Basic construction materials
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Lecture 28
Cement and Concrete 2 - Part 2

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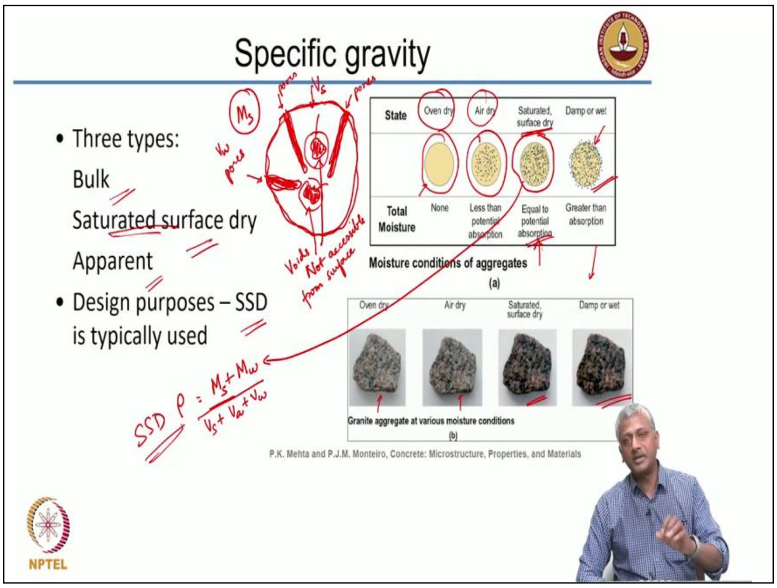

What about density or specific gravity of the aggregate? Now any construction material, whether it be aggregate, brick, stone, concrete, whatever you select most of them are porous materials. Because of this porosity, if I take a piece of aggregate and dip it in water, I can experience different types of moisture states within the material.

If you do not have any moisture, if you take this aggregate and put it inside the oven at 100 degrees Celsius, it drives away all the water from the aggregate. So there is no moisture, that is called oven dry state of the material.

Now if you take the aggregate which is lying on the roadside, that is basically the air dry state. So in that case what will happen is, there may be some moisture which is inside in the air dry state. There may be some moisture and you need to determine it by putting this aggregate inside the oven and finding out how much moisture it has. Especially after a rainy day, you can imagine that the moisture inside the aggregate may have increased significantly.

At a certain point the aggregate will have sufficient moisture inside to block all the porosity that is existing on the surface. Let me draw a slightly easier model to understand. So let us say that is an aggregate and let us say I am just drawing a few pores or voids inside the aggregate. That’s a solid aggregate and those are basically pores or voids that are connected to the surfaces, that are accessible from the surface. And these are voids or pores that are not accessible from surface.

Why is it important to classify the porosity or voids like this because when I wet this aggregate by putting it into water, these voids will never get filled up with water. These voids which are inside and which are inaccessible from the surface obviously will never get filled up with water. Whereas all the ones which have open porosity on the surface will get filled up with water.

So at a given state what may actually happen is all the pores that are exposed at the surface get filled up completely with water and that’s called a condition where the aggregate is saturated. But there is no water clinging to the surface of the aggregate. That’s why we call it saturated surface dry condition. So take an aggregate and put it inside water for let us say 24 hours. Then take it out, use a towel to wipe the moisture from the surface and then you get what is called a saturated surface dry aggregate.

But then when you have aggregates lying outside in the jobsite subjected to rain, you have moisture which is completely saturating the aggregate and also leaving behind a film of water on the surface. That’s called wet aggregate, where the moisture content is greater than the amount that can be absorbed by the aggregate.

So this is exactly equal to potential absorption level, aggregate absorption level and this is more moist than absorption level. When you mix this aggregate into concrete, what will happen is, you have excess water that is coming in because of the aggregate and as I said concrete is a mixture of cement, water, sand and stone. So if the stone and sand are bringing in excess water, then you need to remove some of the water from the mix ingredients that you have decided initially.

On the other hand, if the aggregate is dry like this, either air dry or oven dry, which has a lower moisture content than the limit that can be absorbed, what will happen is when you put this aggregate into concrete, it will start absorbing moisture from the water that you wanted to put in for the mix in the first place. So it’s absorbing moisture. That means you need to put excess water to compensate for this absorption. That is why in concrete mix design, finding out the moisture state of the aggregate is very important.

Now this is something that we do in the lab on a regular basis, but in the field, in the site where they are actually practicing concrete, this becomes one of the single most important aspects that governs the performance of the concrete. Why is that because most aggregates and sites are lying out in the open.

So what happens is, let’s say on a sunny day, aggregates from the external surface are completely dry. But before that sunny day, two days back, a lot of rain has happened. So, in a stockpile of aggregate like this, let us say you have a stockpile of aggregate sitting on the ground and all the surface aggregates are nice and dry. But all the interior aggregate is highly wet. So when you are taking this aggregate and loading it into the concrete mixer, if you take from the surface, you get all dry aggregate. If you take from the inside, you get all wet aggregate.

So what will happen is, in the same concrete mix that you are preparing in your plant, your aggregate moisture content may vary from batch to batch because of that you will get inconsistent performance of your concrete. It’s very important to control the aggregate moisture. So these states of moisture are also shown in this picture, I am not sure how clearly you can see it. This is an oven dry state, this is an air dry state, which has some moisture which is less than the absorption level. Here you can see it’s looking darker that means it is got more moisture in it, it is at the level of absorption and this here is a wet aggregate as it has got a lot of wetness on top.

For design purposes, typically we use the saturated surface dry weight of the material. So because of these different states of matter that the aggregate can exhibit, we have three types of specific gravities, bulk specific gravity, saturated surface dry specific gravity and apparent specific gravity. Now let’s understand what this actually means. Let me work through the same slide here.

Now I have this aggregate here, let's say the solid volume of the aggregate is Vs, that means Vs corresponds to only the solid volume of the aggregate without considering any porosity or voids. And let's say the solid mass of the aggregate is Ms, that means you completely dry the aggregate and measure the solid mass.

If you take the true specific gravity or true density, that should be equal to the solid mass divided by the solid volume. The problem is, we can never determine the true solid volume. Why because these voids that are there inside, which are inaccessible from the surface, you can never determine their volume accurately. So what will happen is, in most cases you will get solid volume plus the air volume that is filled inside these voids. That is, the total volume of air that's filled inside the voids. So that is why we don't call it true specific gravity or true density, we call it apparent density. The apparent density is equal to the dry mass or solid mass of the aggregate divided by the sum total of the volume of the solid and the volume of the inaccessible pores.

If you look at IS 2386, it will tell you how it is actually determined. But let's not go into that now. When you do the experiment in your lab, you will know exactly how it is done. But I wanted to explain to you the theory behind this. Now apparent specific gravity is this.

What about the bulk? The bulk basically considers the entire volume and this entire volume also has these pores that are accessible from the surface. Let's say the volume of those pores which are accessible from the surface is Vw, then the bulk density is equal to Ms divided by Vs + Va + Vw.

$$\text{Bulk density} = \frac{\text{Ms}}{\text{Vs} + \text{Va} + \text{Vw}}$$

Bulk density is the dry mass of the solid divided by the total volume of that rock which includes the volume of the solid volume of the air inside, which cannot be easily determined and the volume of the water.

Now what is saturated surface dry density? So, if you have to do SSD density, the denominator remains the same, that is, total volume. The numerator alone changes to wet mass, that means the mass of the saturated surface dry aggregate. So you take an aggregate, put it inside water for 24 hours, take it out, wipe the surface dry and measure the mass. That is your wet mass and your saturated surface dry density is equal to the wet mass, where moisture is just equal to the absorption divided by the total volume of the rock.

When you start using quantities of aggregates for calculation of your mix design and concrete, make sure you understand what density value is being calculated and what is being used.

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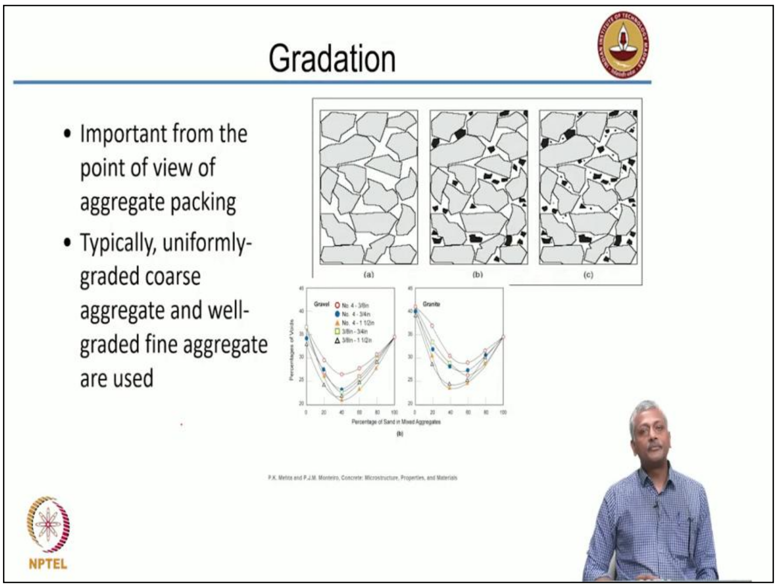

Now as I said earlier, the flakiness, elongation, the roughness, the angularity of the aggregate, all that determines the way that the aggregate packs together. But more importantly, the gradation of the aggregate also needs to be considered for efficient packing. Consider that you have a one cubic meter container and you want to fill it up with concrete. How will you fill it up optimally? You will fill it up optimally by choosing the particles and concrete in such a way that the particles are having a tight fit, leaving behind very less air inside the system or very less void inside the system.

Why? Because when the voids go up, the strength comes down. That’s basically the essence of considering packing of materials together. The higher the voids, the lower the strength. So you want to reduce the voids, as a result of which you get higher strength. So, to reduce the voids the best thing is to use materials inside concrete which follow a gradation that can fill up the gaps left behind by the higher particle sizes.

That’s what is being shown here. You have larger aggregates or coarser aggregates, which leave behind these voids here. Then you choose another size of aggregate that starts filling up these smaller voids and then you choose even smaller aggregates that start filling up the voids left behind still and so on and so forth. So as a result, you choose your gradation of materials or particle sizes in such a way that you maximize the filling of the volume. As a result you get a composite which has the least voids content.

Indeed if you look at this experiment here, the percentage of voids is plotted on the Y axis and the percentage of sand in mixed aggregate is plotted on X axis. They have taken coarse aggregate and sand and they are just mixing the coarse aggregate with sand and finding out that at 40% sand in the mixture, that means 40% sand 60% coarse aggregate, you get the lowest percentage of voids. This is quite easily done, some of you may actually be doing this in your laboratory exercises also.

Generally what happens is when you get the coarse aggregate, it is uniformly graded, that means it will have a narrow range of particle sizes. So coarse aggregates that we use in concrete are first 20 mm to 10 mm and the second size is typically 10 mm to 4.75 mm. Sand on the other hand or fine aggregate is well graded, that means it’s got particles in a large range. It goes all the way from 4.75 mm to 75 microns or 0.075 mm. So particle sizes are varying over a large range because of which they can satisfy this kind of a condition where they start filling up the voids in left behind by the previous set of aggregates.

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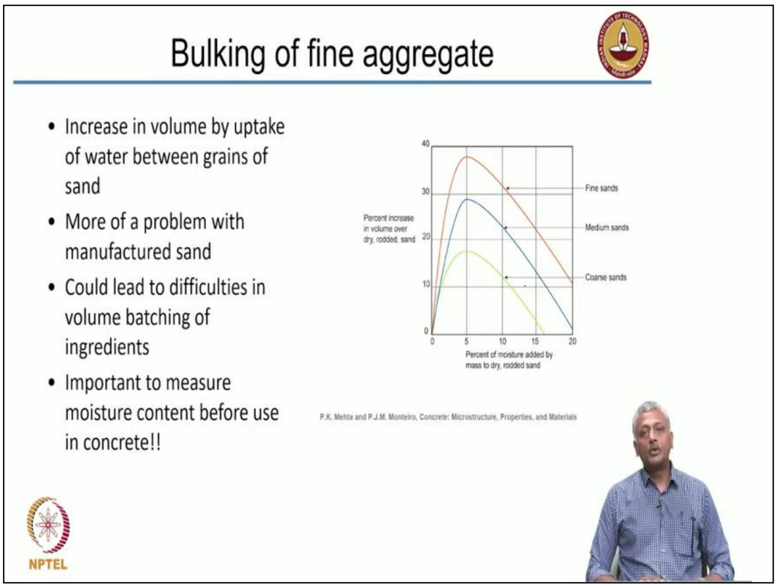

When you leave out sand or stone, as we already talked about stone, stone starts absorbing moisture and then there is a film of water that clings to the surface of the stone. In sand, of course it’s very difficult to see each individual grain but if you take a look at sand as a volume, what will happen is, the fine sand is usually getting packed with some small voids inside. As it absorbs moisture, the water goes in and expands this void that is present between the sand, as a result the sand appears to be larger in volume than it actually is and that process is called bulking.

So bulking is nothing but increase in volume by uptake of moisture between grains of sand. And this is more of a problem with sources of sand that are not natural or sometimes even with crushed stone sand. One thing I must say is that this is truly speaking a big problem only in the case of concrete where you do volume batching. That means you are measuring quantities by volume.

If you are measuring by mass, all you have to do is dry this mass of wet sand and determine how much water is actually inside. That way you can actually get the exact mass of the dry sand and the mass of the water properly input into your concrete mix. If you are checking volume, then you have a problem. So it’s important to measure the moisture content of the aggregate in concrete because that ultimately leads to a lot of hassles in the job site.

Again this is a picture from one of the textbooks on concrete technology, which shows you that the bulking or percent increase in volume is most affected for fine sands. So you can see the increase in volume can be as much as 35% or 36% here. So, if you are thinking you have one cubic meter, it’s actually 1.36 cubic meter because of the water that is getting inside the fine sand.

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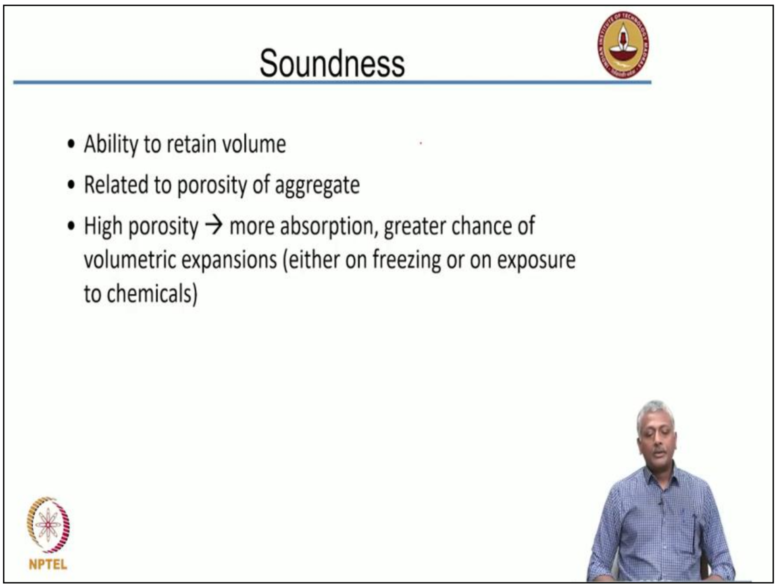

One of the other important properties of aggregate is its soundness. As I said soundness is the ability for the aggregate to retain its volume. Aggregates are porous, so they are going to start taking in water, sometimes some chemicals and these chemicals may leave behind some crystals. And these crystals forming inside the pores could cause the aggregate to expand and the aggregate is weak, it will start cracking.

Soundness is tested in a similar way. Again IS 2386 needs to be referred to. Soundness is tested by using a magnesium sulphate solution. You dip your aggregate into it and you dry it and you dip it and dry it for several cycles, what happens as the result is the porosity in the aggregates, you start forming crystals of magnesium sulphate inside, that causes damage to the aggregate. With higher porosity, you will have a greater chance of volumetric expansion. So you need to restrict aggregate which has poor soundness.

In most cases when you're doing quarrying of the aggregate, you get a uniform source or uniform type of material. In such cases, you don't really get problems with soundness unless you are going with a bad quality mineral. But when you go for riverbed gravel, you will get a mixture of different components and as a result, you may end up with some unsound particles also. You need to be careful about that.

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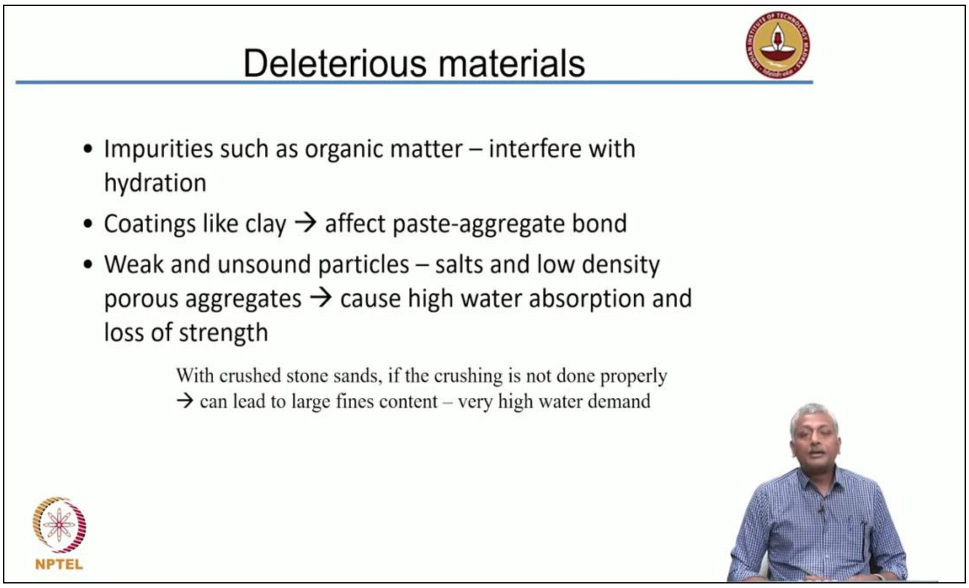

Now as I said again, depending upon where you are collecting your material from, you can get different types of deleterious materials. That means the poor quality materials that are inside the aggregate like organic materials, like clay and so on. And these will affect the properties of the concrete.

Organic materials can interfere with the hydration reaction of the cement and slow it down significantly. So you want to restrict organic material. For example you have humus, some organic decaying soil may also be mixed in with the aggregate, you may get plant extracts which may be still mixed in with the aggregate, fibers and stuff like that. So those types of things can actually affect the hydration process.

When you have clay; when you break down the aggregate and it is got clay in it, the clay may start forming a lining on the surface. Sometimes aggregate that you get is dirty. That's because of clay lining on top. If you don't clean it up well before using, it that will affect the paste aggregate bond. The paste has to bond well with the aggregate and if you have a lining of clay on top of the aggregate, it is going to spoil the bond.

The other aspect is weak and unsound particles. As I said, when you collect aggregate from river beds, you need to be very careful about finding weak and unsound particles. These can cause very high water absorption and loss of strength.

Now, if you go to a construction site, increasingly you will find that very less people are using river sand, at least in Tamilnadu that's the case. In most of India also, the use of river sand is banned or dredging of rivers for mining the sand is banned in most states in India. As a result of which, increasingly more and more people are shifting towards sources of crushed stone to be used as sand. But here you need to be careful.

What happens is when you crush the stone as sand, depending upon the type of mineral that goes into making the stone, you get very large quantity of fines. When you crush the stone through improper techniques, you can actually get very large quantities of fines. Even with a good crushing process, you will still get a lot of fines. And you need to take care that the fines are washed out or removed through some classification scheme, so that you can get a good quality aggregate which has the right size.

So you need to control the amount of material which is lower than 75 micron size, because that may be silt or clay. What will happen if that comes into your concrete from the sand? It will start increasing your water demand tremendously and you will get lot of problems in controlling the quality of your concrete. That’s one thing you need to be worried about when you start using crushed stone sand.

In river sand, you don’t get that because the action of the river nicely washes off the very fine particles and you get a good quality aggregate. However, having said that, apart from that one problem in most cases, crushed stone sands can produce concrete of as good quality as river sand. Crush stone sand and river sand will produce concrete quality which is nearly similar. Except for this one problem that you may get more fines in the sand when you have crushed stone sources. Make sure that these fines are in the limit that is prescribed by IS 383.

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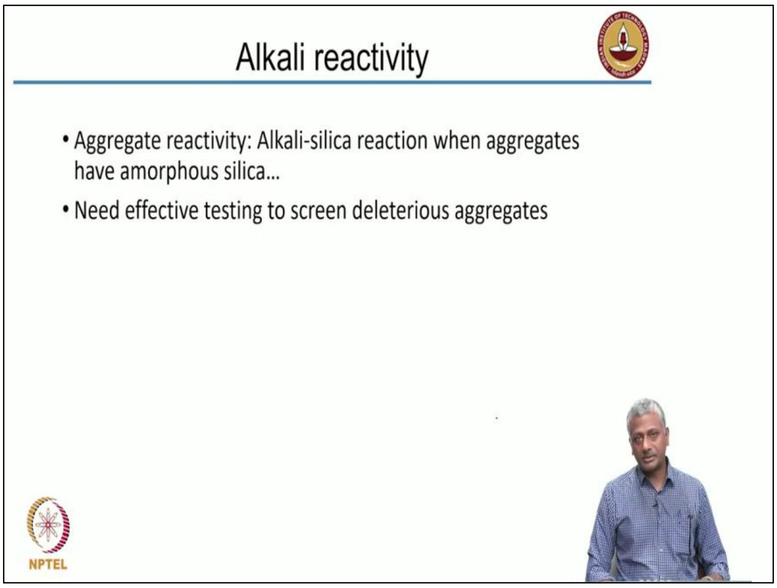

The other problem with some aggregates is that they may experience what is called alkali aggregate reaction. Some volcanic rocks for instance like rhyolite, andesite and so on, if you break them into aggregate size and use in concrete, the cement as I told you in the previous segment has a lot of alkalis in it. And these alkalis may enter into a reaction with the silica in such aggregates and cause the formation of expansive gels. It produces expansions and that leads to cracking and concrete.

So you need to be careful about using alkali reactive aggregate. You need to do effective testing of the material to ensure that it is not going to potentially cause a problem in the concrete.

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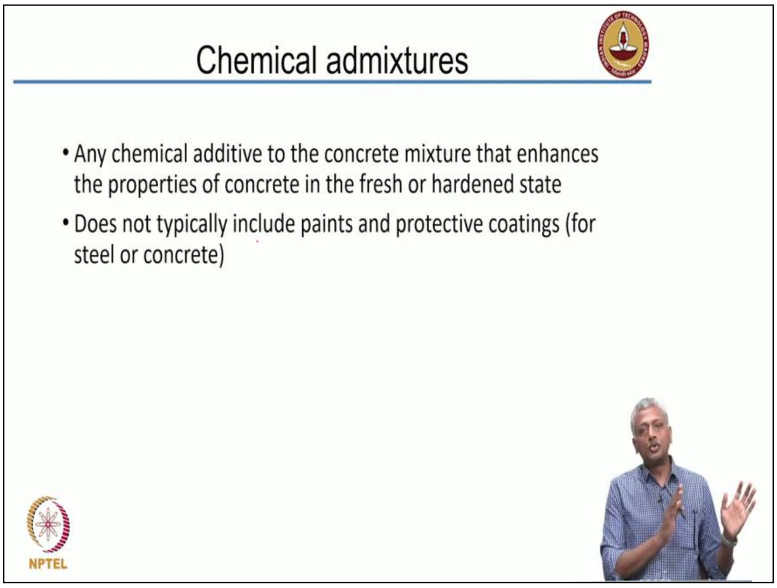

We have talked about the two main ingredients of concrete that is cement and aggregate. I didn't mention anything about water. Before I go to chemical admixtures, let me talk about water. If you look at the standards that govern the use of water inside concrete, of course this is covered in IS-456. IS-456 is basically the building code with plane and reinforced concrete. There, they say that the quality of the water should be so like this. And essentially what we want to use is potable water.

What is potable water? It's simply the water that you can store in your house in a pot and drink from. That quality of water is required for construction of concrete. So for construction with concrete you need potable water. What if you don't have good quality water available? Then what you need to do is, in IS-456 there are clearly limits prescribed on the harmful ingredients that may be present inside the water like alkalis, sodium, potassium etc., sulphates and chlorides and also organic matter. So all that needs to be restricted if you don't have a source of potable water.

And you have another source, let's say the bore water that you have in your locality and you want to use that for construction. Then you need to ensure that the water is tested appropriately and you have good quality water that satisfies the limits that are given in the standard. Obviously you need to pay a lot of attention to water because not only is water used for mixing the cement and aggregate together and also reacting with the cement, the water later is also used for curing the concrete. After the concrete has been formed and you remove the formwork, you start pouring water on the surface and that's called curing. That's a very important process.

So lot of water is required in concrete construction for mixing inside the concrete and as well as for curing and obviously a lot of water is also used for cleaning. When you have a machinery that is utilizing concrete, obviously there will be a lot of cleaning to do. So in a construction site a lot of water is required. So you need to ensure that this good quality water is available.

So we talked about concerns with environmental degradation that we are experiencing with the use of natural aggregate, imagine the amount of water that we use in construction, the amount of water that is getting lost which could be otherwise usefully consumed by humans and other animals on earth. We are obviously relying a lot on the good quality water that is available in very small quantity across the world. So, one needs to make judicious use of the water that is available.

Infact today, some research in concrete is happening where they want to use very uncharacteristic sources of water. For example sewage water, there’s a lot of sewage water and with some minimal treatment can be used for concrete construction.

Some people are looking even at sea water for concrete construction. Of course, the problem is that sea water brings in a lot of chloride and that chloride will lead to deterioration of steel or corrosion of steel. So, generally we want to restrict chloride as much as possible but people are doing a lot of experimentations with alternative sources of water also. That could be a very important thing to consider in the future.

You may have heard of the term carbon footprint. Technologies that evolve a lot of carbon dioxide will be taxed heavily in the future. Interestingly in concrete there is also a term called water footprint, because we use a lot of water for construction. Technologies with concrete that reduce the quantity of water to be used will make a lot of sense. And one of the technologies that can reduce the amount of water to be used in concrete is the use of chemicals and that’s where the use of chemical admixtures comes in.

Chemical admixtures are chemicals that you add to the concrete mixture at the point of mixing. And these admixtures are added from the point of view of improving certain characteristics of concrete. One could be workability, the other could be strength and so on. It does not include paints and coatings because those go on the surface after the concrete is hard. These are the materials that are added along with the concrete at the time of mixing the concrete ingredients together.

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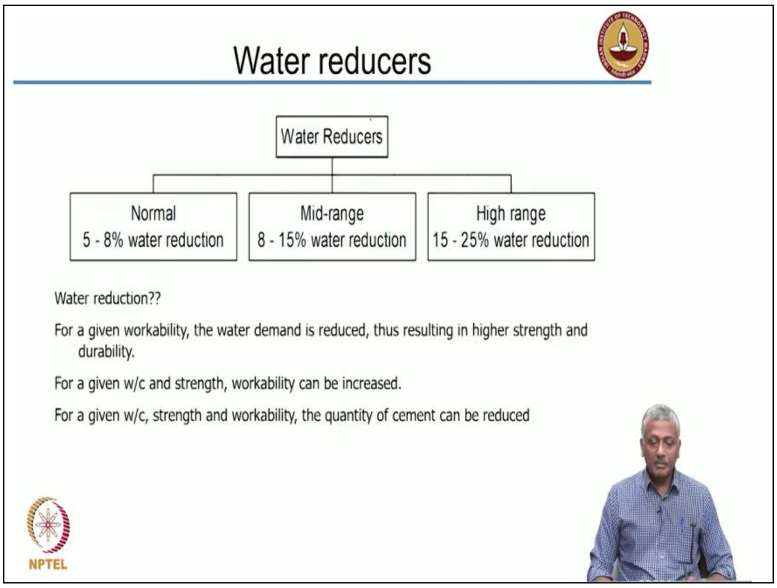

The most important chemical admixtures are the water reducers. They can reduce the quantity of water inside the concrete to attain a certain level of workability, because you need water to make concrete workable, mix it nicely and make it cohesive. You also need water to react with the cement and provide strength, so, two main purposes of having water inside the systems. For that, when you use a water reducer, you can bring down the amount of water that is needed to give you the workability.

When you bring down the water what happens to the strength? Automatically strength goes up. The water to cement ratio, that’s the important concept that you need to remember as the amount of water in concrete to the amount of cement in concrete. As the water - cement ratio goes up, the strength comes down. If you are able to reduce the water cement, you are obviously going to be increasing the strength. And how do you reduce water ratio? By using water reducers.

For a given workability, that means for a given consistency or fluidity of a concrete mix, the water demand can be reduced resulting in higher strength and durability. Alternatively, you don’t change the water cement ratio, keep the strength constant but what you will have is the concrete that moves around freely, it becomes flowable. When concrete starts becoming flowable, you don’t have to spend a lot of energy in trying to compact it. We will come across these processes later.

Alternatively what you can do is, as you are reducing your water, you can also reduce your cement to some extent. That’s the biggest challenge or that’s the biggest achievement that you can get with water reduces. For a same water cement ratio, that means you maintain the strength and durability as constant, when you are reducing the water you also reduce proportionally the cement content in your concrete.

Less cement means what? More economical concrete. Less cement also means more environment friendly concrete. Why is that? We talked about this earlier that when cement is manufactured, it is burnt in the kiln. The burning in the kiln releases lot of carbon dioxide. So more cement that you use in concrete, more effective carbon dioxide emission is happening. Equivalent carbon dioxide emission is more when you use more cement and concrete. So, when you reduce the amount of cement in concrete, you are reducing the overall carbon footprint of the concrete and that's where you get benefits from using super plasticizers or water reducers. These are called high range water reducers, which can really bring down the cement content required to attain a specific type of concrete.

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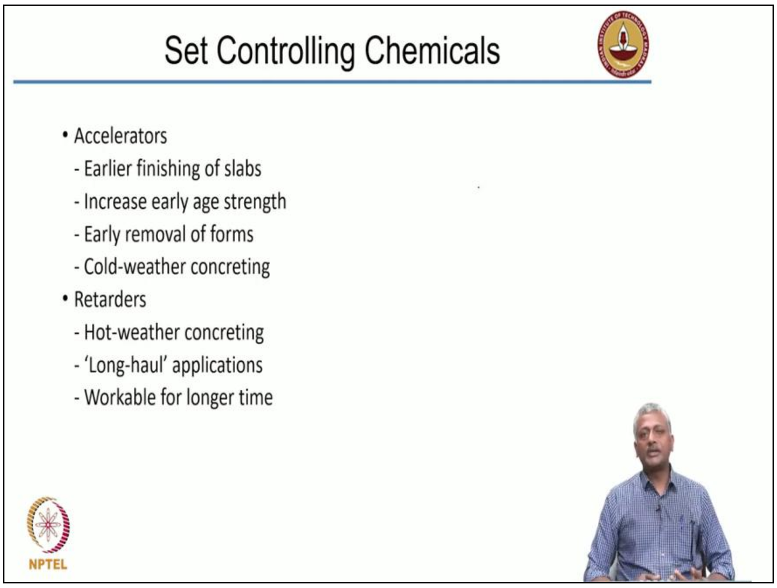

You can sometimes use chemicals that can speed up the reaction or slow down the reaction, depending upon the conditions that you have. When you speed it up, they are called accelerators. When you want to get strength faster or you want to finish the concrete faster, you are working in a cold region like in a hill for instance or in Kashmir for instance, you want the concrete to be setting normally. But because of the cold climate, the setting will happen very slowly or water may inside freeze also sometimes. In such cases we use what are called accelerating admixtures.

On the other hand if you are in southern India, where the heat can be tremendous, you want to use retarders which slow down the reaction to make sure that you get enough time to work with the concrete to put it inside the formwork and compact it and finish it. So that's called retarder.

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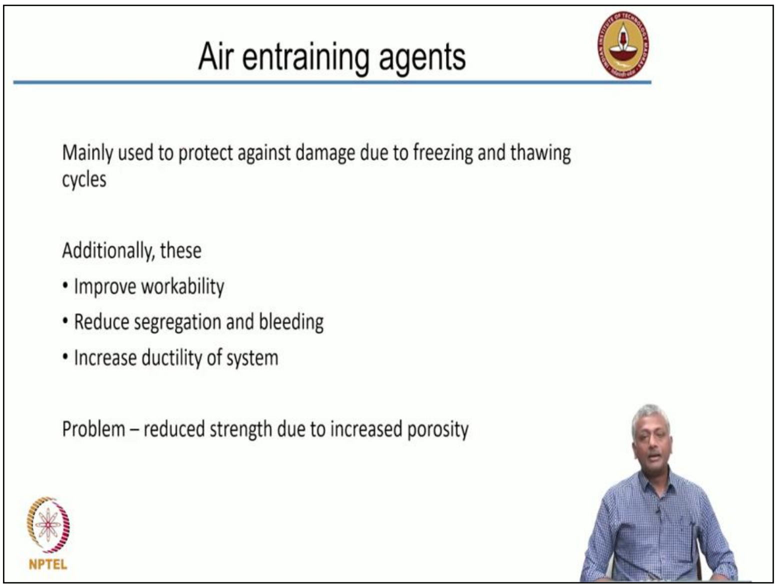

Sometimes in very cold areas you may get temperature fluctuations that can cause the water inside the concrete to freeze and then subsequent increase in temperature causes it to thaw. So it freezes to ice and then it changes back to water. Interestingly for water what happens is, when it transforms to ice, it leads to an expansion in volume. Very few materials exhibit this behaviour. You have an anomalous behaviour with water. When you freeze it, it expands and this expansion leads to stresses in the concrete causing cracking.

In such cases what we do is we put very small air bubbles in the concrete, air entraining agents create small air bubbles in the concrete that provide a space for the water to convert to ice and expand. So that reduces the stress in the concrete and reduces the cracking. Freeze thaw is a major problem in certain parts of the world and that's where air entraining agents can help.

But sometimes they also will lead to additional impacts like improving the workability, reducing segregation and bleeding and increasing ductility of the system. But please remember, we are introducing air inside the concrete. So more air means we are bringing down the strength. Generally for every 1% extra air that we put inside the concrete, we bring down the strength by 5%.

For every 1% extra air that we put inside concrete, the strength comes down by 5%. So we need to be careful by while using air entrainers.

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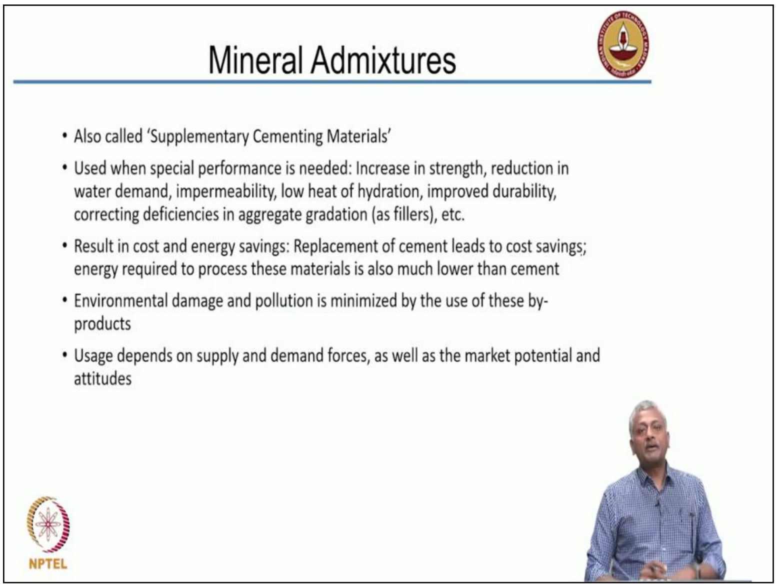

Apart from chemicals we sometimes add minerals also to alter the quality of the concrete. What are these minerals that we add? They are also called supplementary cementing materials. The net impact is, for the same quality of concrete, you're bringing down the consumption of cement inside the concrete. You use less cement by bringing in these minerals called supplementary cementing materials.

These minerals are usually by-products or waste from other industries, but they have very interesting properties because of which they are able to react in a cementitious medium. When we talked about types of cement, we talked about portland pozzolana cement and Portland slag cement. What is this Pozzolan? As I said, mostly its fly ash and fly ash is the ash that comes out from a thermal power plant, which contains some silica in it. And that silica reacts with the calcium hydroxide generated during cement hydration to produce additional CSH.

If you remember our discussions on cement, this additional CSH helps in improving durability of the concrete. So these mineral additives essentially do that. They increase the additional CSH in the concrete that leads to improved durability. Generally these are used for increasing strength and durability. Sometimes they may also be used for reducing the heat of hydration.

Again this is something we talked about previously. If you don't have a low heat cement, all you do is simply replace the cement by fly ash and that brings down the heat significantly. Sometimes you may also add these materials as fillers and they can help improve the overall gradation of your material to get good quality packing inside. Most importantly they will lead to cost and energy savings, because you are replacing cement which is the most costly ingredient with the supplementary material, which is a by-product or a waste from another industry. So it's environmentally friendly and at the same time you are reducing the cost and the overall net energy consumed to make the concrete.

As I said by products are being used, so environmental damage and pollution is getting reduced. But of course, just like anything else in the world the usage of these mineral additives can be dependent a lot on the supply and demand forces that are playing out in the economy that you have.

So, there is a lot of potential for more and more replacement of cement. Today we increasingly see a lot of our cement getting replaced by mineral additives.

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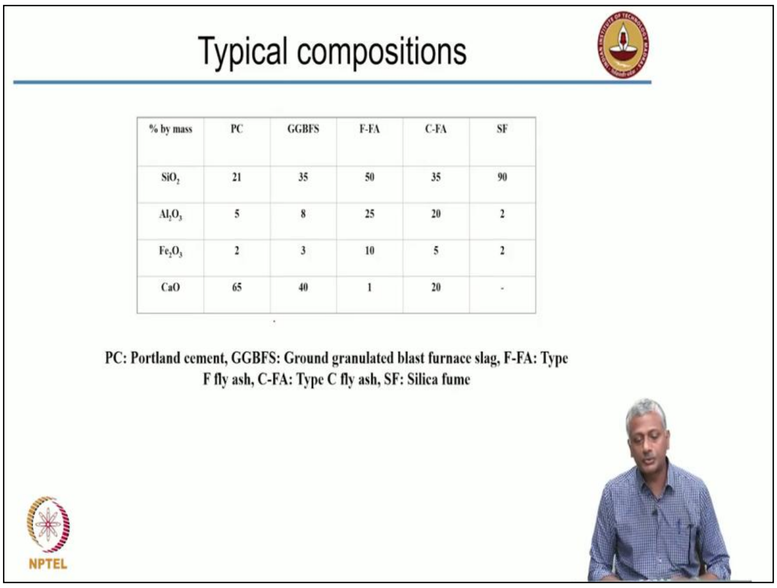

% by mass	PC	GGBFS	F-FA	C-FA	SF
SiO_2	21	35	50	35	90
Al_2O_3	5	8	25	20	2
Fe_2O_3	2	3	10	5	2
CaO	65	40	1	20	-

So, just wanted to give you some examples of typical compositions. So if your cement is here and as I said, cement is mostly composed of calcium oxide, that is, it is rich in calcium oxide and less of silica and alumina and iron oxide. But when you take slag for instance, ground granulated blast furnace slag, it has nearly equal quantities of silica and calcium oxide. And significantly higher quantities of alumina. Type F fly ash is generally obtained from burning of semi-bituminous coal. That means it does not have very much impurities. It has an extremely high amount of silica and almost nil calcium content. It’s also got a very high amount of alumina content. So it’s actually a very interesting material. It’s a silico-aluminate, similar to what you get with clays but not exactly as reactive as the clays.

Type C fly ash, if you have heard of a place called Neyveli in Tamil Nadu, where they have thermal power plants, Neyveli Lignite Corporations. Lignite basically is an impure form of coal. When you burn lignite, you get fly ash that has a large amount of impurities like calcium, silica and alumina. So that’s called type C fly ash or high calcium fly ash.

In certain cases especially when they process silicon metal for the semiconductor industry, you get a very fine dust called silica fume. And this silica fume is almost very high purity silica, more than 90 SiO_2. Please remember, the common feature here is the silica content. And this silica reacts with calcium hydroxide that is generated during cement hydration to produce additional CSH. That’s the most important part to remember. When you use supplementary cementing materials, you end up forming additional CSH and that is responsible for long-term strength and durability.

Durability is the ability of concrete to withstand the forces of the environment around it, not loading but the environmental effects. We will talk about that again towards the end of this chapter on cement and concrete.