Building Materials and Construction
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Module - 3
Lecture - 1
Concrete: Material

If you remember in the last module, last lecture we talked about various materials in construction. In this module, and of course also in subsequent module we shall be talking about the most popular construction material, that is concrete.

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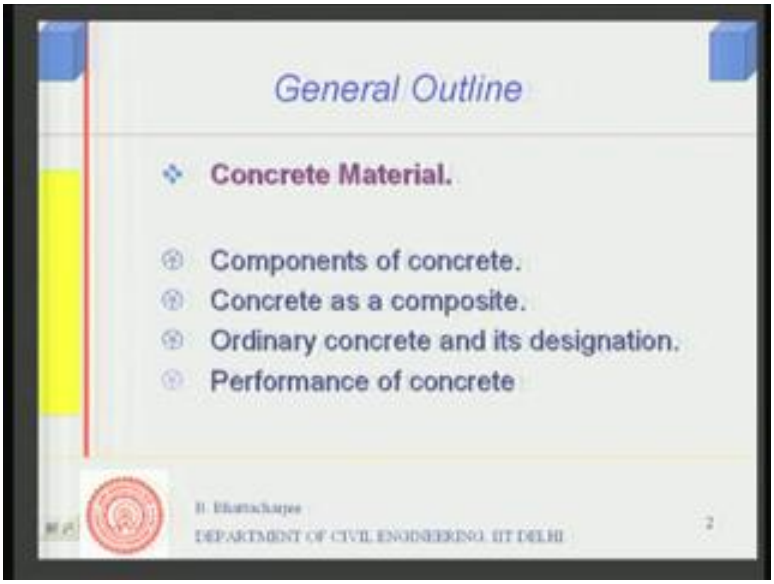

General outline of this lecture would be something like this. First, we will talk of concrete as a material, and therefore in this concrete as the material, we shall be talking about components of concrete. Well, concrete as a composite. Now, what is composite? I shall define this a little bit later, but for the time being let us understand concrete as a composite and that is what we will discuss in this lecture. Concrete has got a wide range of properties these days and naturally, therefore varieties of types of concrete. One of the type is the ordinary concrete, which is most popular and most commonly used and we will then, talk about ordinary concrete and its designation. And lastly, we will talk about performance of concrete. Performance of concrete, we shall be discussing about that at the end.

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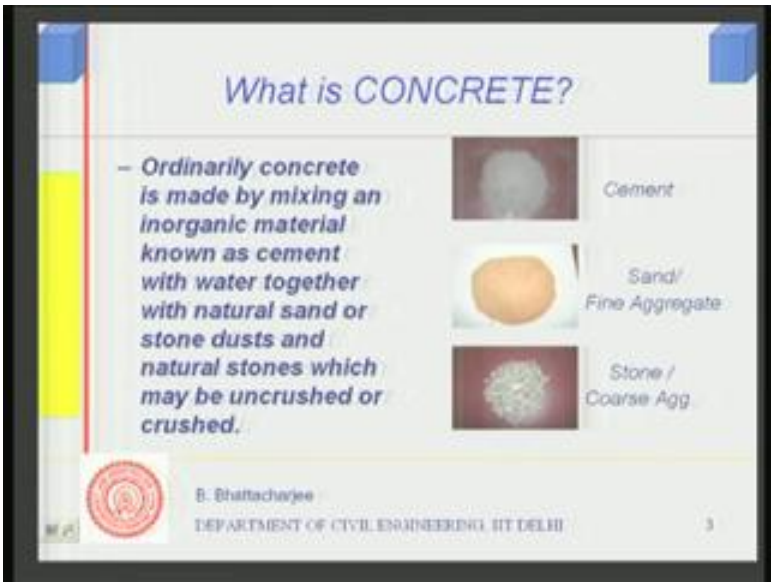

So, to start with, we should talk about what is concrete. Now, first of all, let us understand what it is made of. Ordinary concrete is made by mixing inorganic material known as cement and with water, together with some natural sand or stone dust and natural stones that may be crushed or may be uncrushed. This is visible, this is visible from the figure here. This is visible in the figure here. This is cement, this is sand and this is stone or coarse aggregate cement. When you add with water it reacts, forming artificial stone like structure as solid hardened mass and that is what give us the cementing property as far as concrete is concerned.

But since cement is the costliest of all the materials in case of concrete, therefore we should restrict its use in concrete. Besides, there are some other associated problems of shrinkage, etc.

So, bulk of the materials in concrete system, it is formed by the aggregates and cements are used as cement and water or cementing material of the similar kind are used as binded materials to find this skeleton materials, that is, the aggregates. So, aggregates are binded together by the cement in concrete system. So, that is what is concrete. In other words, it can be set in artificial stones made up of stone sand and a binding material. This binding, common binding material is cement and water.

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So, components of concrete, therefore cement and water, which reacts together and binds the aggregate. The aggregates are nothing but sand and stones, but this is not all. The modern concrete system also uses some sort of admixtures, as you call them, some sort of additional materials, construction chemicals, which when added to the cement system, actually improves its property.

So, there are other ingredients in addition to this four ingredients that I have mentioned. The two varieties of those types are, number one is chemical admixture, which could be accelerators. Now, I mentioned, that cement reacts with water forming a stone like a material. When you put also sand and aggregate into, they bind together this materials to form a system of hardened mass that we call as concrete.

Now, cement and water, as they react, this is not instantaneous. This prolongs over a very long period of time. Initially, the reaction rate is relatively fast, then it slows down, but it continuous to react over a long period of time. So, I may like to enhance this rate of reaction and that is what I do using what is called accelerators.

The process of cement mixing with water and solidification of the same, we call it setting, that is, when I add cement to water and also, may be sand aggregate, etcetera, initially they are in a sort of semi liquid form or I may call it as a plastic form, plastic state. That means, if you apply some forces, it will deform on its own. Liquid, of course, just you know, if you apply force they will, simply it will move, simply flow.

Plastic is one, which will deform, so plastic is semi liquid form or semi solid form in between the two. So, from this initial state of cement water aggregates, their mixture is in plastic state, then it gradually solidified into a solid and that is what we call as setting. So, it sets to a solid, the plastic cement water aggregate mixture sets to a solid, then it starts hardening and finally harden to a strong mass.

So, setting I might use, I might use, you know, some sort of admixture to reduce the setting time, reduce the, reduce the setting, reduce to a, you know, reduce the setting characteristic. In other words, increase the setting time and also, might use to reduce the amount of water required to produce a plastic mix.

So, there are various types of application. This will become subsequently clear as we discuss properties of concrete or properties of cement and its hydration process, this, all this will become gradually clear. This is one type of admixture.

The second type of admixture is the mineral admixture. These are some inorganic materials, many of them are industrial waste, like fly ash. Now, fly ash, as you might be knowing, is the material comes out from thermal power plant. We burn coal in thermal power plant, but the coal that is obtained from mines are contaminated with clay materials, usually that is abandoned in motherland. So, clay will contaminate most of the mineral and when we get the clay from the coal from the mines, clay is always present as contaminate.

We grind this coal into fine particles before binding into the thermal power plant. And as we burn coal, that is mostly carbon, that is converted into carbon dioxide. But the clay, which was there that forms an ash remains as ash, mainly of silicon oxide, Si O 2, and aluminum oxide. This ash, which are larger in size, they go to the bottom and final ones fly with flu gas that is what we call as fly ash. And that is used as a mineral admixtures in case of concrete system.

Similarly, there is another byproduct available from silicon industry called condensed silicafume or micro silica. These are also used as mineral admixture. A third mineral admixture could be rice husk ash. Rice husk, after husking the rice, the rice husk that is left, that can be burnt and processed to form, what is called, rice husk ash.

So, all these sort of materials can be used as mineral admixtures. These class of materials are mostly silica and since they can react with lime forming cement hydrates like product

or product of cement's reaction with water, these class of materials as known as pozzolana, pozzolana, after the name of volcanic gas, that is, reaches in silica and exhibited a property similar to fly ash, silicafume, etcetera, etc. And these materials, in general, this class of materials are called pozzolana fly ash silicafume. So, these usually are the major mineral admixtures used in case of concrete.

So, what we see in totality, most common, of course, materials in concrete production would be cement and water together with sand and aggregate system, sand and stone, which we call together as aggregate. And then, some admixtures, which could be chemical admixture or could be mineral admixture.

So, this forms ingredients of concrete modern concrete. Well, it may be the first cement, water and sand and aggregate, that forms mostly the ordinary concrete, but in modern concrete, even in ordinary concrete this mineral admixtures are almost an essential part. But in high strength concrete system there will be definitely present. We will just define what is high strength concrete sometime later on.

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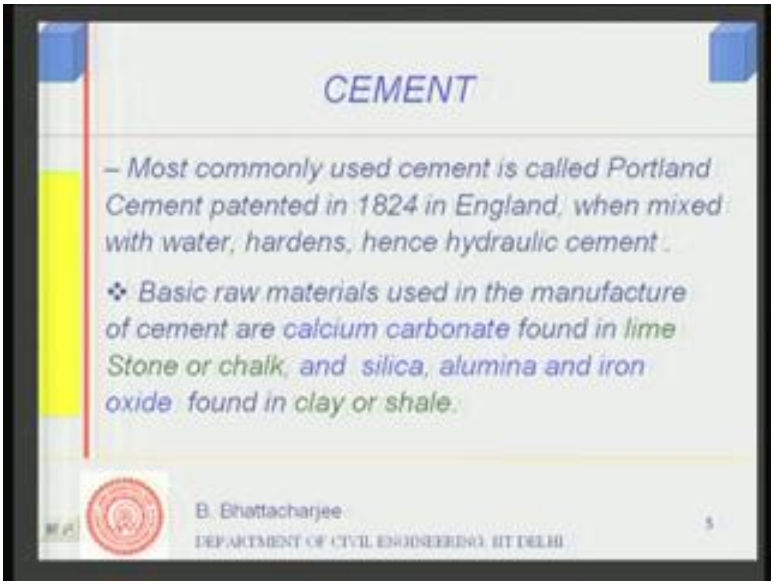

The most commonly used cement, we call it as Portland cement. It was patented in 1824 in England and this mixed with water hardens. And since it mixes with water and hardens, we call it hydraulic cement. Now, there are, that means, there are other kind of cement also, which need not be cementing material, may be, which need not use water. So, hydraulic cement is of this type.

How is this ((Refer Time: 11:39)) material produced? Basic raw materials that are used in the manufacture of cement are calcium carbonate. This is found usually in limestone or chalk. And of course, the other chemical inorganic oxides that go into composition of cement are silica, alumina and iron oxide. These are found in clay or shale. So, what we see is, or you shall see further is, that mainly the material present in cement are oxides of calcium, silicon oxide, aluminum oxide, iron oxide and alkalies, etcetera.

The raw materials, those are limestone and clay or minerals, which are rich in lime, rich in lime and rich in silica and alumina, these materials are burnt together at a temperature of about 1400 degree centigrade or so to form, what is known as, clinker, which is nothing but a solid solution of these minerals forming different cement compounds.

We will talk about the cement compounds at an appropriate time, but right now we can understand, that cement is manufactured by burning lime and clay together to form into a solid solution and this product formed is called clinker, which is grinded further and mixed with a little bit of gypsum, of the order of around 5 percent gypsum to control its setting properties. This gives us, when we grind, inter grind clinker and 5 percent gypsum together, we get what is known as ordinary Portland cement.

The name has been derived from a stone called portlandite that was discovered in the beginning and followed by this, you know, formation of like patent, patenting of cement as a material. Today, of course, you have different varieties of cement, not only the Portland cement with lime and silica burning together with and then grinding them with the gypsum. But you can also mix materials like fly ash to form or to produce, what is called, Portland pozzolana.

The mineral admixture, which I mentioned earlier, they can be added in the production of cement and inter grinded together with clinker and gypsum to form various type of Portland pozzolana cement. Another material, which is also may be used in cement production is blast furnace slag, a waste product from iron industry.

So, cements can be of varieties of kind, which we will discuss some time later on. They are mainly produced from lime and silica or clay as raw materials and they can be also mixed with some sort of pozzolana or slag to form varieties of cement, right.

So, this is how we produce cement and this, when reacts with water or added with water, they react forming into a hard solid mass, a stone like mass and that chemically, of

course, we call it as cement hydrates and its various, its compositions, etcetera, we shall discuss with appropriate time.

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The second in component is aggregates, which forms the skeleton. These aggregates are nothing but stone, natural stone, either broken down or crushed to form the right kind of sizes that we require in case of, for making concrete, or they can be rounded stones as available naturally, say gravels. So, they are naturally available, but most often we use crushed aggregate depending upon the availability.

Since they form the skeleton in concrete, you can see, the stones can be seen something like this. This is the part of the stone, so they are the aggregates. This is piece of hardened concrete, core taken from hardened concrete. And we can see, this is the stone piece that is the aggregate. This is the aggregate, even this is the aggregate, this is the aggregate and this aggregate is actually sort of placed or embedded in the mortar matrix, which contains sand and cement.

So, mortar matrix is here and this is the coarse aggregate. In fact, mortar matrix is the large matrix in which this kind of embedded, but closely spaced cement, sand, mortar against, contains sand as an inclusion in cement paste, cement water that forms into paste or hardened paste matrix. So, that is what a hardened concrete will look like.

This aggregate forms the bulk of the material, that is, about 60 to 75 percent by volume and 25 to 40 percent is paste, but still some voids are left, that is, about 1 to 2 percent.

The bulk of the material is the paste, the bulk of the material is aggregate and that is what imparts major properties. They should be strong.

Strength is imparted by aggregate, but it is also important to have good strength between the aggregate and mortar interface as strength is governed by the weakest link in the system. So, aggregate mortar interface is the one, which is, which is important from the strength point of view. However, if the aggregate itself is weak, the concrete cannot be strong. So, strength of concrete is important.

Also, it should be inert, that means, should not react with the environment present and thereby, deteriorate with time. It should remain inert from the environment because after all, concrete as a material will be exposed to environment and there it may come in contact with various aggressive chemicals. For example, like concrete put in a marine environment in sea will come in contact with magnesium sulphate, calcium sulphate, sodium chloride, etcetera, various other materials. Some of these materials can react with the concrete system, so and deteriorating, and in the process it can deteriorate.

So, the aggregate should be such, that it is inert, do not react with most of the materials present in the surrounding environment. So, the characteristics of the aggregate should be, should be strong and it should be inert, it should be strong as well as inert, should not react with the surrounding materials. That is how it should provide, that is how it can provide durable concrete. So, that is the role of aggregate.

Now, I mentioned earlier, that modern concrete always have some other kind of admixtures together with the basic materials, that is, cement and water, sand and the largest stone, which together we call as aggregate. The chemical admixture are used for enhancing the property of concrete or sometime we call it performance.

Performances are defined in terms of various properties, how it should perform, functionally perform in when it is exposed during its service condition to environment, when it is exposed to environment during its service condition, how should it perform.

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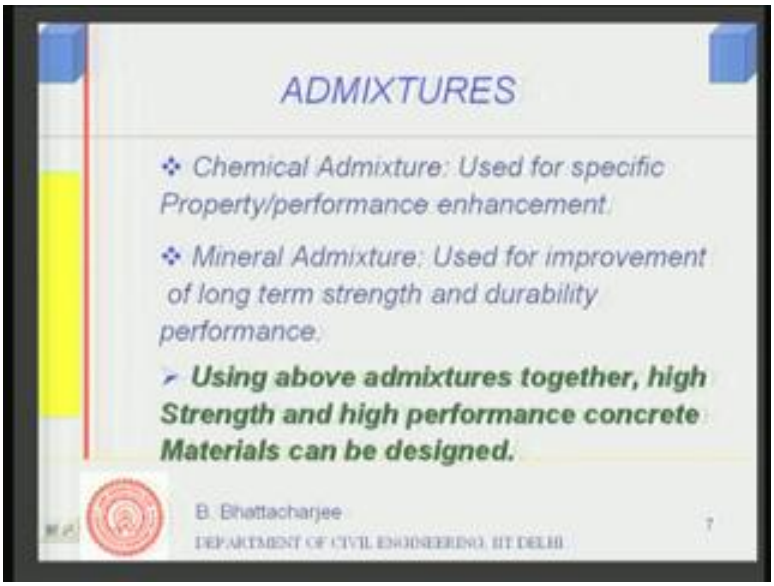

So, it depends upon certain properties. So, therefore we want to enhance certain properties or its performance, we use these chemical admixtures. What are those chemical admixtures? Some of them we will be discussing later on, in some of our lectures. Mineral admixture, as I mentioned, like fly ash silica fume, they are used for improvement of long term strength and durability performance.

So, historically speaking, when concrete was actually developed as a material and its scientific study started, was started being conducted somewhere around beginning or earliest part of last century, around 1925, the researchers were mostly bothered about its strength property, strength characteristic and later on they found, that okay, one has to look into its durability properties also. But early 50s, the strength of concrete was fairly low. It was rarely exceeding anything more than 50 mega Pascal compressed strength.

But with the advent of chemical admixtures, these properties could be enhanced further. Mineral admixture in chemical admixture, together they opened up the avenues of improving the strength of concrete and modern high strength concrete or very high strength cement based. Composites have become possible only due to use of this mineral admixture as well chemical admixture.

So, using above admixtures together, that is, mineral, chemical admixture and mineral admixture, high strength and high performance concrete materials can be designed.

So, what we see, therefore concrete as a material I can obtain at normal, ordinary strength or at high strength using various kind of admixtures. Therefore, all this gives certain advantages of concrete.

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First of all, ordinary concrete, it uses stones and major volume of it is actually stones and naturally available sand or crushed stone, again, which are naturally available, thereby it is cheap. So, it will have low cost of production. First of all, cement is the costliest material among all of it, but then, cement paste, as we have seen, occupies only 25 to about maximum 40 percent in some special concrete, rest all is naturally available material. Therefore, it is cheap to produce.

Well, since it is durable, I can make a durable material out of concrete, therefore its maintenance cost also likely to be lower, putting these two together. The concrete has got lower life cycle cost, a low initial cost and also low maintenance cost, thereby it has got low life cycle cost. During its life cycle, the cost is relatively low.

Then, we said that we prepare concrete ourselves by adding cement and water. So, therefore, cement water aggregate, etcetera, etcetera, initially it is in plastic state and I can mould it into any shapes since I start from the plastic state of the material and I can produce at any place I like. So, therefore it is moldable, I can cast into any shape, which may not be possible for other materials.

So, concrete can be cast into any shape of any, any, any shape you desire and that is why, that is why, it has got mouldability. So, this is again another big advantage. I can cast into any shape I like, so it has got the property of mouldability.

It has got the property of robustness, which some other materials may not have. The robustness is the property associated it, its massivity. For example, a retaining wall, a wall which retains soil would have a tendency to slide due to soil pressure or might also overturn or topple due to pressure of the soil, or sometime it can happen, that it can in case of dam due to water pressure it may slide or topple. Under such a situation, massivity of the structure is very much necessity and such massive structure can be made of concrete. Therefore, it provides robustness. The robustness is the big advantage for concrete.

So, concrete has got lower life cycle cost, it is moldable, it has got robustness and since I design the materials myself, I can change the ingredients proportion and things like that. Therefore, I can design it for the desirable property, particularly the strength. And its strength today, of course, is ranges, about very wide range as we will see in the next slide. So, it has got advantage of lower cycle cost, mouldability. Robustness can be available for concrete and can be designed for desired property.

There are certain disadvantages, but we overcome these disadvantages. We can add additional materials to concrete and make it as, you know, required, as required for the desired functional performance, okay. Let us see what are the disadvantages of concrete?

Since it is made from particulate system, we are actually, you know, putting together aggregate sand and stone, which are aggregate, as I mentioned. These are simply particle and since we are bonding by a cementing material, the most common is the cement and water. So, it is a particulate system bonded by some sort of bonding.

Now, this bonding is not usually of the chemical nature, they are of the physical nature usually due to, what is called, Van der Wall’s forces. So, these bonds are not very strong to withstand the pull or tensile forces. However, they are very strong in compression or push from two sides. So, therefore it is strong in compression, but its disadvantage is, it is weak in tension, therefore it has got lower tensile strength.

Then, another property is, whenever trying to load, when we load it under high load, when it fails, it does not give much warning concrete, does not have much capacity to deform unlike a material, let us say, steel, unlike a material like steel.

Ductility is the property that is related to its capacity to deform before failure. If it deforms sufficiently, then it will give us a lot of warning prior to failure. Therefore some, some sort of remedial or you know, some sort of actions can be taken. So, ductility is the property, which is related to capacity to deform concrete, does not have this deformation capacity and therefore it is brittle.

So, these are the two major disadvantages of concrete, that is, it has got the lower strength, the tensile strength and low ductility. However, to overcome this what we do? We reinforce the concrete either with conventional reinforcement. So, what we use most commonly is reinforce concrete or ((Refer Time: 27:21)) concrete.

Reinforce concrete is the one, which gives me both ductility and lower, you know, takes care of the lower tensile strength. So, by using reinforcement, most commonly used reinforcement is steel, we can make use of concrete in elements where it requires tensile strength as well as ductility.

However, I can also use small, discrete, randomly oriented fibers to improve the ductility property of the concrete matrix itself and these are called fiber reinforcement. We will talk about it in the next slide again.

So, therefore concrete has got lot of advantages although it has got some disadvantages. We can take care of it by various means. Thus, it is the most popular construction material in, in, in all over the world today, particularly in country like India, okay. So, this is by and large what I talked about so far, is related to ordinary concrete. And I mention, that I can make a high strength material out of it, what we call as high strength concrete. However, concrete system today, not, I mean, one can call possibly a cement base composite system today is very, very versatile and you can get high strength material using this hydraulic, hydraulic cement and water and some sort of aggregate system.

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So, overall concrete can be, you know, thought to, thought of as a composite today, that is why, so concrete and other composites, one may say. So, this includes materials like normal strength concrete, a high strength or high performance concrete, something called ultra-high strength concrete, something called fiber reinforced concrete, something called densified with small particle. I will just define one by one a little bit. Then, something called macro defect free matrix, reactive powder concrete, polymer concrete and polymer cement concrete.

So, if we see concrete and composite related composite system today, there are so many classes of material. Normal strength concrete is the one, which I have been just talking about, that is, you have cement, water, sand and aggregates giving us strength of the order of the about 50 mpa, 60 mpa and not beyond.

Then, I can enhance the strength of the concrete by using mineral and chemical admixtures beyond 60 mpa, as we shall define, and I can produce what is called high strength concrete system and, or high performance concrete by using various kind of admixtures. And then, I can make concrete of much higher strength, which I call as high ultra-high strength.

Now, since these materials are all brittle, I can introduce fiber to improve its ductility and resistance, impact resistance, resistance against impact, etcetera, and I get a material

called fiber reinforce concrete. So, in this material, actually reinforce, the concrete with various kind of discrete fiber.

Then there are some special class of cement based composites, which do not have coarse aggregate, larger aggregates, but usually have cement, sometime cement with simply another filler material, like silica fume and with some chemical admixtures, such as, such materials, one of this is called densified with small particle. Cement, you densify small particle.

Then there are something called macro defect free matrix in which this, this, this material, this set of these three materials densified with small particle, macro defect free matrix and reactive powder concrete. They are very high strength material. This material, again, has got cement and, and polymeric material together with materials like silica fume and they are produced in a given manner to get very high strength material. Reactive powder concrete also uses cement silica fume, most commonly with quartz and sometime heat treated ((Refer Time: 31:48)) to get very high strength concrete.

So, these three are cement based composites, do not have large size aggregates, but the strength is very high. This is the strength achieved for this in the laboratories of the order of around 800 mpa compressive strength. So, these are very high end materials, not used for structures very often, but used for mechanical part or substrate for electronics material, etc. So, these are very high strength materials ((Refer Time: 32:17)) kind of cement based composites.

So, if you put all of them together, these are cement based composites, all these can be set to be cement based composites. In addition to this I said, that hydraulic cement binder concrete is one variety of concrete. Supposing I remove the hydraulic cement and water as a binder and replace it with polymer, then I get what is known as polymer concrete. This material is used very much for repair works today. And in some cases, I remove only part of this cement binder, but use a polymer and also part cement for binding and this is also a repair material and this is called polymer cement concrete.

So, if I look at concrete and concrete composite system today, that includes normal strength concrete and high strength or high performance concrete, ultra-high strength concrete, fiber reinforced concrete, denisified with small particle, macro defect free matrix, reactive powder concrete, polymer concrete and polymer cement concrete. So,

these are all the materials, which can be called as concrete, and concrete, or cement based composite material. And you can see, the strength varies over a wide range, there are various properties varies over wide range and therefore, can be used and designed and used for specific purposes.

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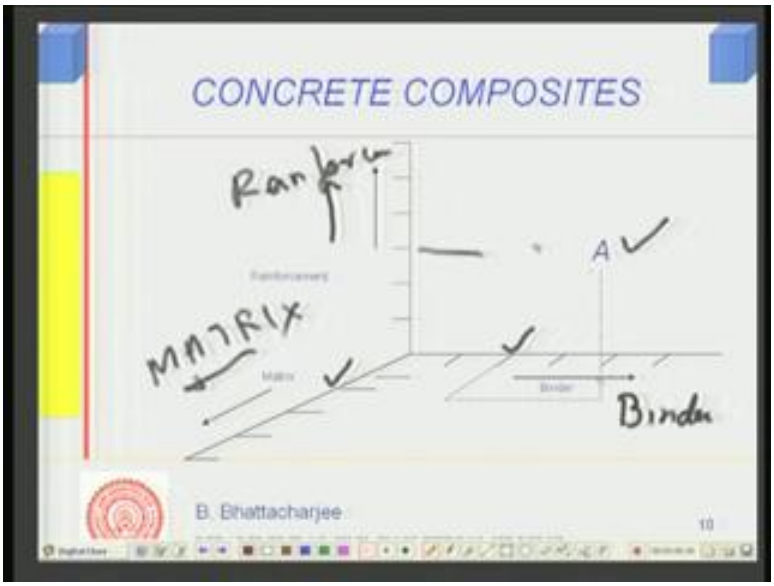

So, I can express, possibly this material I can represent in a three-dimensional matrix; I can represent this in a three-dimensional matrix. For example, this is, this axis I can represent a binder, you know, this is binder, binder along this axis. So, this is the three-dimensional representation and some sort of reinforcement, you know, reinforcement. These are I am talking of fiber enforcement here, not the conventional reinforcement. So, binder may represent three-dimensional, represent of, representation of all these generalized materials.

Cement and cement based composite can be drawn like this in, in, I will have some binder, which could be cement and water, OPC, ordinary Portland cement and water or some pozzolanic cement and water. I mentioned to you what is, you know, Portland pozzolana cement and so on. Some sort of cement, hydraulic cement and water that would form binder or it can be polymer, as I mentioned in the previous slide or polymer cement. So, there can be varieties of binders.

The matrix can form simply of aggregates of large stones and small sand or crushed stone and crushed stone powder as sand. So, there can be various possibilities of using in

matrix. Or I may not have at all the large size stone, but only have quartz sand, and then some sort of reinforcement. Those are normally of the form of fibers, the steel fibers, polypropylene fibers, carbon fibers, etc. So, there is various, various possibility.

There can be various combination of these binders, matrix and reinforcement forming a material. As an example, let us say, take A as a particular cement based composite. It uses this binder, binder number 2, let us say, 1, 2, 3, 4, etcetera, etc. So, it uses binder number 2, uses a matrix. This is again this one and, and, and possibly uses a reinforcement of third kind. So, by making use of different reinforcement, different binder and different matrix, I can get combination of materials, those are cement based composites.

Depending upon the property I need or I desire to have or its functional performance in actual structure, I can choose the binder matrix and the reinforcement. For example, if I need high ductility, I can choose a reinforcement. If I do not need ductility, I am not really interested, I am getting ductility from some other things, a conventional reinforcement, I may not use the fiber.

The matrix could depend upon what type of material is available or what sort of strength I require for large, a very large high strength material, I do not use large size aggregate, cement binders or polymer binder. That would depend upon usage. For example, for a repair work I might use a polymer as the binder, polymer concrete, say apoxy concrete. So, apoxy as a binder for repair work because it would depend upon what is my usage and the performance I require during its service. So, you know, based on this one can select the material, right. That is what is a, alright, this is what is a material, right.

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Now, this is, so far I have talked about concrete and cement composites, now let us come back to our most common material, that is, ordinary concrete, in general, concrete. Although I have talked about concrete and cement based composites, which have got wide range of properties and wide range of application also the most commonly used composites, cement based composites is ordinary concrete. This ordinary concrete strength ranges less than 60 MPa. We shall see this later on.

But then, how do we designate the concrete? All concrete do not have same property, same strength, so I designate the ordinary concrete by its 28 days standard cube compressive strength.

Why 28 days? I mentioned the cement and water reacts and this reaction is not instantaneous. It prolongs over a long time. By about 28 days, about 90 percent of the reaction is completed. Most of the strength development takes place by 28 days. So, when concrete material's scientific background starting developing, let us say, around 1925, people, the researchers, actually they, they found, that around by about 4 weeks, the strength development is, 90 percent of the strength development is complete.

So, therefore for ordinary Portland cement concrete, that was most popular at that time, they designated 28 days strength as a, 28 days, strength at 28 days age as a, you know, standard at which strength.

Now, how do I test such material for their compressive strength? I have to prepare samples again since this, you know, it is unlike other materials. For example, steel where you can test a rod for its tensile strength, one has to conceive the kind of sample one would use. So, in Europe, by and large they adopted cubical samples and in North America, they adopted cylindrical samples. And they were tested under compressive loading to find out the compressive strength.

Since we follow also the European or British practices mostly, therefore we also in India, also we test cubes and the size of the standard cube in India is 15 centimeter side length. So, 15 by 15 by 15 size cube we test in India, and we designate the strength of concrete by strength of such standard cube. So, we are talking of only compressive strength because concrete is weak in tension. So, we talk of compressive strength of concrete and we test the concrete cube, which we make from the concrete and test at the age of 28 days.

So, Indian Standard Code, as I mentioned in one of the earlier lecture, that is, since there are the civil engineering or construction is lot more practice based than purely on scientific or scientific, you know, ideas completely. So, therefore one has to follow codes of practices and the code of practice that is relevant for concrete is called Indian Standard 456. Its latest version is IS 456 2000.

So, there again we define the concrete or designate the concrete by its cube compressive strength at 28 days. The cube has to cast, has to be cast in a standard manner. So, we pack it or compact it in a standard manner. Then, we put it, or, or you know, put it in a given condition for 28 days, which we call as curing, put in actually water for 28 days at a given temperature, water at the given temperature. So, cured in a standard manner.

And then, we test it also in a standard manner, so that the variation that we get is because of only the material and not of the test condition or of the curing condition or because of the casting. So, we test them a 28 days, the standard cube as we call it, and we define the designate, the concrete, by what is known as its characteristic cube compressive strength.

What is characteristic cube compressive strength? Characteristic means, that if I test 100 cubes, 95 of those standard cube should show a strength about this value of strength. So, that strength I take, which will be exceeded by 95 cubes out of 100, only 5 percent of the cube can show lower strength. That is what we call as characteristic strength. This will

again become clear in our subsequent lecture. So, we designate a concrete by its 95 percent characteristic cube strength at the age of 28 days.

So, when I say a concrete as M25, they are written like this, mix 25 or M25, M30, M20, etc. So, I designate concrete as M20, M25, M30, etc. or M40. And when I say, a concrete is M25, I mean, that in 28 days, cube, standard cube strength characteristic, standard cube strength is 25 MPa. I repeat, M25 concrete has a 28 days characteristic cube strength of 25 MPa. If it is M30, it will have 28 days cube, characteristic cube standard strength as 30 MPa and so on. So, that is how we designate ordinary concrete, right.

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So, strength is one criteria and I said, normal strength concrete is 60 MPa. So, high strength concrete we define as one, which got 60 to 120 MPa cube strength. And ultra-high strength concrete will be greater than 120 MPa. Now, strength is one criteria, but since we make concrete in its plastic state and then it hardens. And then it, actually its long term properties are also important. It should be durable, therefore we talked sometimes in terms of performance of concrete.

So, performance of concrete in the fresh state, when I say fresh state what could be the performance? That means, how easily it is mouldable? If it is very easily moldable, I might say its performance is very good. If it is not so easily moldable, I might say, its performance is not as good. However, both have got usage.

For example, a concrete, which is known as roller compacting concrete, may not require any mouldability. I may not, I can, should, you know, I might be able to use a lot of energy to mould it. So, its mouldability performance may not be high, mouldability performance may not be required thing because roller compacted concrete is relatively dry and compacted using road rollers.

So, I do not require the property of mouldability in such kind of concrete, whereas there can be another kind of concrete where I may not use any energy to vibrate or compact it. Such kind of concrete we call as self-compacting concrete. This concrete flows on its own and that gets compacted on its own. It is called self-compacting concrete. So, performance at the fresh state is also important. Performance at the fresh state is also important and we can define the performance as we require, depending upon its mouldability characteristics.

Then, long term durability performance in service concrete may be exposed to a very aggressive environment such as marine environment or environment where it is subjected to sodium sulphate, exposure to sodium sulphate or calcium sulphate, etcetera, some sort of sulphate, which can react with cement hydrates or product of hydration of cement or some other conditions where aggregate can react with alkali present in the cement itself.

So, there are various kind of reactions possible with the environmental material, that is present around the concrete and it should be able to withstand against deterioration due to such reactions and that is, what is, durability of concrete. Its strength increases with time, but chemical agents present in the surrounding react with concrete and cause its deterioration and that is what we call as durability.

So, various kind of deterioration, you know, various conditions where it can deteriorate or things like sulphate ((Refer Time: 46:13)), freeze, thaw, freeze, thaw, when it is freezing and thawing of concrete takes place in cold climate or marine environment. So, in such situations concrete may deteriorate with time and therefore, we might be able to define the performance of concrete in such situation over a long time period. That is what we call as long term, long term durability performance.

So, when I talk about performance of concrete, we talk in terms of its strength property. We also talk in terms of its performance during fresh state, during its long term service condition. So, performance is defined in all this.

Now, from looking at the concrete as the composite and other cement based composite, concrete or cement based composite overall is a very, very versatile construction material. It can, it can show, you know, a strength from 10 MPa, about 800 MPa in laboratory for reactive powder concrete. But in case of ordinary concrete, at least 120 MPa, just compare this. All this we are talking, of course, is the compressive strength. We must be, it is not very strong in tension. That too, of course, is known to us.

Now, one additional thing is, that the tensile strength disadvantage. You can take care of by reinforcing or ((Refer Time: 46:34)) it in an appropriate way. So, it can form into a very versatile material showing a wide range of strength properties. We can make it very durable by proper design and we can get its fresh state performance according to our desire. According to our desire may require no mouldability property or may require very high mouldability property as required by our construction, you know of the structure or construction practices. So, it is a very versatile material. This material is a very versatile material.

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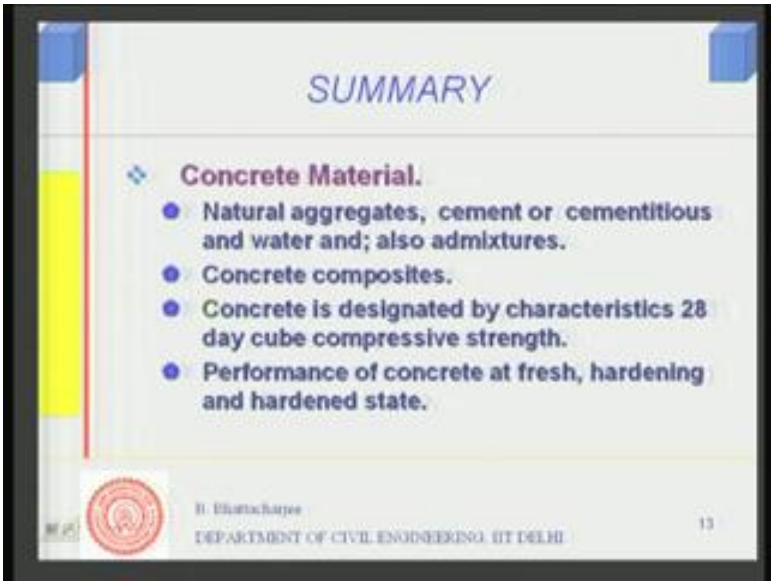

So, if I look at, then in summary what we have discussed. We have discussed concrete as the material and we have said, that its ingredients are natural aggregates, cement or cementitious. Now, let me highlight cementitious for a moment because I have talked of cement, cementitious, and all other pozzolana, which I mentioned.

So, ingredients are natural aggregates, cement or cementitious and water and also, we have discussed that there are admixtures into it. Then, we have looked into concrete composites, overall composite system, cement based composite and concrete, all put together. The whole, whole, whole complete concrete system we have discussed.

And then, we have also talked about designation of concrete, how it designate the normal strength concrete, and then lastly, we talked about performance of concrete in its fresh state, hardened state and hardening state and hardening state, right.

So, I think, with this concrete as a basic introduction to concrete as the material is complete. Then, we can now next look into the process of concrete production followed by the properties of, properties of cement and cement water system and concrete system as a whole, how it, how the strength is developed, how the property is developed, etcetera, etcetera.

So, thank you very much for hearing and this completes this particular lecture on concrete material as an introduction.