portland cement based paste system or identified in powers model. And efforts are taken to correlate those factors with porosity and strength. So, that is the special thing in powers model. In addition to that power basically introduces 2 micro structural parameters namely degree of hydration and gel to space ratio. So, let us first see; what are these micro structural parameters before heading on to the powers model.

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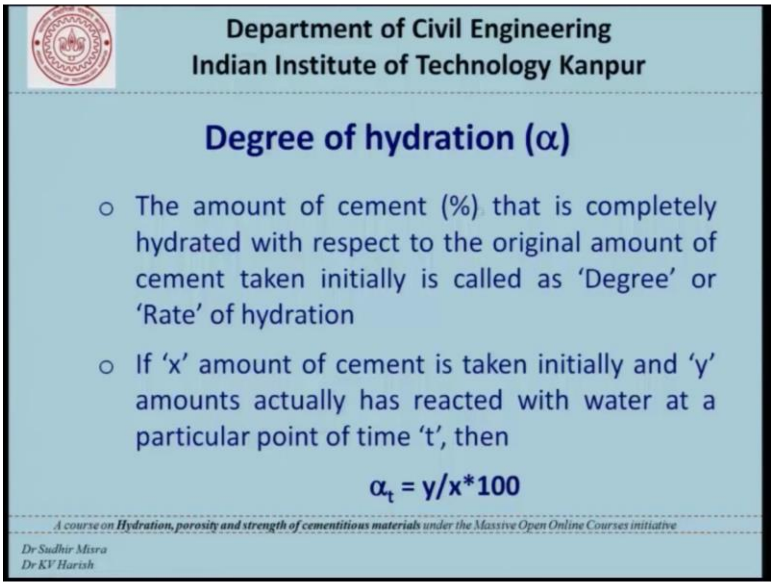

So, degree of hydration in this lecture as well as in the coming lectures will be denoted by the terminology alpha. So, the amount of cement that is completely hydrated with respect to the original amount of cement taken initially is called as degree of hydration or rate of hydration.

So, for example, assume that you take a certain quantity of water and you take certain quantity of cement, initially and assume that those are mixed together and hydrated for say about 7 days. So, after 7 days the amount of cement that you have originally taken a part of it would have reacted. So, so how much is reacted is actually is called as degree of hydration. So, if x amount of cement is taken initially and y amounts reacts with water at a particular point of time t, then alpha t at that particular point of time is equal to y divided by x into hundred. Remember that alpha is a function of time because alpha does not remain constant cement hydration from the time you add water to cement until it achieves a 28 to 90 days' alpha keeps on varying that is very important primarily because cement keeps on hydrating.

So, the movement cements keep on hydrating the hydrated cement is getting reduced and alpha is always increasing.

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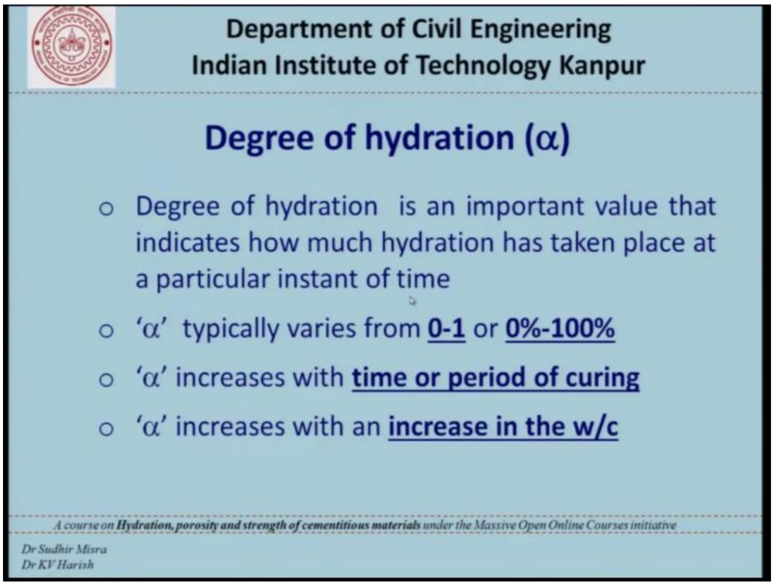

Degree of hydration is an important value that indicates how much hydration has taken place at a particular instant of time. And what you should also remember that alpha typically varies from 0 to 1. Or in other words if you want to express in terms of percentage 0 percentage to 100 percentages, and remember that in Portland cement based paste system, usually it is very difficult to achieve 100 percentage hydration and hence this 100 percentage may be understood as a theoretical and hypothetical value.

Usually the degree of hydration for a matured cement paste is usually in the range of 7 ty percentage to 90 percentages usually it does not exceed 90 percentage. So, 100 percentage is something that is hypothetical which is usually difficult to achieve even after one or 2 years of curing. So, alpha typical varies from 0 to 1 or 0 percentage to 100 percentage 100 percentage taken to be a hypothetical value. In addition to that alpha also increases with time or period of curing as we have already seen in this formula alpha is a function of t with the time, alpha changes. Likewise alpha also increases with increase in the water to cement ratio. Remember that water is a important parameter in the cement hydration process.

So, if you increase the water then alpha also increases.

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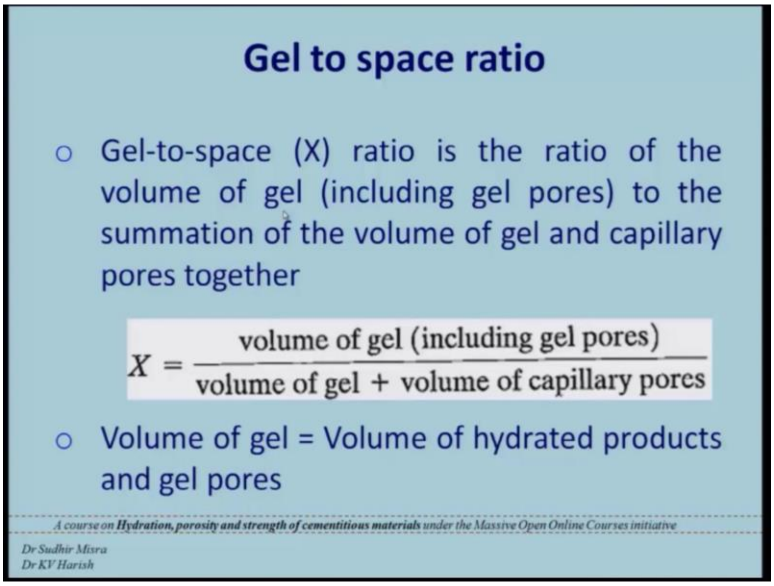

Now, the second parameter is gel to space ratio. Gel to space ratio indicated as x is the ratio of the volume of gel. Remember volume of gel includes also the gel pores to the summation of the volume of gel and capillary force together. So, and remember the x this is denoted as capital letters, this is not the same as the X that we denoted in the couple of slides before.

So, capital X is equal to volume of gel which includes even the gel pores divided by volume of gel plus volume of capillary pores. So, what does it indicate if you if you basically go to this figure. So, if you take this area. So, what you will find is you will find this unhydrated cement grain. So, if you remove that and unhydrated cement grain, you have the gels or hydrated compounds. Remember gels are also called as hydrated compounds and you may have pores in the gels and you may also have capillary pores.

So, if you know the volume of the capillary pores and if you know the volume of gel, then you can find out the microstructural parameter, gel to space ratio where if you take the numerator that includes the volume of gel which is the volume of pores in the gel as well as the hydrated compounds, plus volume of capillary pores. Remember the numerator does not include unhydrated cement grain. And in the numerator what you have is the volume of gel including gel pore which does not include the capillary pores or unhydrated cement grain.

So, this is a very important parameter, and if the gel to space ratio increases; that means, that the volume of gel basically increases. Because if this ratio x increases then it means that the numerator is increasing which means a volume of gel is increasing. So, if the volume of gel increases will it increase the strength or decrease the strength will it increase the properties of concrete or decrease the properties of concrete. So, that is what we are going to see in the next few slides next few slides or in the next lecture. Now volume of gel includes volume of hydration products plus the gel pores. So, that is all about this microstructural parameter definition of degree of hydration and gel to space ratio.

Now, what are the basic assumptions and powers model.

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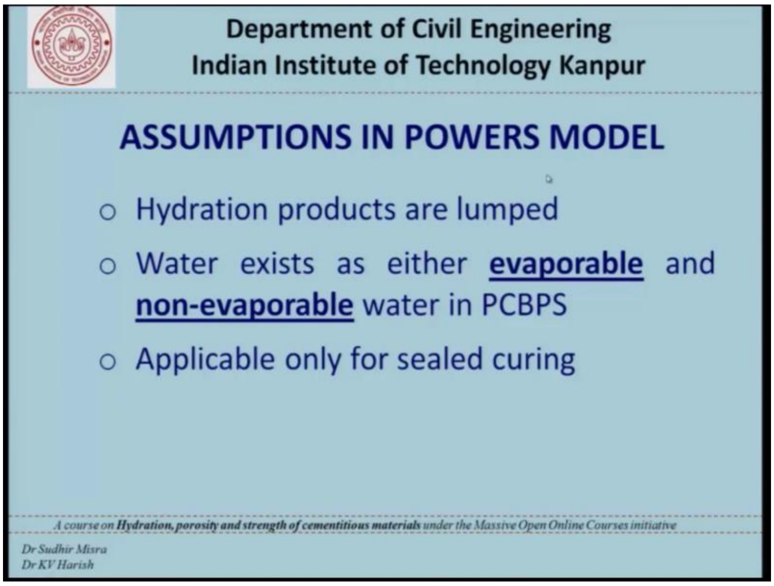

The first simple assumption is that hydration products or lumped nature they are not present individually; they are all present together as lumped particle. Water exist either as evaporable water or non-evaporable water in the Portland cement based paste system. And in addition the curing that power studied when he checked his formulas using experimental work is sealed curing. So, whatever he has done is applicable only for sealed curing. Remember that powers model was developed in 90s 40s or 50s. So, it is approximately 80 years old from now. So, at that time they were doing only sealed curing, but nowadays we have a lot of different types of curing methods. So, let us not get into that. So, these are the 3 assumptions and what do you mean by evaporable and non evaporable water we will discuss the next slide.

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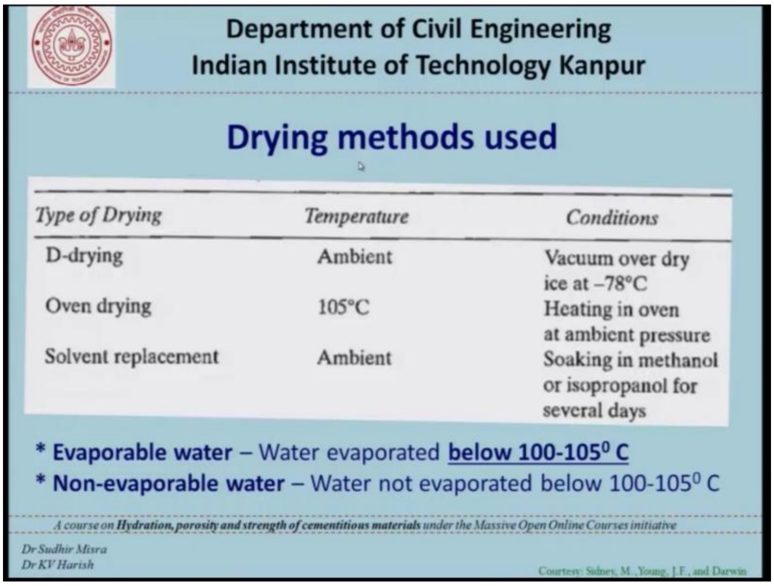

So, now what are the commonly available drying methods? For example, you have the cement paste cement and water together mix together, and you have the mixture with you and you want to dry the mixture. Why you want to dry is you may have your own reasons why you want to dry. So, if you want to dry then what are the methods available? The common methods or d drying which means you just keep the sample in the ambient temperature. And this is done by vacuuming over dry ice at minus 78 degree Celsius.

And the second type of drying is oven drying instead of keeping it in ambient temperature you can also keep it in oven set at 105 degree Celsius that is what is usually done in the lab if we want to dry some cement paste or motor or concrete samples. And remember that the oven we generally use ambient pressure we do not use extra pressure whatever is there in the ambient the same pressure is used. You can also dry sample by solvent replacement that is also done at ambient temperature and for that you typically use special chemicals life methanol or isopropanol, and these are the normal drying methods that are used.

Let us come to know what is evaporable water and non evaporable water as mentioned in the previous slide. So, when power says that water exist as evaporable and non evaporable water, he is talking about the hydrated cement paste. So, water that you had added at early stage either is available in evaporable form or non evaporable form. So, if you want to find out what is the evaporable form of water you have to basically heat the sample to say up to 100 to 105 degree Celsius and whatever water that actually escapes whatever weight of water that escapes that is basically the evaporable water in the system? Remember that all water that is present in the Portland cement based paste system does not evaporate at 100-105 degree Celsius.

So, some remain in the system and primarily recall what we have seen in the previous lectures since some compounds hydrate compounds like calcium silicate hydrate gel, calcium hydroxide, ettringite and monosulfoaluminates have substantial water referred as combined water, in the previous lecture those still remain in the system even after heating to 100 or 105 degrees Celsius. So, what are club together is called as non evaporable water.

So, power basically uses evaporable water and non evaporable water, in his experiments in order to find out some equation, which he uses in the theoretical derivations to confirm his results anyway. In any way we are not getting through the derivations that are not important for the course. So, that is about evaporable and non evaporable water.

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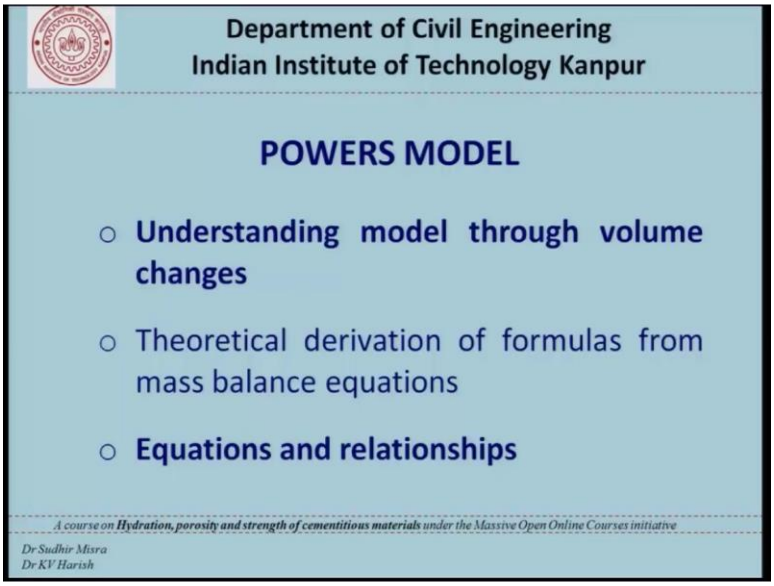

Now, coming on to the powers representation volume representation and how to understand.

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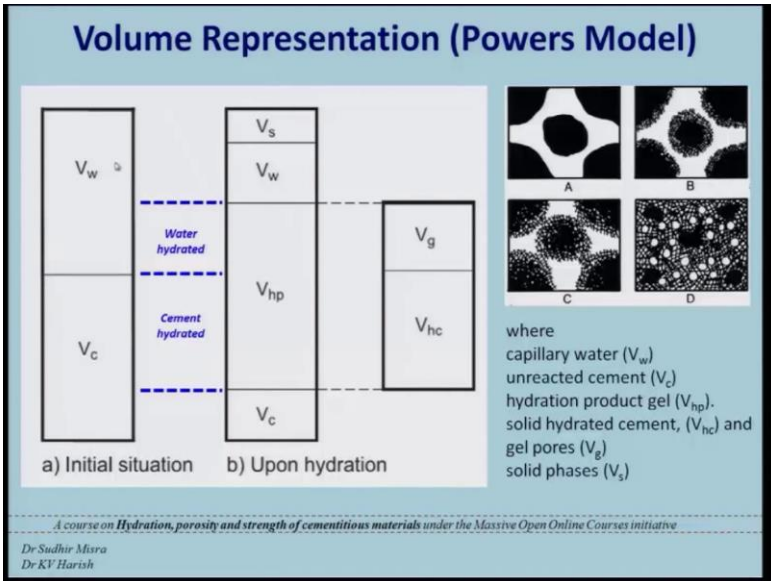

So, there are 2 cases that are given and one is the initial situation the other one as upon hydration. So, what he basically does is he gives a volumetric 2 d representation, where one portion of it is actually water and other portion of it is cement. And remember that this is completely unreacted water and this is completely and reacted cement.

So, initial situation water and cement are available as you can see in the case a. Now upon hydration what basically happens is of this entire volume of cements a portion of it hydrates. So, here whatever is shown we see this portion has not hydrated. So, the portion of it from here to here hydrates, and it forms hydrated paste. And likewise the water that you have taken here not all participates in the hydration process parts of it participate. And here it is denoted by this between these levels. So, this water from this portion reacts with this portion of cement and forms the hydration products.

So, you basically have some cement that is unhydrated from this initial cement that is taken. Likewise, you also have some water which is not utilized in the hydration process; remember that this water remains in the system in the capillary pores. Remember the initial amount of water that you have taken is what you see in this figure in the white space and after hydration you still have some water which can be left in the capillary pores.

So, that is denoted by Vw. And Vs is the volume of solid phases which could also be present in the capillary pores; and now if you go to the next level of explanation, where this volume of hydrated cement paste is divided into 2 parts. Remember volume of hydrated cement paste is nothing, but the gel itself. So, the gel is basically divided into 2 part, one is the solid phase the other one is the gel pores. And the gel pores may contain water or it may not contain water. If you actually recall some of the slides that we have discussed in the previous lecture, the water that is present in the gel pores they are they constitute of 3 part one as the interlayer water and the other one is a micro power water and other one is the chemically combined water.

So, we will see that in the next slide we will see that in the subsequent slides.

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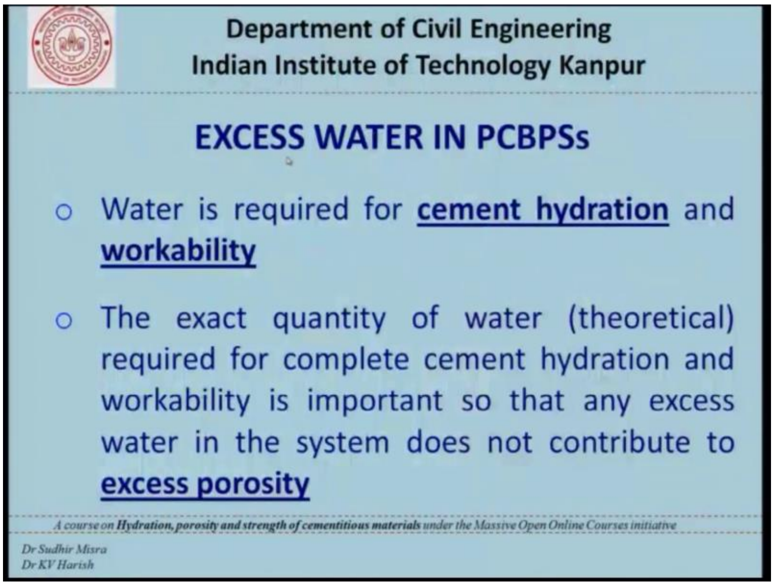

So, excess water in Portland cement based paste system. So, what is the excess water that is available this is largely the excess water which is not utilized in the hydration process. So, water is required for cement hydration and workability. So, if you recall if you go back to the previous slide, the water that you have used here this is the hydrated water. In addition to that you have used this water that is primarily for workability at the early stage.

So, water is required for cement hydration and workability. The exact quantity of water required for complete cement hydration which means this exact value and the exact quantity of water that is required for workability is extremely important. So, that any excess water in the system does not contribute to excess porosity. We always prefer that our Portland cement based paste system should be should have low porosity as for as possible. So, that higher strength and can be obtained as a general rule lower the porosity higher will be the strength. So, we want to make sure that the excess water does not contribute to excess porosity. Excess porosity is a direct function of the amount of capillary pores in the system. So, if you again get back to the slide this is the capillary pore water and this is the excess porosity that we generally do not need.

So, that is a direct function of capillary for water. Excess porosity can be reduced by reducing the capillary pores. And this is achieved by reducing the water to cement ratio, but remember that you cannot simply reduce the water cement ratio without understanding the volume changes. So, that is that is one of the reason why we have section 2 which we will see in the next lecture, where you change where you can see the changes in the volumes of different water that is present in the Portland cement based paste systems. In theoretical models reducing the capillary porosity to 0 merely by changing the water the water to cement ratio is possible.

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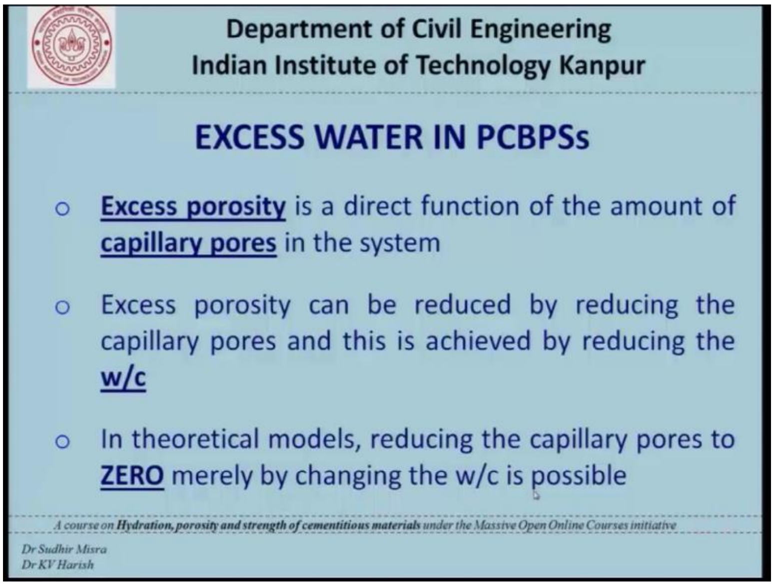

Remember the word theoretical model is important, because the actual cases are much more complicated. And hence the realistic cases could be such that the capillary porosity cannot be reduced to 0 primarily due to the fact that all these pores are the microstructural level.

So, now what are in gel pore and the gel?

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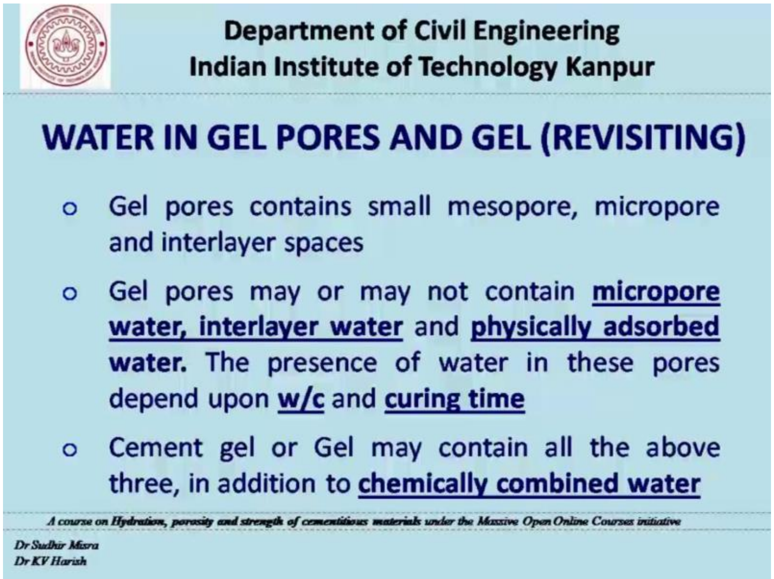

So, we are actually revisiting what we saw a couple of lectures before when we discussed about gel and gel pores. So, you can consider this slide as a revisiting slide. Gel pores contain mesopores micropores and interlayer sheet. Remember these are pores they are different from gels this is gel pores and gels are relatively different. Gel pores may contain mesopores, micropore and interlayer water. Gel pores may or may not contain micropore water interlayer water and physically absorbed water the presence of water. In these pores primarily depend on water cement ratio and curing time.

And remember that wherever curing time comes to picture you will also have alpha coming into picture which is degree of hydration, for the simple reason the degree of hydration is directly proportional to the curing time. The gel pores I repeated the gel pores may or may not contain micropore water interlayer water and physically absorbed water, but they may contain mesopore microphone or in an interlayer, but they may not contain water presence of water depends on water to cement ratio and curing time.

Cement gel or gel may contain all the above remember all 3 of them in addition to chemically combined water. Now another representation of gel or cement gel is provided for easy understanding of the audience. So, this is actually a hydrated cement system that is shown at the meso scale level. And if you actually get into a nano scale you will typically find that you have the hydrated cement gel in the form of layers like what we have seen in the other model and you have interlayer sheets.

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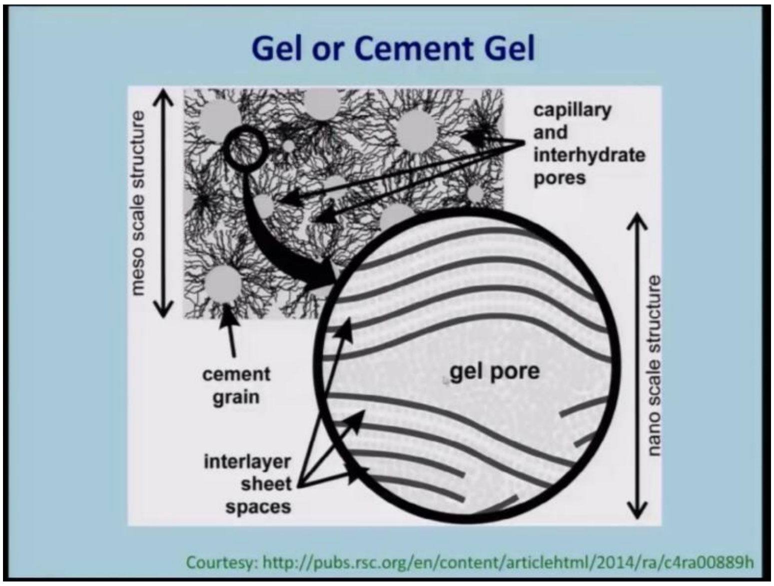

You will also have gel pore is actually shown where you can have water in between the interlayer or you can have water in the gel pores or you can have in other locations. So, and the grey color or light white color or light grey color spot indicates the cement grain.

Now, what is the specialty of water that is present in the pore water in pore and gel pores depend on 3 important factors degree of hydration period of curing and water to cement ratio.

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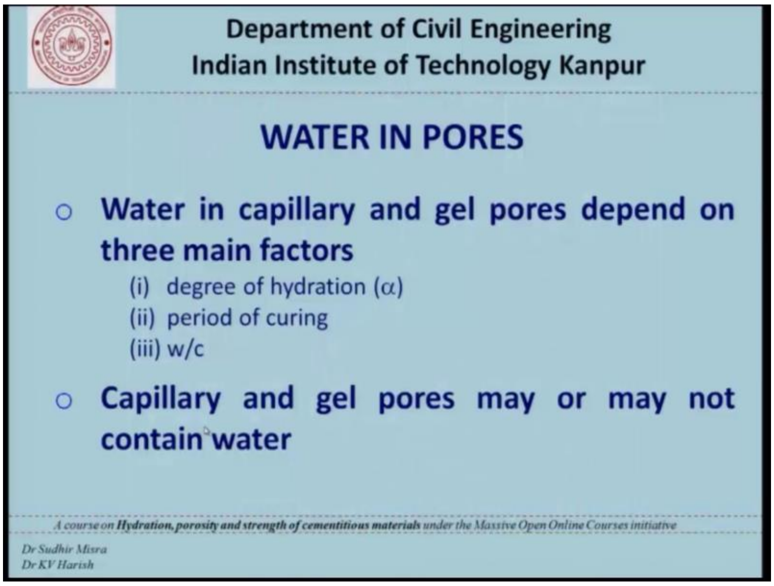

Remember, this is water present in the capillary pore and gel pores. Both of them depend on we have already seen in the couple of slides before that the water that is present in the gel pores depends on water to cement ratio and curing time. Likewise, the water present in capillary pores also depends on all 3 factors. Capillary pores and gel pores may or may not contain water this is very important and because of these 3 parameters.

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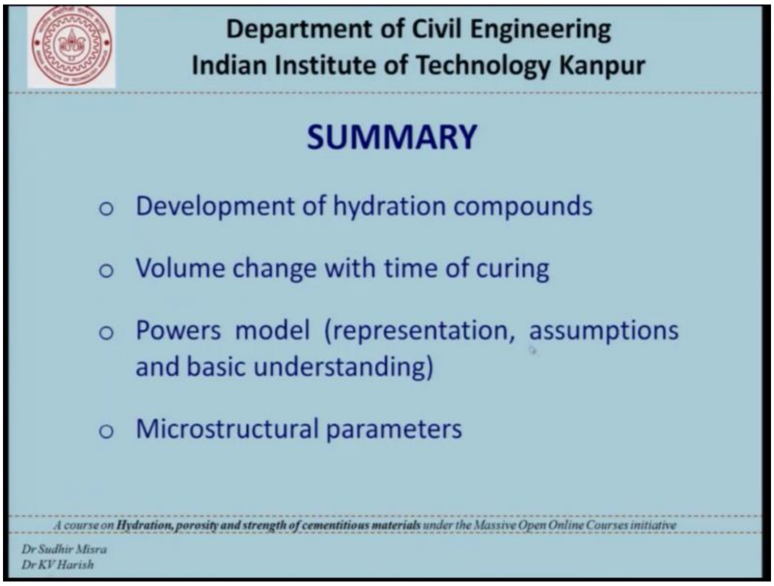

So, in summary what we have seen until now is development of hydration compounds, we have seen what are the different compounds that may be formed from the time water is added to cement to the time, say it achieves say in 80 to 90 percentage hydration which is until 28 days or 90 days. We have also seen how was how is the volume change that is happening with time of curing. And we have also seen an introduction to the powers model and understanding through representations, some of the assumptions that are made in the model. And we have also seen what are the micro structural parameters like degree of hydration and gel to space ratio.

And now the lecturer is over and in the next lecture we will see more information about the powers model and other relationships.

Thank you.