Hydration, Porosity and Strength of Cementitious Materials
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Lecture – 31
From paste to concrete

[FL] and welcome to this lecture 31, in the course on hydration porosity and strength of cementitious materials where we will discuss paste to concrete transition.

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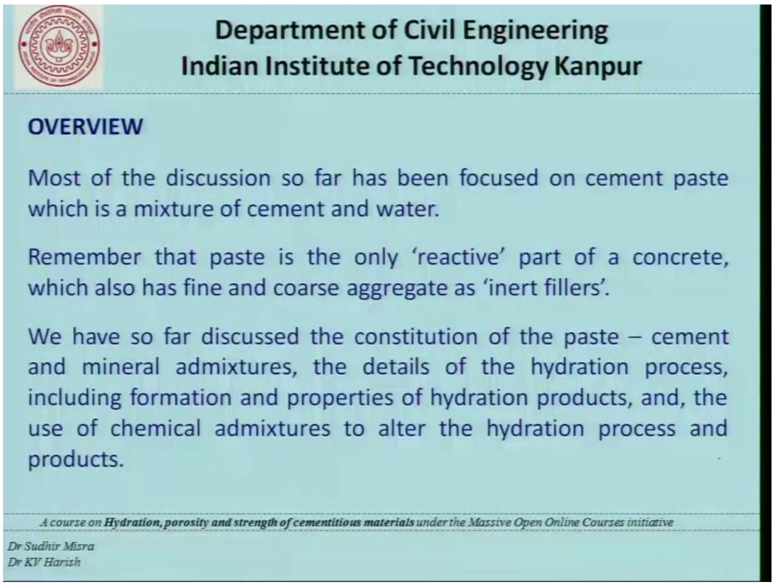

Most of the discussions so far in this course has been focused on cement paste which is a mixture of cement and water, we must remember that paste is the only reactive part of a concrete which also has fine and coarse aggregates and these aggregates acts as inert fillers, they provide the volume and the paste provides the matrix.

We have also discussed the constitution of the paste in terms of cement being partly replaced by mineral admixtures and the details of the hydration process including formation and properties of hydration products the heat of hydration involved, the hydration reactions, the kinetics of hydration, the mechanics of hydration reactions. The components of the cement in terms of the tri calcium silicate and the tri calcium aluminates and in terms of the constituents of cement like C 3AC2S and so on and of course, also the use of chemical admixtures to all to the hydration products and also the use of chemical admixtures to alter the hydration process and the products we could use accelerators retarders air in trainers plasticizers and so on.

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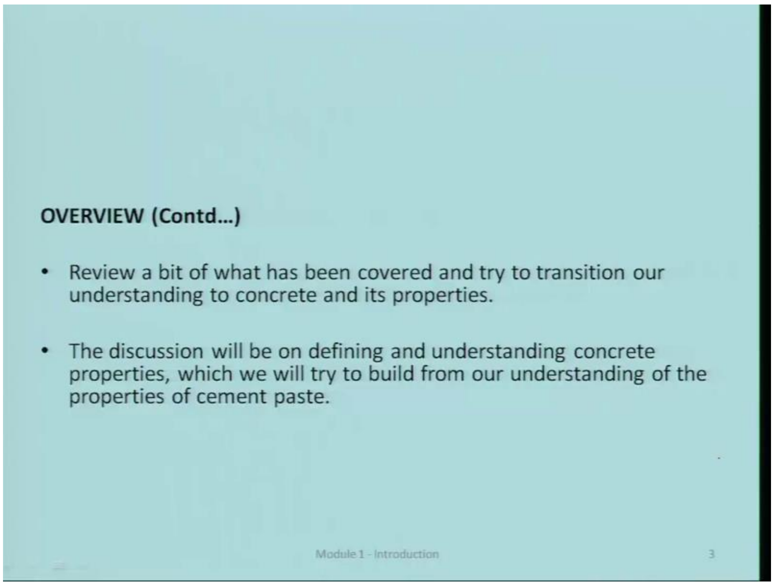

What will to do today is to review a bit of what has been covered and try to transition our understanding to concrete and its properties in light of that we already done at the bottom of the whole thing is the fact that the coarse aggregate and the fine aggregates are only filler material as far as concrete is concerned the paste is the only reactive part and that is something which needs to be emphasized over and over again the discussion will be on defining and understanding concrete properties which we will try to build from our understanding of the properties of cement paste.

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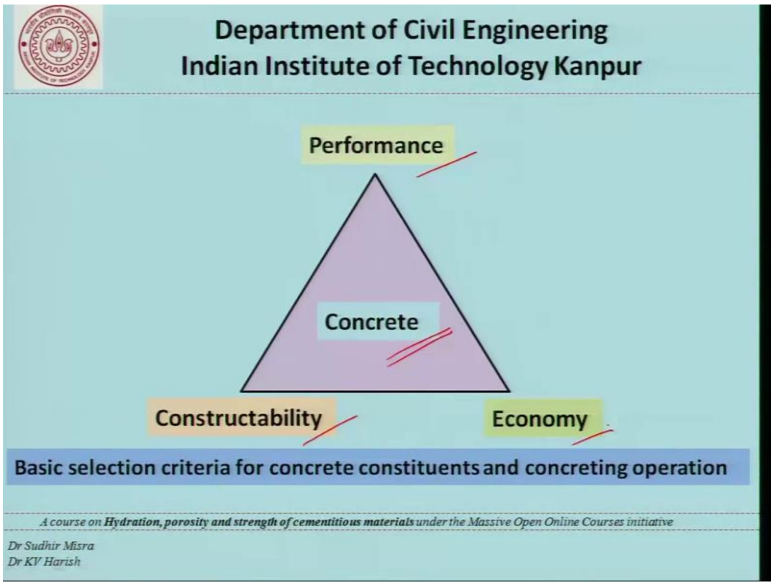

Now, going back to this slide which is more or less the same as what we used perhaps in the first few lectures concrete needs to evaluated from the point of view of performance constructability and economy and we need to have the basic selection criteria for concrete constituents and concreting operation keeping these 3 things in mind. How do we want the concrete to perform in the fresh state or hardened state whether the concrete that we have can we used for the kind of construction process that have in mind and at the end of it is the whole operation going to be economical.

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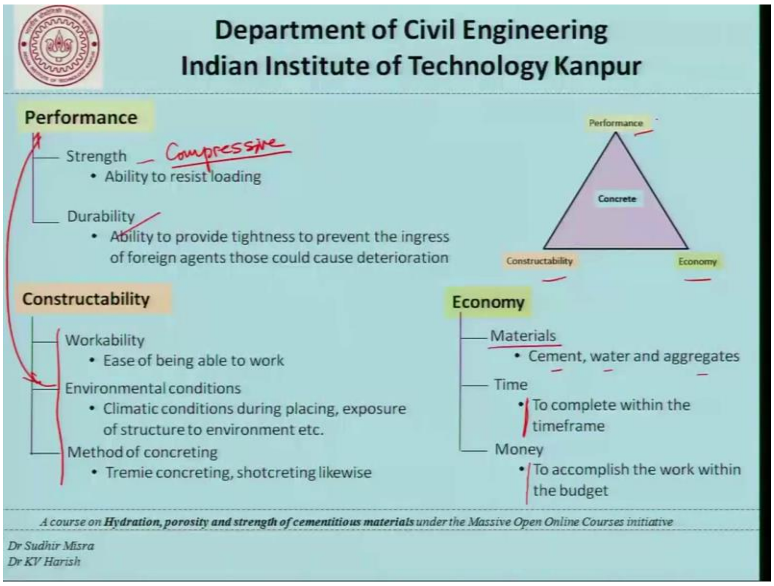

Now, for that point of view if we examine performance; performance can be viewed in terms of strength and let say durability the strength is the ability to resist load and in the case of concrete most of the time when we talk of strength we are talking of compressive strength even though we have situations where we are interested in tensile strength or flexural strength most of the time we are concerned with the compressive strength and the designers are concerned with the characteristic compressive strength and those details we have already covered to some extent in this course and we will also come back to them later on.

Then performance can be in terms of the durability of the concrete which is basically the ability of the material to provide tightness to prevent ingress of foreign agents or those that can cause deterioration to the concrete matrix. Now where it comes to constructability the ease with which the construction can we carried out we have to see the workability of the concrete there is the ease with which it can be worked in fresh state to different shapes and sizes without segregating that is without the coarse aggregate being separated from mortar without the paste being separated from the sand and without the water appearing on the top as if the other materials have been allowed to settle down.

Then there are environmental conditions that are important to consider when are talking about constructability and these could be in terms of exposure condition of their structure or the condition during placing for example, we have situations where the temperature is very high or it is very low. So, we need to put in place conditions or specifications for hot weather concreting or cold weather concreting sometimes we are trying to place the concrete under water. So, that is a very challenging situation and we need to design our concrete accordingly coming to the method of construction we have shotcreting where the concrete is just shot it is gunited it is placed under pressure using a gun on a surface and in those kind of cases the kind of properties that we need as far as the concrete is concerned are quite different from that of normal concrete.

Similarly, if we are using tremies a place concrete under water the kind of properties that we looking for are quite different. So, we can relate any of these things here to finely the performance that we want and lastly there is the economy there is a aspect of not making the concrete construction too expressive that can be achieved by talking about materials whether it is cement or its water or its aggregates or it is the chemical admixtures or mineral admixtures which are involved and so on.

Economy can also be in terms of time how much time it takes or it will take to complete a structure sometimes the time available to us is very small that is say for example, true when we talk about repair work we cannot close a bridge for too long in that case we have a limited time to complete the operation and therefore, time is of essence.

Similarly, there is the fund available to us; what is the kind of funds available to be able to complete a project? So, these are the kind of things and interplay between constructability economy and performance that is what is the challenge to an engineer to come up with the right kind of concrete.

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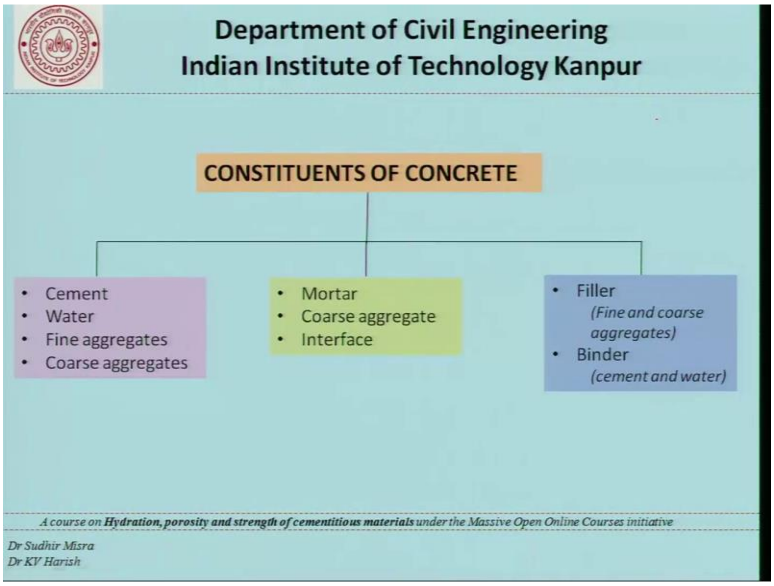

As far as the constituents are concerned normally we talk of concrete made up of cement water fine aggregates and coarse aggregates we talk in terms of mortar coarse aggregate and the interface and we talk in terms of filler that is the fine and coarse aggregates and the binder which is the water and cement.

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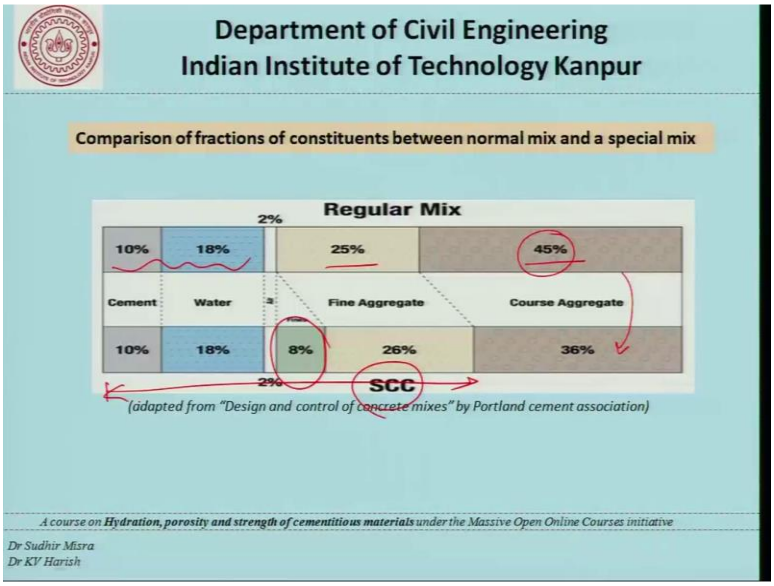

This here is a comparative picture of what normal concrete which is called the regular mix here looks like if we say that 45 percent of it is course aggregate 25 percent is fine aggregate and above twenty eight percent is the volume of paste. Now for a special purpose for example, in the case of self compacting concrete the course aggregate fraction instead of 45 percent comes down to about 36 percent and the sand remaining the same this kind of eight percent of additional fines are added. So, the total mortar content increases. So, these are the kind of adjustments that we make when we go for the design of special concretes.

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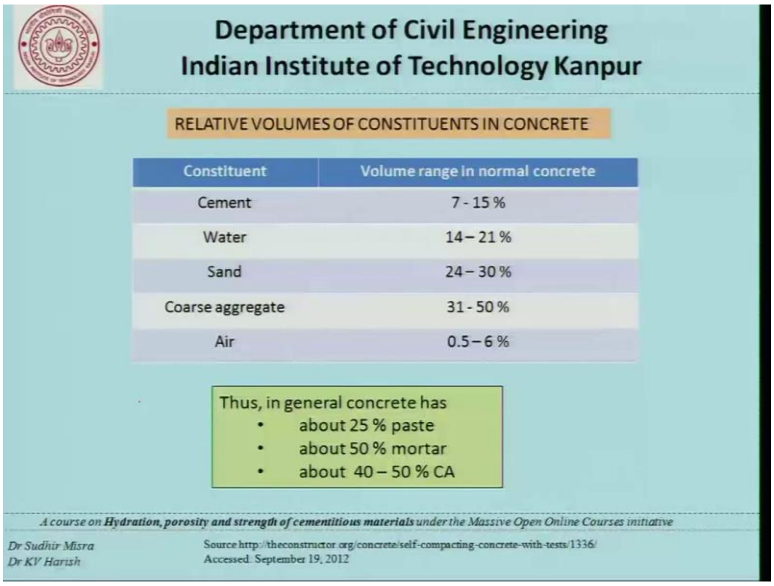

This is just a reiteration of the pervious figure cement by volume ranges from 7 to 15 percent water about 14 to 21 sand is about 24 to 30 coarse aggregate is 31 to 50 and air varies from about half a percent to 6 percent and concrete generally has above 25 percent of paste 50 percent of mortar and about 40 to 50 percent of coarse aggregate.

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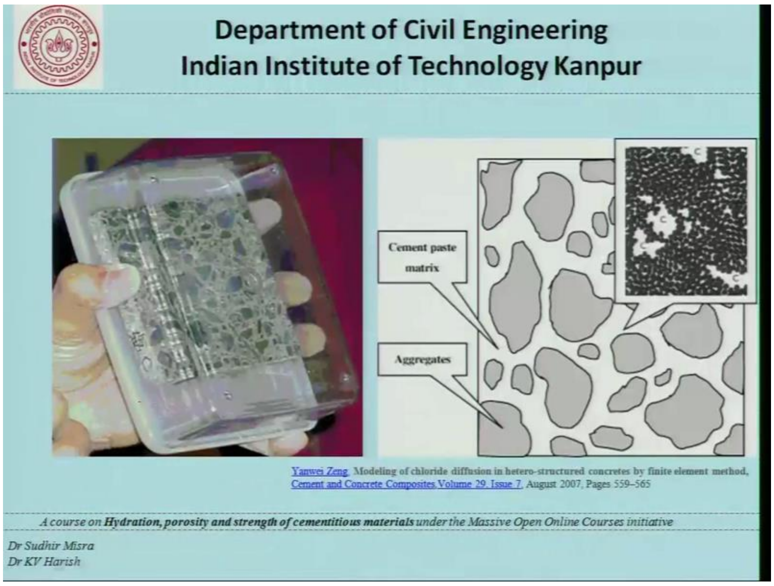

Now, this is the concrete that we deal with this is a slice of hardened concrete and it can be seen that is made up of coarse aggregate with this a slice of hardened concrete which is modeled as aggregates whether they are fine or course suspended in a cement matrix which has hardened cement paste the solids and some voids within the pate.

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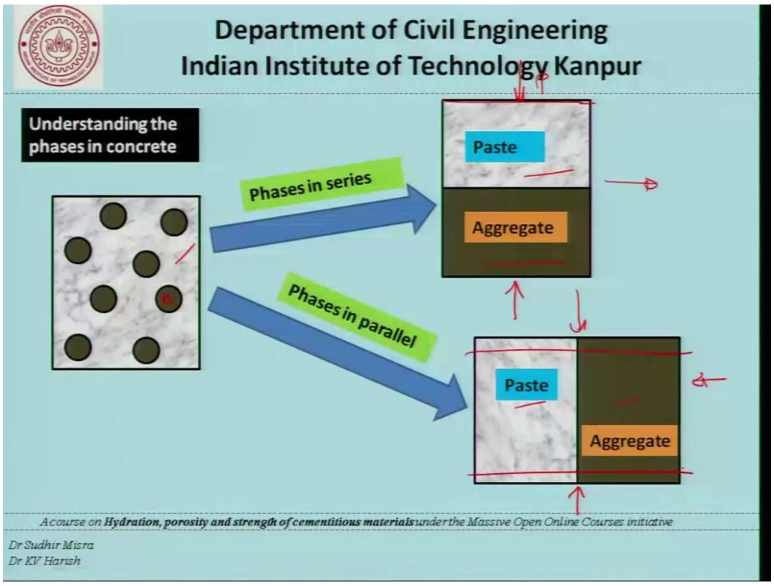

Now, from this slide we get into models were we say that if there are aggregates suspended in paste they can be placed like this that is these are the aggregates and this is the paste. So, the aggregates are all here the paste is here and this is the phases are series and similarly we can talk in terms of a situation where the aggregate phase and the paste phase is placed in parallel now the series and parallel comes from the fact that if we apply a load like this in these cases this is what is the parallel part of it and this is the series.

So, as the load transfer mechanism is different in this case since the force is being applied on a certain area the stresses in the 2 phases will be the same the strains or the deformation will be different whereas, in this case the deformation in the 2 phases will be the same and the stresses they carry or the forces they carry will be different. So, this is the difference between the series and parallel configurations as far as concretes are concerned and; obviously, in real life concrete neither the aggregates are in series nor they are in parallel what some kind of a combination.

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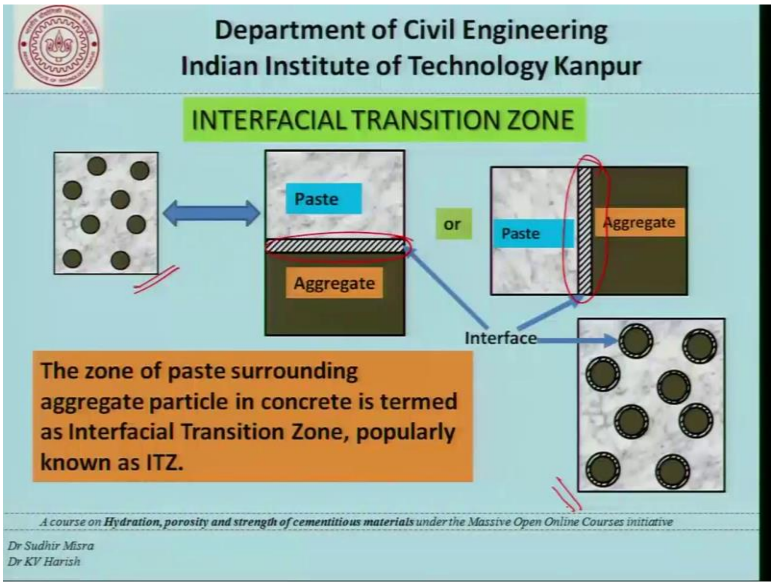

So, what we need to understand and appreciate is that a model of concrete or our understanding of concrete has to be that yes it is a material which is a composite where one phase and the other phase are different and at the end they also have an interface this interface is the. So, called ITZ and this is how the interface appears in the 2 configurations that we saw. So, this is a zone surrounding the aggregate particles in concrete and is commonly referred to as the i t z which in a diagrammatic form the way we have represented this picture here will become something like this.

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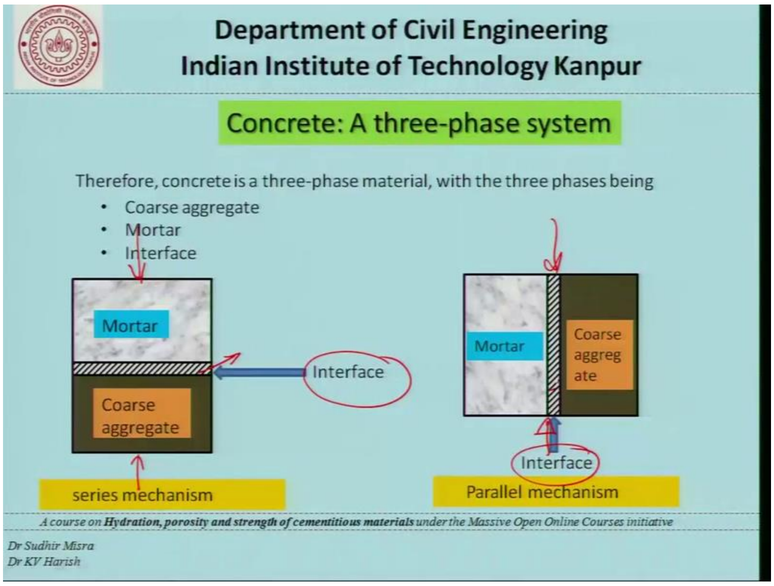

Now, if you look at concrete as A 3 phase system we have the coarse aggregate the mortar and the interface we can also look at it as aggregate cement paste and the interface now when the 2 phases which is the mortar in the coarse aggregate of paste and the aggregate they are held in series and when they are held in parallel the importance of this interface is; obviously, different. So, when the load is applied the weight is shown here versus the load is applied when it is shown here in this case the role of interface is quite different from the role of the interfere is here and that is something which we must keep in mind when we model our concrete or when we understand the bulk properties of concrete.

Now, how does this interfere form this interface is formed because of bleeding that is one of the reasons for forming this interface bleeding is the separation of water from the other constituents we must remember that as far as concrete concerned all the constituent materials sand coarse aggregate and cement they are all heavier then water and therefore, they tend to settle down and when they are fixed with water in other words water appears at the top and that is the bleeding that we talk about we have discussed this in our initial discussion and you may go back to the that discussion and understand the situation little better.

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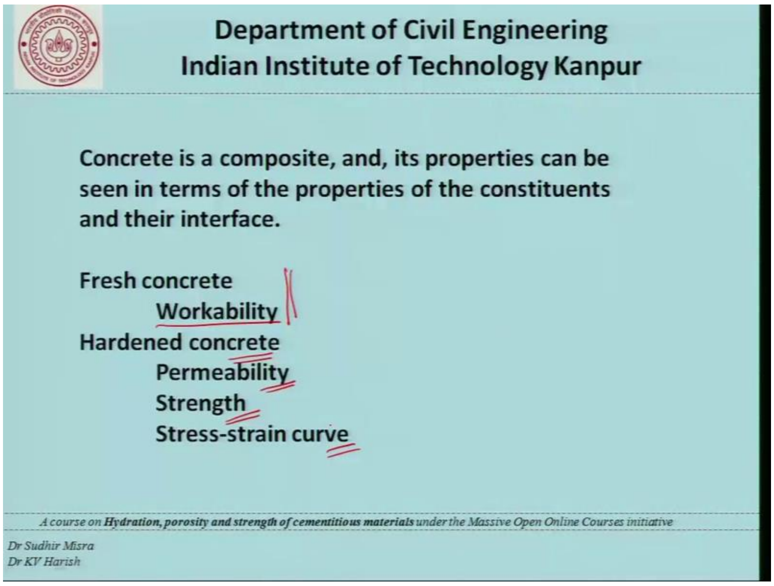

Now, having said all these finally, we have concrete as a composite and its properties can be seen in terms of the properties of the constituents and their interface. So, what will we looking at in the subsequent lectures is the properties of concrete that is workability in the fresher's state and in the hardened state we will be taking about permeability strength and the stress strain curve. So, this set of properties is what will be talking about building from our understanding of cement paste we have understood or we have worked about cement paste the hydration and the hydration products and so on. We will now graduate to understand the workability of concrete the permeability of concrete the strength and the stress strain curve of concrete from that understanding and the fact that the paste is an important part, but yet it is only about 25 percent as far as the volume is concerned.

So, when we talk about the bulk properties of concrete whether it is permeability or strength or it is a stress strain curve or the workability for that matter we will keep the properties of the ingredient. So, for example, when it comes to workability the properties coarse aggregate are also very important to keep in mind. So, we have already studied the properties of coarse aggregates and it is now only a matter of applying that understanding to the properties of concrete.

So, now this is over work plan for the next few lectures now before we move on to that I would like to take time today to talk a little bit also about the classification of cements here.

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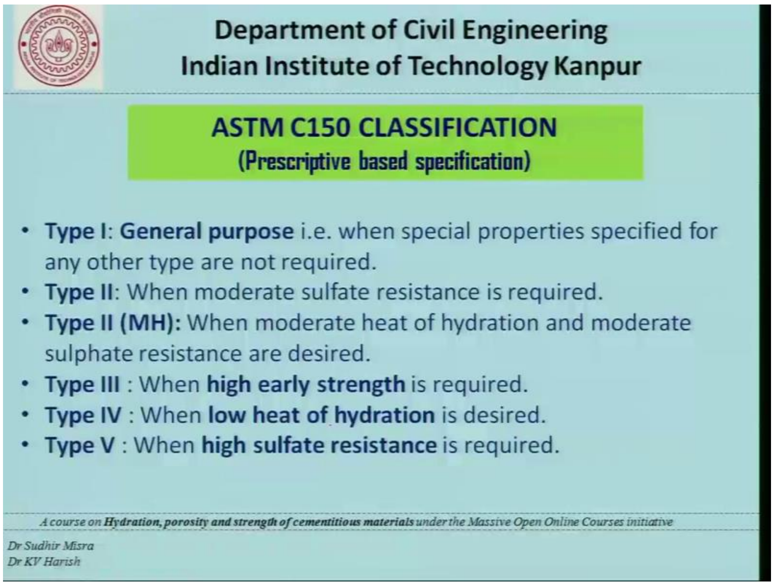

We show the ASTM C150 classification of cements which is prescriptive based specification and we can see that cements have been divided into 6 types of cement type

1, type 2 MH, type 3 and type 4 and type 5 whereas type 1 is a general purpose cement which is used when special properties specified for any other type are not required type 2 cements are moderate sulfate resisting cements type 2 m h are those which are moderate heat of hydration and moderate sulfate resistance cements type 3 are high early strength cements type 4 are low heat of hydration cements and type 5 are high sulfate resistance cements.

Now, how are these cements different from each other that is one question and can there be another system for classification of cements is the other question.

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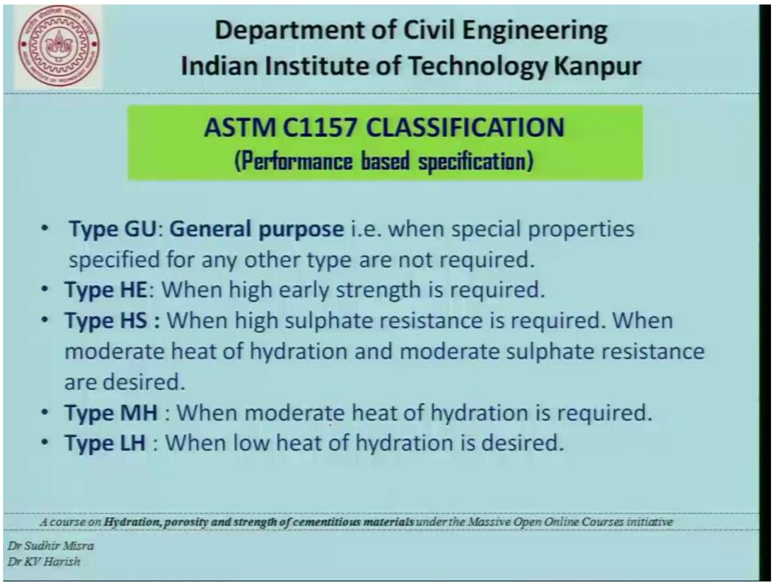

Now, taking up the second question first ASTM C1157 classifies cements based on performance and that is type GU, type HE, HS, MH and LH with the description which is given here. So, the general purpose cement is when no special properties are required HE is high early strength cement, HS is high sulfate resistance cement, MH is moderate heat of hydration and LH is the low heat of hydration.

So, now what are the properties of cement that need to be borne in mind when we are trying to classify the cements if we look at this table here?

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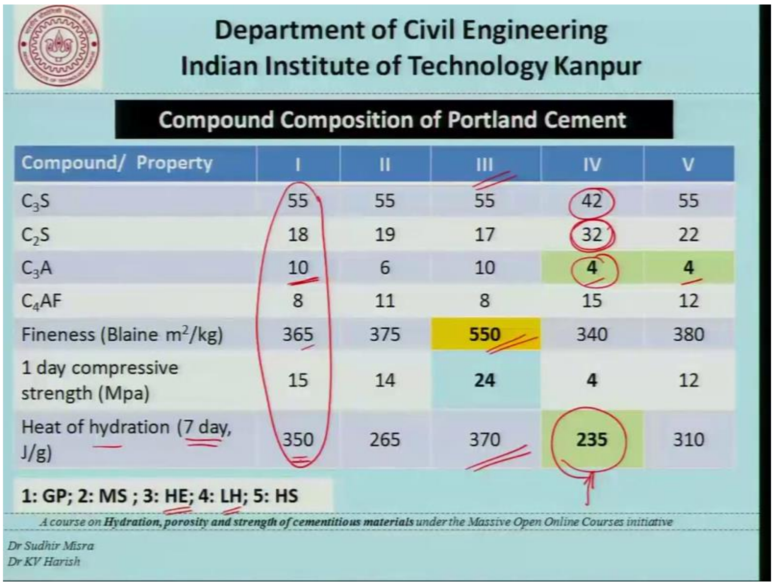

Compound/ Property	I	II	III	IV	V
C_3S	55	55	55	42	55
C_2S	18	19	17	32	22
C_3A	10	6	10	4	4
C_4AF	8	11	8	15	12
Fineness (Blaine m^2/kg)	365	375	550	340	380
1 day compressive strength (Mpa)	15	14	24	4	12
Heat of hydration (7 day, J/g)	350	265	370	235	310

For example there is a compound composition and physical properties of cement for the different types. So, type 1, 2, 3, 4 and 5 if you look at this table. So, we use type 1 cement which is the general purpose cement as the basis for discussion. So, now, if we look at for example, type 3 cement which is the high early strength cement there is virtually no difference between C3S, C2S, C3A and the C4AF content, but the Blaine fineness is 550 square meters per kg whereas, in the other cases it is about 365, 375, 340 and 380.

So, basically what has been done is that it is nothing, but type one cement or general purpose cement which is ground much finer. So, increasing the fineness of cement makes more surface area available for hydration and therefore, has high early strength development. So, as far as specifications are concerned we can say that well unless the cement has certain fineness it will not be classified or it will not be called a high early strength cement. So, fineness is a parameter which we use in this case we must also see that as we increase the fineness the heat of hydration is also increased. So, these are the kind of things that we would like to keep in mind similarly if you look at type 4 and type 5 the C3A content is lower than what we have here in type 1.

Similarly, when it comes to the heat of hydration in the case of type 4 which the low heat of hydration cement we are talking of 235 now how this 235 is achieved is by reducing the C3S and the C3A and increasing the C2S content. So, it is the early stage of hydration we want to control the amount of heat that is liberated and that is why we have specifications on the 7 days heat of hydration in terms of joules per gram as 235 which is the lowest among all of them and is fair much lower compared to the type 1 cement.

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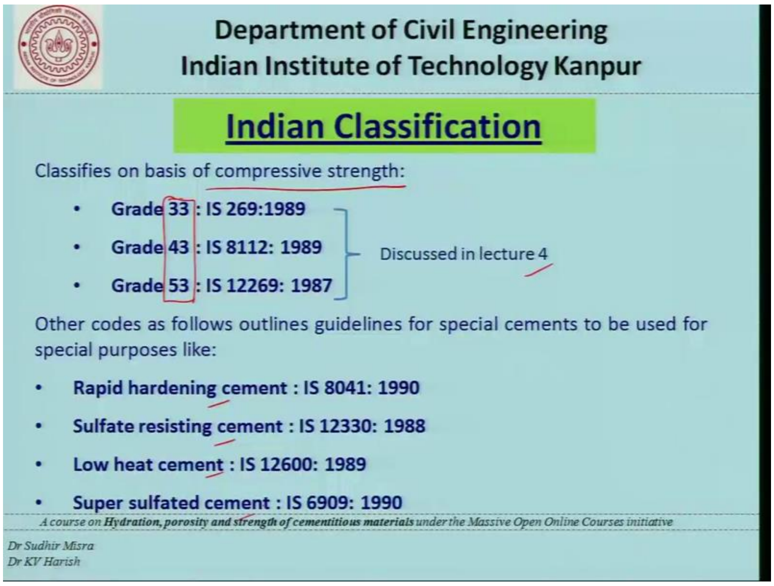

So, this slide here is basically an illustrative example to have you think about the different classifications and also the properties of cement coming to the Indian standards from the same point of view.

One basis for classifying the cement in India is compressive strength and in the 4th lecture, we have talked about grade 33, 43 and 53 cements and other than that we also have rapid hardening cement or the sulfate resisting cement the low heat cement and the super sulfated cement.

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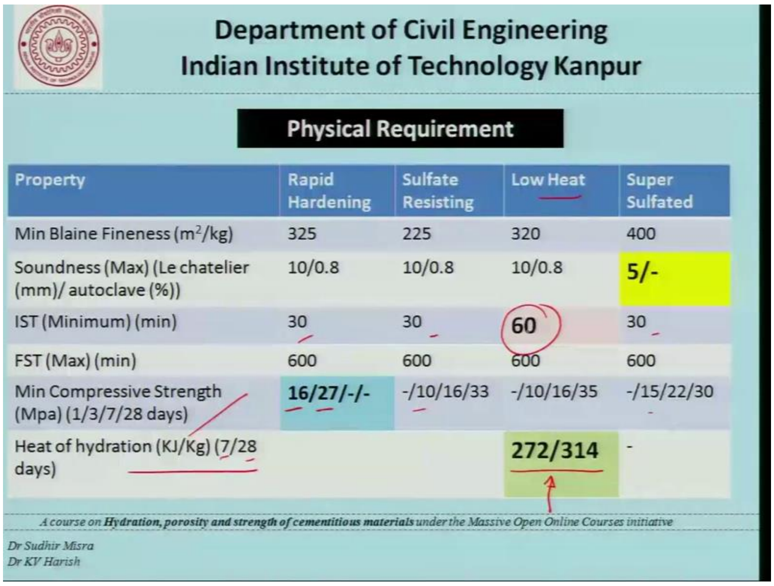

Property	Rapid Hardening	Sulfate Resisting	Low Heat	Super Sulfated
Min Blaine Fineness (m^2/kg)	325	225	320	400
Soundness (Max) (Le chatelier (mm)/ autoclave (%))	10/0.8	10/0.8	10/0.8	5/-
IST (Minimum) (min)	30	30	60	30
FST (Max) (min)	600	600	600	600
Min Compressive Strength (Mpa) (1/3/7/28 days)	16/27/-/-	-/10/16/33	-/10/16/35	-/15/22/30
Heat of hydration (KJ/Kg) (7/28 days)			272/314	-

Now, if you look at these cements here we have a similar comparative statement or a table which compares the physical requirements for the rapid hardening of the sulfate resisting or the super sulfated at the low heat cements.

So, now here if you look at our numbers when it comes to low heat cement we are talking of 272 or 314 kilo calories per kg of the heat of hydration at 7 and 28 days, it is only in this case in India that a certain number has been laid down. Similarly for the minimum compressive strength for the rapid hardening cements the number is much higher compared to the others I would also like to draw your attention to the fact that in the case of low heat cement the initial setting time requirement is not 30 as it is in the other cases.

But it is 60 which means that we expect the low heat cement we are prepared for the fact the low heat cements will hydrate more slowly to begin with. So, what we have done today is to prepare the groundwork to transit from the properties of cement paste and discussion of hydration reactions and so on to the properties of concrete in terms of strength durability permeability the stress strain curve and so on. We also spend some time trying to put the classification of cements together in light of the properties of cement that we are familiar with.

Thank you.