Basic construction materials
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Lecture 26
Cement and Concrete 1 - Part 3

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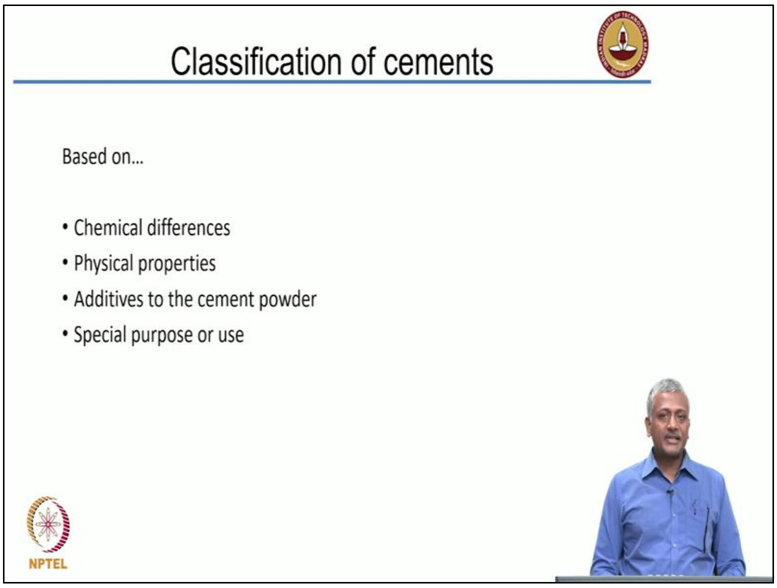

Let us look at how cement can be classified; they sometimes are used in different applications. I already told you the example of using cement in a column in a high raised building versus using the same cement in a dam. We need different characteristics for the applications. Because of that, we sometimes have to define cement of different types which can be employed for specific applications.

So cement can be classified based on differences in the chemical composition differences in physical properties; for example, some cement is much finer than the others. Differences in terms of sometimes putting extra additives into the cement powder or sometimes we may have very special purpose cement are not used for general-purpose construction. So let us give examples of different types of cement here.

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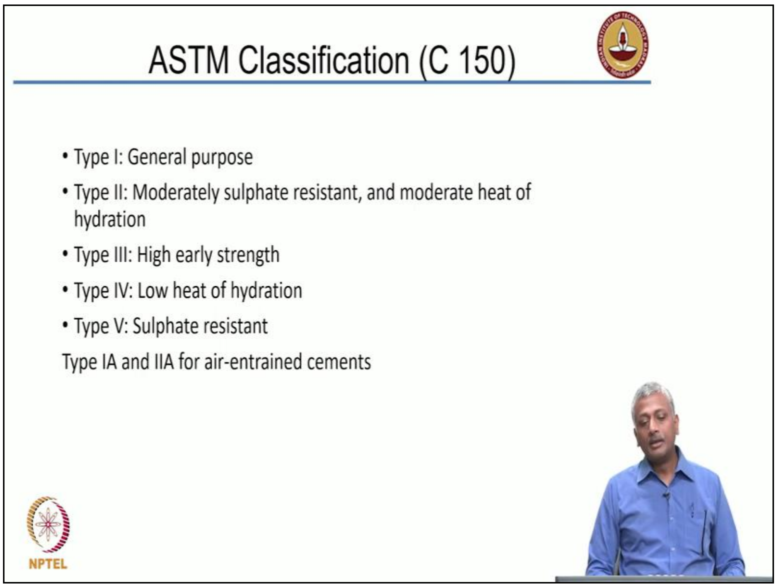

We are going with this universally applied classification called ASTM or American Society For Testing and Materials ASTM. It brings out standards and all kinds of materials and processes and test methods and so on. So the ASTM classification for cement is included in ASTM C 150.

According to this, cement is classified as general-purpose type I cements, Moderately sulphate resistant and moderate heat of hydration type II cement high early strength cement which is type III cement, low heat of hydration cement that is type IV cement and sulphate resistant cement is type V cement. And sometimes we add what is called an air-entraining agent to type I and type II cement to call it type Ia and type IIa. I will not confuse you with all these cements but let me just give you a basic understanding of the differential components present in these cement.

So, of course, type I is a general-purpose cement that is available for use everywhere. We can take this sort of formulation and make adjustments to get the other type of cement. So let us take two examples; the first one, a high early strength. So what are the ways in which we can increase the early strength of the cement? We already talked about two possible ways one is increasing the C_3S content.

As we already discussed that C_3S is responsible for early strength; the more the C_3S is, the greater will be the early strength. So, where do we need higher strength in cement? Suppose we want to build something very quickly, we can use highly strength cement. Supposing we want to build in a cold weather where it may start freezing the water in the concrete because of the external temperature, we want high early strength cement to gain strength much faster. So that it does not start freezing, so in such applications, we want high early strength cement. So increasing C_3S will lead to higher strength; we could also increase the fineness of the cement to increase the fineness grind it much finer that will make it more reactive, and increase the rate of strength gain. So, increase C_3S, increase fineness to get high early strength cement.

What about low heat of hydration cement? We talked about the different cementitious compounds, and the one that had low heat of hydration was C_2S. So C_2S has a low heat of hydration, so in a low heat of hydration cement, we will have more C_2S than general-purpose cement. Just so this is how we look at producing different characteristics from the same set of compounds.

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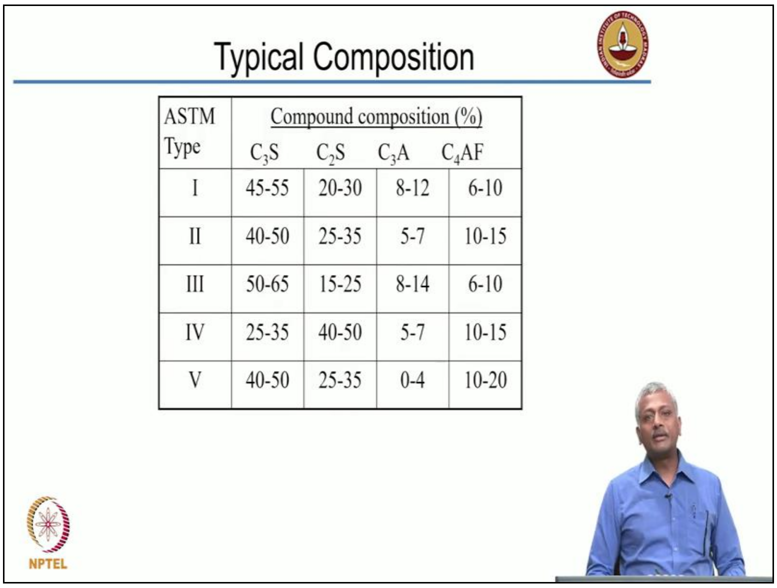

ASTM Type	Compound composition (%)			
	C_3S	C_2S	C_3A	C_4AF
I	45-55	20-30	8-12	6-10
II	40-50	25-35	5-7	10-15
III	50-65	15-25	8-14	6-10
IV	25-35	40-50	5-7	10-15
V	40-50	25-35	0-4	10-20

So this is overall the typical composition that ASTM gives for the five different types of cement. So as we discussed, I compared high early strength cement type III with the general purpose cement type I, so instead of 45-55 C_3S, we have 50-65 in type III, so we have more C_3S. **We may also want to increase our C_3A, because that is also responsible for early strengthening**.

What about type IV? We saw that our C_2S was 20-30 in type I, but in type IV, that is low heat cement; we have 40-50 C_2S. Moreover, we reduce the components that produce high heat, like C_3S or C_3A. So all these characteristics we need to keep in mind while thinking about how alternative or different types of cement are designed.

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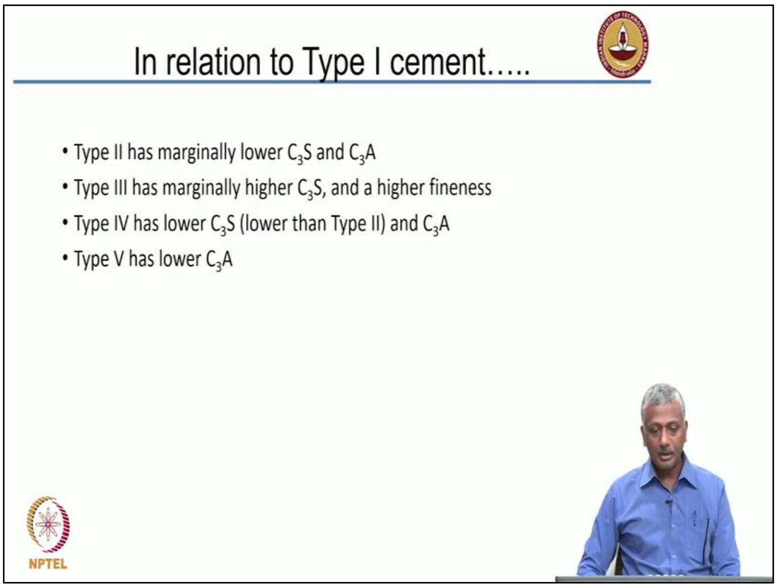

So in relation to type I cement that is general purpose cement, type II will have marginally lower C_3S, and C_3A type III will have marginally higher C_3S and a higher fineness. Type IV will have a lower C_3S and also lower C_3A content and generally much higher C_2S content. Type V will have a lower C_3A content; that is what we see in this table regarding the quantities of the compounds present in different types of cement.

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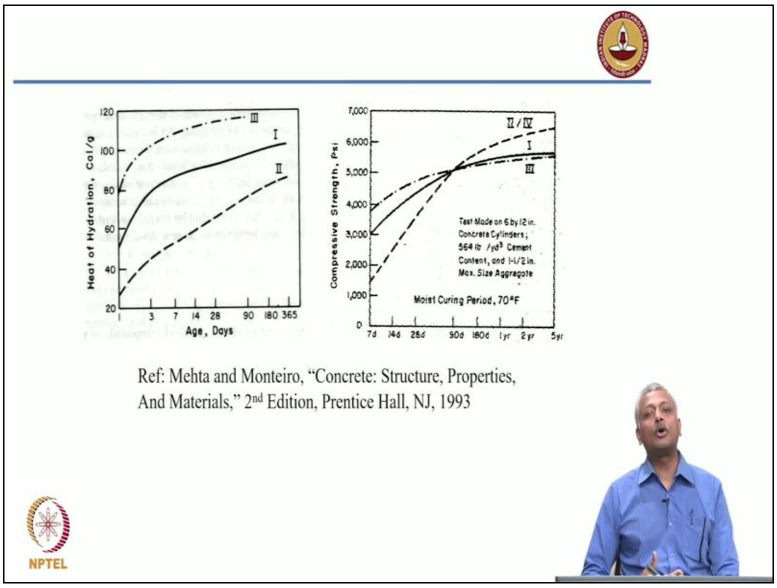

These are just examples of how these cements affect concrete properties from a textbook by Mehta and Montero. So we see here what is plotted on the y axis is the heat of hydration that means how much heat is getting evolved in the calories per gram versus age. So the type I cement or general purpose cement is here. So it evolves heat quite rapidly in the beginning, and then the rate of heat evolution slows down later and stabilizes. Type III cement is the high early strength cement that liberates a lot of heat initially and slows down, which means it is reacting much faster. Type II; cement which is lower heat of hydration compared to type I, starts slowly and then continues to go as long as hydration happens.

So please remember that as long as cement is reacting with water, heat will continue to get liberated, but since the bulk of the cement is already reacted at later ages, the rate of heat evolution will come down. With respect to strength development, if this is a type I cement, it starts rapidly initially, but then it slows down towards the end. If we compare type III cement which is high early strength cement in the initial stages, we have much more rapid strength development. However, then, in the long term, we may end up lower than type I cement.

If we look at type II or type IV, cement which is low heat, they will start very slow, but they will continue to gain strength and may **even overtake type I cement**. So, in other words, if we allow the cement to react with water in the long term continuously, it may produce a more robust structure than our general purpose cement with type I.

However, please remember that all this depends on a continuous supply of water to the cement. If water stops and cement does not have access to water, its reaction also will stop. So whatever water is inside the concrete, as long as it is available for reaction, the reaction will continue, and the cement will continue to hydrate. However, if there is no water reaction will stop.

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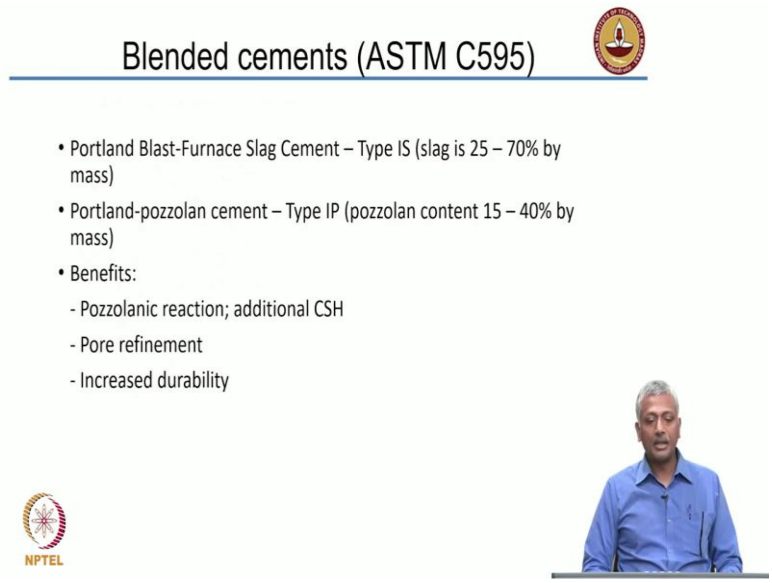

In some cases, we blend certain components to enhance the cement's properties or lower the cost. So there are different types of blended cements that are permissible as per the ASTM standards. One is called Portland blast furnace slag cement called type Is, and the slag is nearly 25 to 70% by mass in the cement. Now, what is this blast furnace slag?

We must have learned about the blast furnace process in the manufacture of steel in our school; we may have some lessons in which we say that the iron ore is put in this blast furnace along with limestone and carbon or coke. Limestone is used as a flux. It lowers the temperature at which our reduction of the iron ore happens to form iron now; what happens is this limestone has calcium oxide in it, and our iron ore will have many impurities in the form of silica-alumina and some additional iron oxide that is present.

So what will happen is this slag which comes out as an impurity from the blast furnace process, ends up having a nice composition of calcium oxide, silicon dioxide, and aluminum oxide, and sometimes even iron oxide. So it is almost similar to cement; the molten slag that comes out is floating on top of the pig iron in the blast furnace process can be used as a cementic material.

So it is rapidly cooled or quenched, solidified, broken into a powder and then used as a cement replacement. So this is what used in a Portland blast furnace slag cement called type Is cement, and slag content is typically 25 to 70 % by mass. We can also have a Portland pozzolanic cement, in which case we use a smaller replacement of 15 to 40% of the cement by a pozzolana.

A pozzolana is nothing but **reactive silica**. So this combines with the **calcium hydroxide** that forms from the reaction of cement hydration to produce more CSH; that is what the pozzolana does. It combines with the calcium oxide to produce more CSH, which is called the pozzolanic reaction. And as we discussed, as we form more and more solid products, it will start filling up porosity.

So the pores will get more refined; as a result, our concrete will be more durable. So when we replace our Portland cement with blended cement, we end up with more durable concrete; please remember that. When we increase the durability when we change from OPC to other forms of cement.

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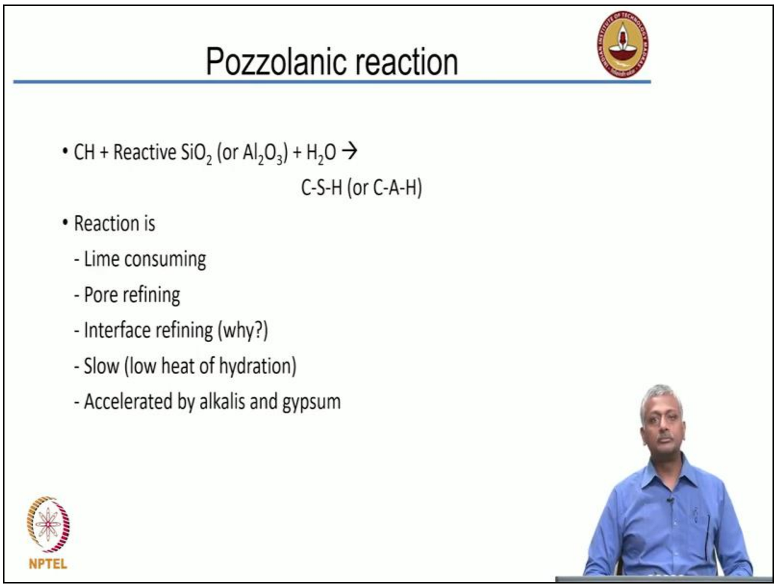

Again, the pozzolanic reaction is the reaction between calcium hydroxide that forms from cement hydration and reactive silica that we get from the pozzolanic material to produce additional calcium silicate hydrate. So what we are doing is we are consuming this lime, we are refining our porosity, and we are also refining the interfaces. So if we consider aggregates, the cement paste around the aggregate is getting a lot denser in the case of a pozzolanic reaction.

This reaction is slow, so basically, it leads to an overall reduction in the heat of hydration. So when cement is replaced by fly ash or slag, the heat of hydration reduces. So what happens is instead of using a low heat cement for certain applications like a dam, for instance, We can still use a general purpose cement type one cement but replace it partly with fly ash or slag that will bring down the extent of heat. This reaction is much slower than the reaction of cement hydration.

However, one way in which it gets accelerated is by the presence of alkalis and gypsum. Interestingly both alkalis and gypsum are contributed from cement. We saw earlier in the cement composition that there are oxides like alkali oxides sodium and potassium oxide and, we add gypsum in the final stages of cement manufacture. So, all these components are still present to accelerate the reaction of the pozzolanic material.

Nevertheless, the pozzolanic reaction is much slower than cement, which leads to a much better durability in the long term and reduces the heat of hydration in the early stages.

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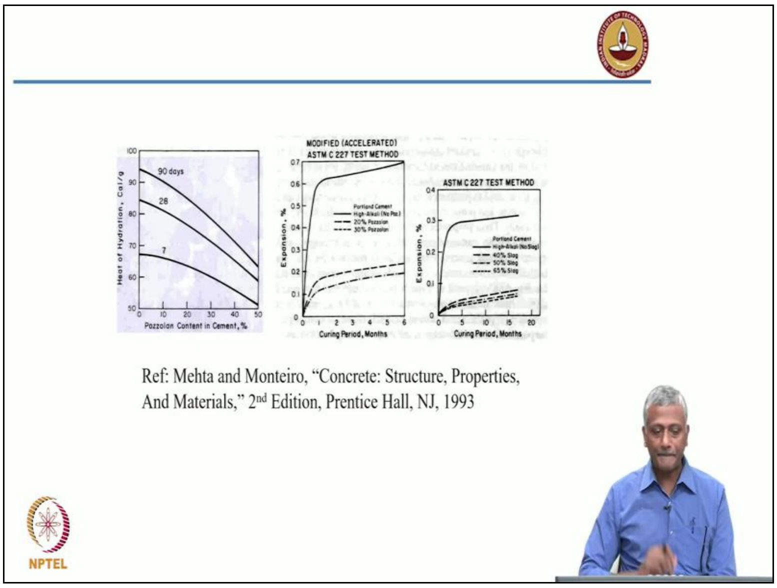

Again, this shows us the heat of hydration in calories per gram with respect to the pozzolanic content in the cement at seven days; it is coming down a little bit at 90 days the extent of reduction of the heat of hydration is significant. In some instances where we have problems of undue expansions of the concrete, pozzolanic materials bring down the expansion and reduce the tendency for cracking.

So overall today, increasingly, we have to prepare concrete with cementitious additives which are pozzolanic to ensure that we produce concrete of a much better long-term durability.

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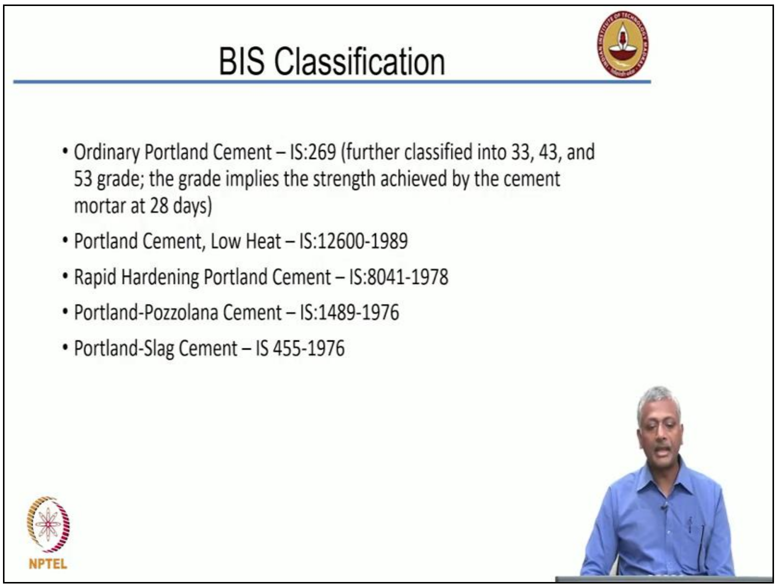

If we look at the Indian standard classifications covered essentially in this **IS 269** for ordinary Portland cement. So if we look at ordinary potent cement in India, we define it into three grades 33, 43, and 53 grade and the grade of the cement corresponds to the strength achieved by the cement mortar at 28 days. So as I said earlier, this compressive strength of cement is determined on the mortar. So, the grade of 33, 43, and 53 refers to the strength attained by the cement mortar, which is as per a particular formulation.

We should also know that the tests for cement are covered in is **IS 4031** and **IS 4032**. One is related to physical properties involving specific gravity, fineness, compressive strength, etcetera. The other is chemical properties, how to determine the oxide compositions, and so on. So 33, 43, and 53 grades refer to the strength in Mega Pascal. The grade implies the strength in mega Pascal achieved by the cement mortar at 28 days.

Now, this 28 is quite funny because we will see this coming later in concrete design also. We always design for what is the 28-day strength. Now 28 days is taken as the definition of the characteristic time for the strength of the concrete. When we design concrete of a particular strength for a construction project, we will also prepare some cubes and measure the strength at 28 days on those cubes to ascertain whether the concrete in the structure has met the demands of what is required.

So these 28 days is a very sacred number. So a couple of questions for us to understand why we consider 28 days strength? It is because most of the cement that is likely to hydrate would complete its hydration within 28 days for a general-purpose cement when we are dealing with type I cement or general-purpose cement. If we think about low heat cement, 28 days is probably not enough to think about; we may have to think about a much longer time period, to increase the time over which the reaction happens with water.
So very often, in construction sites, we are interested in finding out the 28-day strength. When we design concrete in the laboratory, we talk about 28-day strength very often; we also look at early age trends at seven days and three days depending upon our requirements. However, here if we look at the grades of cement, they would have specified strengths at three days, seven days, and 28 days.

The cement which is tested per that standard has to meet strength requirements at three days, seven days, and 28 days. Now, of course, similar to ASTM standards, Indian Standards also describe low heat cement, rapid hardening, or high early strength cement. It also calls

Portland pozzolanic cement or PPC or Portland slag cement, otherwise known as PSC. In India, when we go to the market, we will talk about OPC, PPC, and PSC.

OPC itself mostly what we will get in the market will be 43 grade or 53 grade these days we do not get the lower grade cement in the market, we only get 43 or 53 grade cement in the market. **There are no grades defined for PPC and PSC**. We will only get one type of PPC or PSC. Of course, we get many different cement brands in India; there is no dearth of brands. There are so many different cement manufacturers that we get all kinds of brands of cement.

So how do we make sure the cement is suitable for construction again? Take the cement, do the analysis determine the chemical composition, do the physical properties, do those basic tests that we talked about previously, and ensure that everything matches the requirements given in these standards. Whatever cement we buy in the market, it is fit to concrete as long as it meets these standards.

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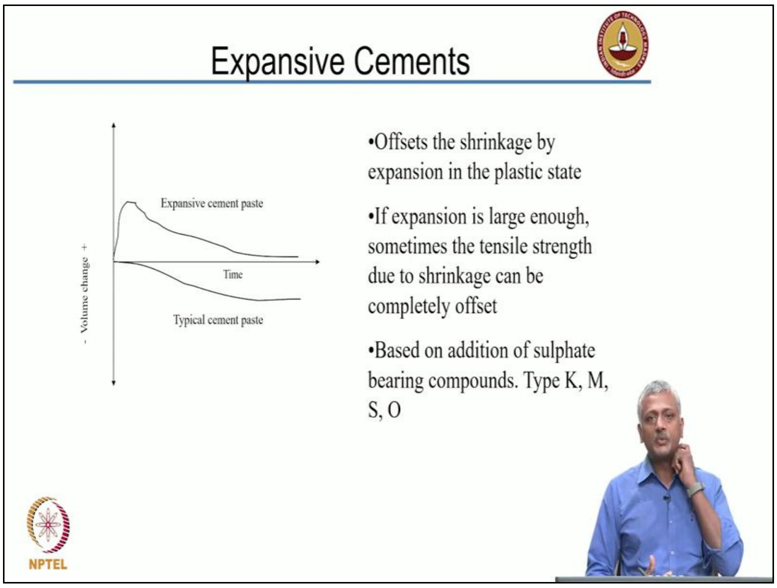

Now there is certain cement that does not belong to the same category that we just talked about from the basic composition of the four different compounds we have. These are cements that are produced in a slightly different manner. So, one such cement is called expansive cement. One of the common problems with concrete is its tendency to shrink we mix cement with water some water goes into the reaction with cement; some water is free.

And slowly, this free water will start drying out of the concrete. In other words, because of the removal of water from the concrete, the cement structure will change, and there will be a slow reduction in the volume or contraction of the volume, which we otherwise call shrinkage of the concrete. We call that shrinkage. **If the shrinkage happens freely, there is no stress generated in the concrete**.

However, if the **shrinkage is prevented** from happening, it starts forming cracks in the concrete. So we want to avoid excessive shrinkage so that concrete does not crack. So in such cases, we use these special cement called expansive cement. In a usual case, a typical cement paste would shrink with respect to time, whereas an expansive paste will first expand when it is hydrating, and then it will slowly shrink, just like normal cement paste.

However, what is happening, as a result, our net shrinkage is being brought down significantly. The net shrinkage is being reduced significantly, which means the stresses caused by shrinkage will be reduced in an expansive cement paste. For several applications, we use expansive cement to produce a net zero shrinkage or sometimes even a net expansion in the concrete.

These are produced by adding special compounds to the cement; they are not regular cement, but they are produced specially. Not all cement plants will produce all types of cement or all special purpose cements; only some cement plants will produce all these special cements.

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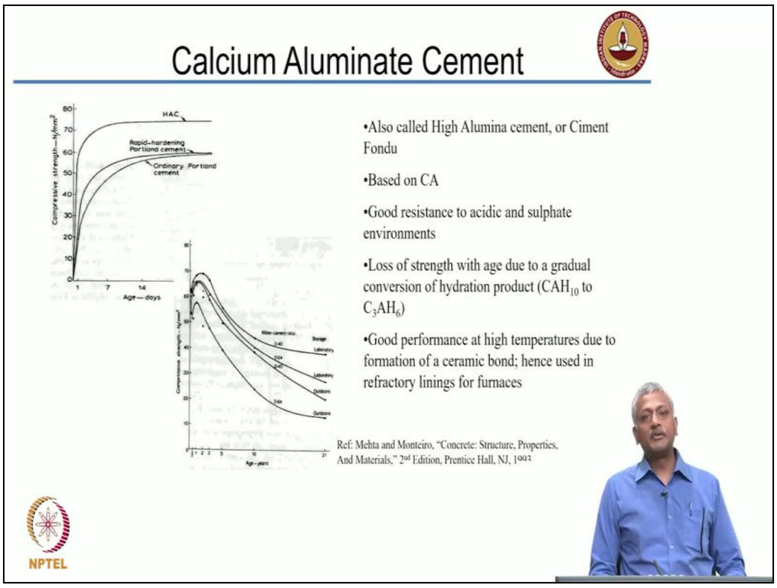

There is also a cement called calcium Aluminate cement where the raw materials are not the calcium carbonate limestone and clay, but limestone and bauxite that is aluminum oxide. So these produce compounds that are rich in calcium oxide and aluminum oxide or calcium aluminate. These are calcium Aluminate cements also called high alumina cement.

This type of cement became very popular after the end of the Second World War, especially in Germany where they wanted to rebuild their infrastructure that had been wholly bombarded and destroyed because of the war. So they started building rapidly because **this cement gained strength very rapidly;** as we can see from this picture of strength versus age the high alumina cement gains strength much more rapidly than rapid hardening cement or OPC.

So we started developing a lot of structures with high alumina cement which gained strength rapidly. As this concrete made with the cement was exposed to the external environment with moderately high temperatures and humidity, the strength dropped over time. This happens because of an internal chemical compound composition that is changing as it is subjected to continuous exposure to temperature and humidity. And because of that, we have a problem using cement for normal construction; many of these structures built after the war had to be removed or destroyed because the concrete started reducing in strength. As a result, we had many failures in these structures. So this happens primarily because of the gradual conversion of the products of hydration. I am not going deep into the chemistry here**; the idea is to tell us that high aluminum cement is not good for general purpose construction**.

However, it is a very good concrete to use at very high temperatures, especially inside kilns; for instance, inside a kiln where the temperature is 1000 degrees and more, the high alumina cement forms a nice ceramic bond, and because of which we will get an excellent material that is resistant to heat.

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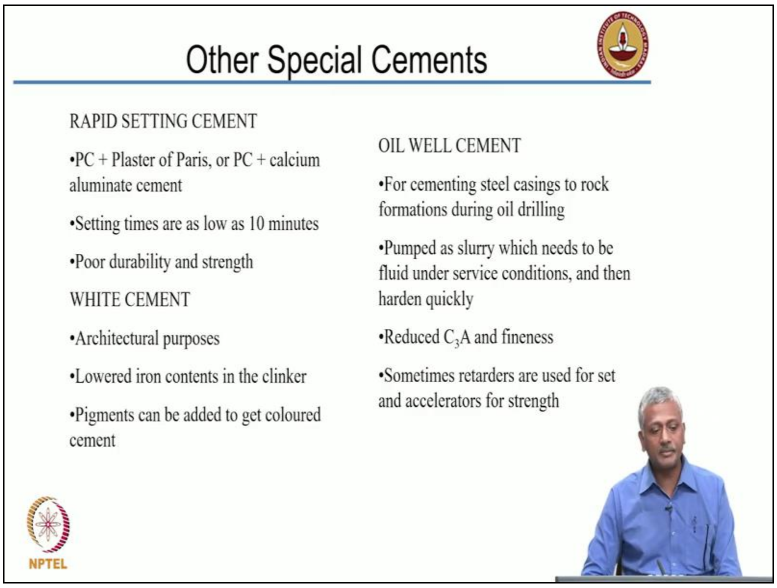

There are other special types of cement also which are used for very specific purposes like **rapid setting cement** is generally consisting of some amount of plaster of Paris which is calcium sulphate hemihydrate or sometimes it may have Portland cement plus calcium aluminum cement so that as soon as we mix with water within a short period of time let us say as low as 10 minutes, we get a rapid stiffening.

So, for example, we want to plug a hole in a water tank; for instance, we could use something like a **rapid setting cement; it is not rapid hardening cement**. We talked earlier about rapid hardening cement or high early strength cement; those cements were formulated to develop **strength at an early age, but they are not necessarily rapid setting;** they set normally but can get strength at an early age.

Here we are talking about **rapid setting**. Then we have white cement; we often see their ad on our televisions that we use white cement to make these putties. White cement is used for decorative purposes or for lining between the tiles; when we join the tiles, we often see it is filled with white cement paste because a gray will not appear very nice. So, white cement is used for very specific purposes.

So as the color is white, we can imagine that it has very little iron content; almost zero iron content is available or low iron content. Moreover, the advantage of white cement is that we can pigment it to make it any color. Then there are other special types of cement-like oil well cement, used for oil well drilling applications. So when we drill very long bores into the rock to extract oil to prevent the soil from collapsing, we need to line up the walls of the boar that we have dug with cement.

Moreover, the cement should be such that it can flow very long distances after mixing, but at the same time, when it comes to rest, it should be forming that layer on the soil surface so that the soil does not cave in. So it is a very uniquely formulated cement, and it needs to have a combination of different types of additives to ensure that it is flowable for a long time. However, when it comes to rest, it sets and hardens almost immediately. So again, this is something that needs to be formulated very carefully.

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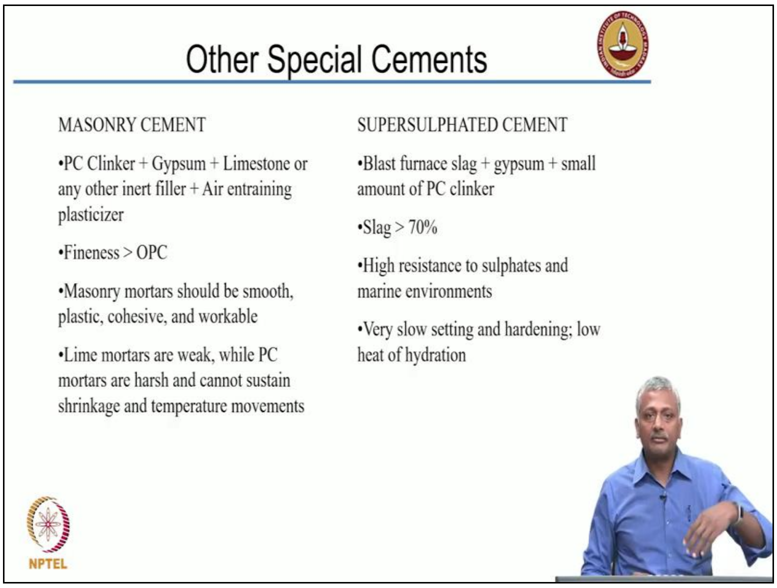

Sometimes we may also, in some markets, have special purpose cement for masonry applications where we do not want to use lime; we do not want to use ordinary cement because it produces very high heats of hydration and can cause cracking of our plaster, for instance; We can use what is called masonry cement. This is a mixture of cement, gypsum, limestone, or sometimes other fillers and some air entraining agents, which causes a very nice consistency and ease of application instead of regular cement. Of course, it does not have as good strength as our regular Portland cement, but at the same time, it is much better suited for applications for masonry purposes.

Another special cement is called super sulphated cement, which is based on blast furnace slag as we have a large quantity of blast furnace slag and do not have much cement clinker in the composition.

And it is used for **good resistance to chemical attacks** which are otherwise quite dangerous for regular Portland cement-like. In the long term, the problem is that we have a slow reduction in strength, which is why super sulphated cements are not typically used for general purpose construction; in fact, they are not manufactured also to a large extent around the world.

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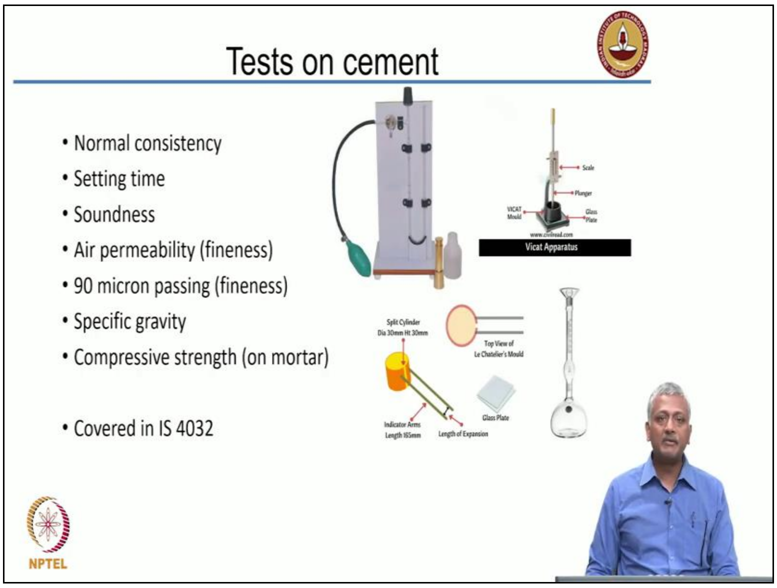

I was talking previously about tests and cement. I am just showing the same here the normal consistency and the setting time are done with the Vicat apparatus, shown here. So we have a mould into which we mix our cement paste and put it inside; then we have a plunger of one centimeter, which is made to rest on the top of the cement paste and then dropped, and this plunger plunges into the cement paste.

And when it is at a certain distance from the bottom, if it stops, it is called normal consistency that one-centimeter plunge is used for determining the normal consistency. The normal consistency is nothing but the water content at the point at which the plunger comes to rest about 5 millimeters above the bottom of this mould. Now the initial setting for the initial setting, we use a 1-millimeter needle.

We use a penetrating needle that is 1 millimeter in diameter. For consistency, we use a plunger of one centimeter. For the setting time, we use one millimeter. And this one millimetre needle penetrates the cement paste up to a distance of five to 7 millimeters from the bottom that is called the initial set, and the point at which it does not penetrate the top is called the final set.

The soundness is measured typically with the help of this Le Chatelier's mould. So the freshly mixed cement paste is packed into this mould, and we can put it in a special chamber where it is subjected to temperature and pressure to accelerate the reaction. At the end of one day, we see how much expansion or how much opening of this mould has happened. So that is called soundness.

Fineness is measured in terms of the air permeability test. So this is the air permeability instrument which is also called the Blane apparatus. So here, what we do is pack the cement. Cement is packed into a bed here, and what we are simply trying to apply pressure we are trying to make air pass through the cement bed. So if the cement is very fine, what will happen is the gaps between it will be small.

So the velocity of air passing through the cement bed will be much lower. It will be passing very slowly. If the cement is coarse, that means not fine it will have large gaps in it, so the air will pass much faster. So based upon the speed of flow of air, which is determined with this U tube or a manometer, we can then determine the relative fineness, so we need to have the fineness of a standard material like a standard cement known.

Moreover, this standard summit is available from the national cement-based materials, the center for national cementitious-based materials. Then we have the test for specific gravity; sometimes finest is also exhibited in terms of the amount of material that passes through a 90-micron sieve. So take a sieve of 90 microns to put our cement through, and the amount of material passing 90-micron sieve or retained on 90 micron sieve can also be used as a measure of the fineness.

The specific gravity can be determined by a pycnometer method using this Le Chatelier flask; this is a straightforward test; all we are doing is putting our powder here and filling it up with a liquid-like oil or kerosene up to a certain point. And then we do the same test without the powder and fill it up, and then by measurement of masses, we can then determine, or measure the mass of the material added we could then determine the specific gravity.

Then we have compressive strength as I said on mortar, so these tests are covered in IS 4032, whereas the chemical composition tests for cement are covered in IS 4031. Now it is very important that while this course is going on, we get access to the different Indian standards, whatever I have been mentioning in my lectures. We talked about brick and stone standard concrete block standards, then we are talking primarily about the types of cement standards for that and then testing of cement all these standards that will be good.

Suppose we go through these and then get ourselves familiar with the kind of approaches that are there in these standard test methods. So we will stop with this for today.