Advanced Concrete Technology
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Lecture – 11
Aggregates for Concrete – Part 1

Good morning everybody, today we will start of a new chapter that on aggregates in concrete, now this is something that most of you already have lot of information about but what we will try and do in this chapter is look at some aspects that you would not have learnt earlier in terms of how the aggregate mineralogy affects its interaction with the cement paste and that leads to interesting properties in the concrete.

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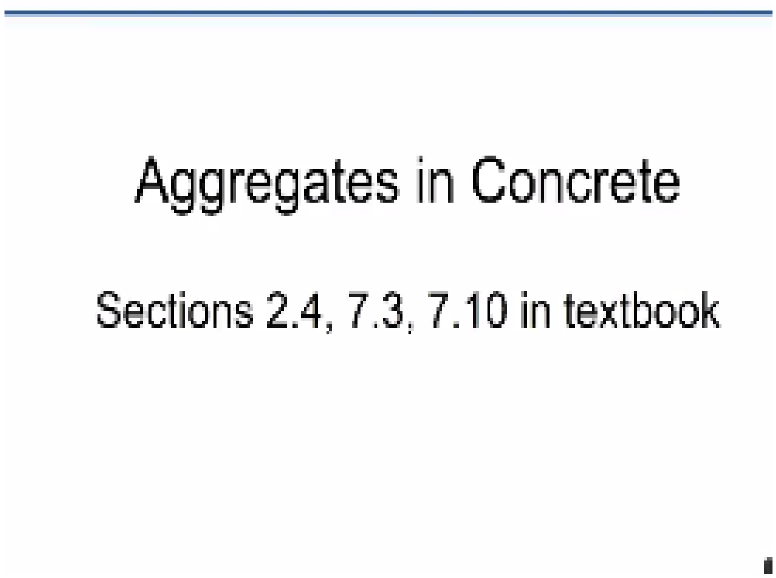

Now, of course basic properties of aggregates and some of these advance characteristics are already covered quite well in the textbook, so I have marked here the relevant sections from the textbook where you can get sufficient information, background information that I expected you to have already, include the role of the different types of sources for the aggregate, the kind of types of aggregates are used for concrete.

The effect of the aggregates on the properties of concrete and of course, the other aspect about the availability of aggregate, the sizing of the aggregates and classification and so on and the relevant test methods on the aggregates most of you will be performing these in laboratory classes, so I am not go over those in detail. What we try to explore here is the relationship between aggregate properties and concrete properties, so that will be the focus of this chapter.

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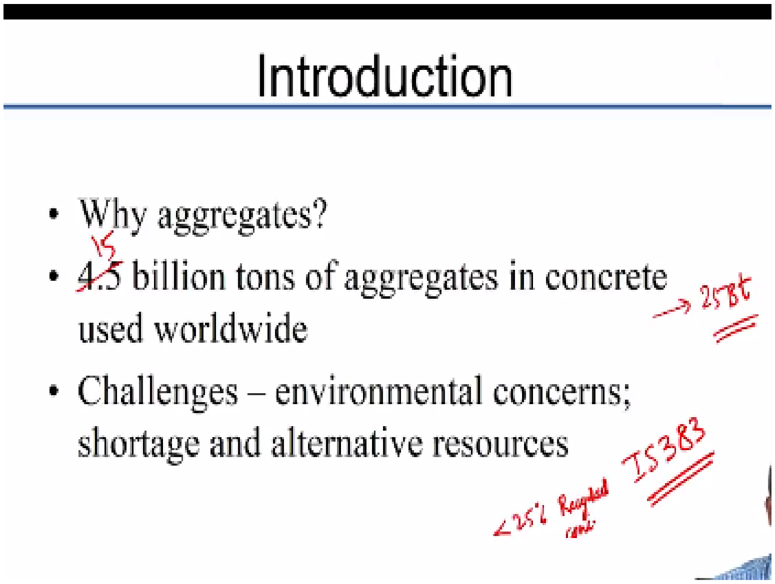

So of course we know very well, why we want to use aggregate in concrete, we have a lot of demand for concrete around the world and because of this demand for concrete, demand for aggregate is also very high, now I must correct this figure, it is not anymore 4.5 billion tonnes, it should be close to about 15 billion tonnes that we actually use now, I have missed a 1 there, it should be about 15 billion tonnes; 15 billion tonnes of aggregates are used in concrete worldwide.

How much of concrete is used, approximately you think, if it is 15 billion tonnes of aggregate, how much concrete would you use around the world? About 25 billion tonnes of concrete, 25 billion tonnes of concrete implies that concrete is the second largest used material on Earth after, all of you heard that many times, so it is not new to you right now, so concrete is the second largest used material in the world after water.

And so we use about 25 billion tonnes of concrete worldwide, so we need aggregate for what; in concrete why do we add aggregate? I can make cement paste which is stronger than concrete. Why do we use concrete? To fill up the bulk because of; what concentrations? If you will have only cement, there will be a lot of heat, but what is the primary consideration, why we want to use aggregate.

Somebody said cost, yes that is the correct answer, the idea is to reduce cost of concrete, cement is the most costly or expensive ingredient in concrete because of which if you use more cement, your concrete is going to be more expensive, so idea is to pack as much as the concrete volume is possible with aggregate and use only as much cement paste as required to be obtain; what characteristics?

Bonding, what else; what else the cement paste providing in the concrete? Workability, bonding with the aggregate, workability and of course the compactness of the entire system leads to the strength and durability of the system**.** So, ultimately, we want to maximise aggregate usage in concrete because of which we need such large quantities around the world.

Now, obviously we are mining natural resources, so the major challenge in using aggregate is the environmental concerns, we are depleting natural resources. What common types of aggregate do you know of? Granite, what else do we use as aggregate in concrete, of course most of you from the south, so we use granite; granite or other forms of granites like charnockite for instance, it is another form of granite type rock.

What else; what are the other types of rock? basalt, yeah, if you are from the Deccan Plateau mostly you will be using basaltic aggregates, like for example in Mumbai, most aggregates will be based on basalt, if you go further north like Delhi, you may have totally different aggregate, you may have something like quartzite. So, depending obviously on the location in which you are, you will be using different types of aggregate.

If you are in the Andaman’s, and you want to use the local aggregate, you will have to rely on the volcanic andesite rock, you cannot get good quality rock, so you have to rely on andesite, I will talk about why andesite may have poor quality is a little bit later. So, aggregate has to be used locally, whatever is available locally because we need such large quantities of it, cement can be shipped from one location to another.

But aggregate cannot because the volumes for shipping are too large, right for it to make sense because of that what we end up with is utilising whatever is locally available and obviously that the depletes our natural resources, we are mining this material from the earth as a result we are depleting the natural resources. Now, the challenge now is to find what are the alternative sources for aggregate?

You might have heard of some of these already and if you look at the aggregate standards, you know what the aggregate standard is; IS383, standard for coarse and fine aggregates in concrete, if you look at that it will tell you a host of different resources from which you can actually get the material to make your concrete aggregate, IS383. Now, you all have to be familiar with the standard, look at the provisions of the standard.

Because lot of work has actually gone into the revision, it has been recently revised and indeed it actually gives you scope to utilise alternative sources of aggregate to ensure that you do not really have to deplete natural resource as much, there is a particular table which actually gives you the limits of other types of aggregate that can be utilised to make the concrete. For example, it allows you up to 25% of recycled concrete aggregate; up to 25% of the fine aggregate is allowed to be recycled concrete aggregate.

That means you crush recycled concrete and make fine aggregate from it, so there is a lot of development that has taken place in trying to identify alternative sources of aggregate and that is going to be probably the biggest challenge in the future is how to actually determine the right quantities of materials available for making aggregate in concrete. Now, while granite, limestone, quartzite all these are available quite, a plenty of amounts available at the current stage in the future obviously, it is going to go down.

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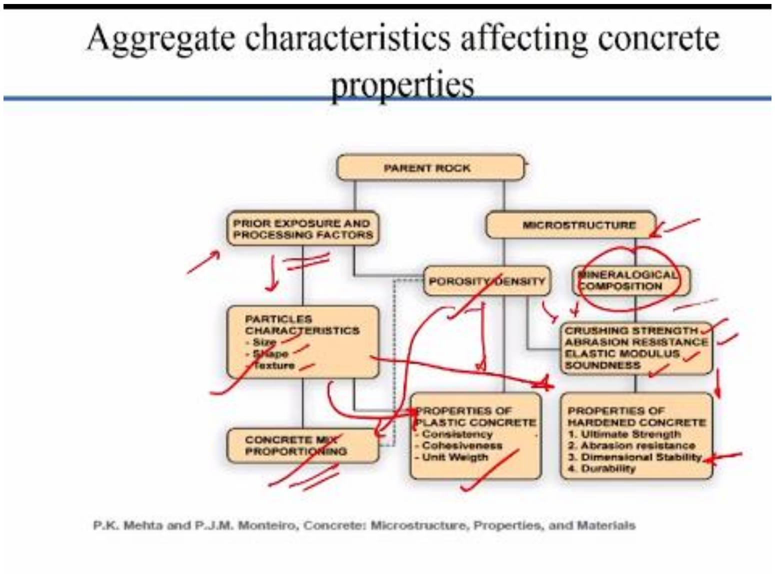

So, we have to rely on increasingly the alternative sources of aggregate. Now the characteristics of the aggregate are derived from the rock from which you get the aggregates, so the parent rock is responsible for giving the kind of characteristics to the aggregate, which creates different kinds of behaviour in concrete. So, the parent rock is exposed to a certain environment, for example you know that sedimentary rocks are formed upon deposition of sediments over millions of years.

And these sediments typically are deposited under seawater, so they have been subjected to a very high water pressure for a longer period of time. And to a large extent that governs the kind of behaviour that you get from limestone or dolomite or other sedimentary rock, you know that river gravel is subjected to the weathering action of the continuous movement of the river, waters continuously weathering the river gravel because of which, it will have 3 distinct properties.

So there are properties that you get from the aggregate that are because of the prior exposure and processing factors. And then there is the internal structure of the aggregate or the microstructure which is again responsible for a number of other things like porosity or density of the aggregate, mineralogical composition that means what is it made up of, what type of minerals constitute the aggregate, and both porosity and density and the mineralogical composition are responsible for a range of properties of the aggregate which include the crushing strength, the abrasion resistance, the elastic models and the soundness of the aggregate.

So, you know that most of these are determined in the laboratory before we deem an aggregate to be suitable for concrete production. Now, how do these affect properties of concrete and what properties are affected primarily, the ultimate strength of the concrete is affected, the abrasion resistance of the concrete, the dimensional stability and durability, out of these the one that is probably affected the most is the dimensional stability of the concrete.

So, aggregates are primarily required to make concrete dimensionally stable, in other words you need aggregate to ensure that there is resistance to time dependent deformation like creep and shrinkage, only aggregates can bring that about in concrete, it is not the cement paste but the aggregate which does that. The porosity and density also affect properties of the plastic concrete like consistency, cohesiveness and unit weight of the concrete.

And the porosity and density will also play a role in determining the appropriate mixture proportions for your concrete, why, voids are there in the aggregate so, how do you account for that in a mixed design; moisture correction, the aggregates absorb moisture because of porosity and because of that you need to do a moisture correction in your concrete mixture proportioning. So, the prior exposure and processing factors lead to interesting characteristics in the aggregate which changes the size, the shape and texture of the aggregate.

You know very well that river gravel because of the continuous weathering reaction of the water, is nicely rounded and smooth, on the other hand aggregates that you obtained from quarries are rough and angular, so because of that you get very different bonding characteristics with the concrete, with the cement paste and that will obviously affect the way in which you mix proportion in your concrete and it will also affect the concrete properties and probably also the harden characteristics.

Because the bond between paste and aggregate will differ based upon the surface texture of the aggregate for instance, smoother aggregate will give lesser bond as opposed to rougher aggregate, so all these are factors that you already learnt in the past but one part that might not have been treated well is what is the role of the mineralogical composition on the properties of concrete, all these size, shape, texture, mix proportioning, role of density and porosity, properties of concrete affected by aggregate, you have had some exposure to.

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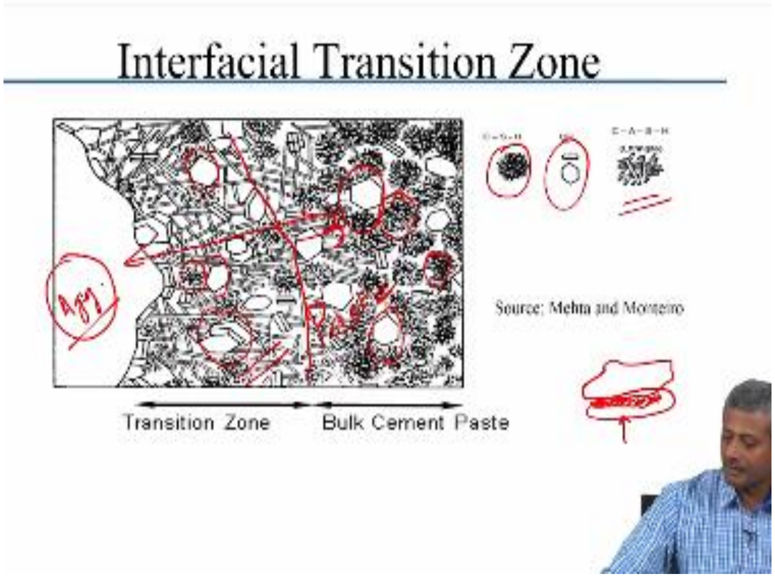

But one thing you may not have covered in detail is the mineralogical composition and why is it responsible for giving unique properties? So, the basis for understanding this influence of mineralogical composition on the concrete properties is the role of the interfacial transition zone again, just put in perspective you have the aggregate here, you have the paste here and in general, what has been found by experimental observation is that the paste which is away from the aggregate is generally denser, that means it got less porosity.

The paste away from the aggregate has more CSH and the paste away from the aggregate has less calcium hydroxide, on the other hand the paste which is close to the aggregate has more porosity, less CSH and more amount of calcium hydroxide and possibly, when ettringite or calcium aluminosulphate which are present in abundance close to the aggregate. Now, I told you already that there are researchers who believe that this is not correct; this is an artefact of the view that we do mixing for instance.

But a lot of research which is looked at concrete properties in general and the influence of the ITZ in particular have fairly well demonstrated that a presence of a weak link like this can answer many of the questions that you have about concrete. Now, one of the common observation is when you break a cube, you must have seen the fracture surface of the cubes, you might have seen that the cube fracture goes around the aggregates and not through the aggregate.

Now, you might have also seen, if you have broken very high strand concrete cubes, something which is more than 60, 70 mega Pascal's that the failure is very explosive, the concrete simply falls apart and that happens primarily because your cracke now, does not go around the aggregate, it goes right through the aggregate, does that mean the aggregate has become weaker than the paste?

Probably not, it probably means that the ITZ has been strengthened to an extent that the crack now tries to take the shortest path rather than the path of least resistance, so because of that you have a change in behaviour from low strength to high strength concrete, from a ductile to a brittle behaviour, so high strength concrete, you all know it is brittle and that brittle is caused because you are more or less homogeneous that means your ITZ is no longer much different from the paste.

And the paste has sufficiently high strength that it is comparable to the aggregate, so you have now homogenous mixture which leads to a brittle failure, on the other hand in ductile concrete or in low strength concrete, your paste is of much lower stiffness as opposed to the aggregate, so because of that the zone around the paste; zone around the aggregate tends to crack first and you have a slow development of failure, which goes around the aggregate rather than through the aggregate.

So, there are fundamental differences in the way that concrete fails, when subject it to the load and that happens because of the presence of interfacial transition zone. Now, what factors do you think will contribute to the interfacial transition zone, what factors will contribute? The size of the aggregate may contribute, yes, shape of the aggregate; in what way, if the surface area is large, then we get more ITZ you are saying, any other; water cement ratio, why would that effect?

Yeah, exactly, if there is more water available, there is greater tendency with the water to get attracted to the surface of the aggregate, the other reason is bleeding, in concrete bleeding is a phenomenon that you cannot control, it will happen because what is the lightest ingredient it will try to come up to the surface and when it encounters aggregate particles, the water that is coming up will tend to trap; get trapped under the aggregate particles.

So, what happens when the concrete becomes hardened, this zone under the aggregate particles becomes a large porosity and it is very common to observe that because aggregates are an obstacle to the path of water rising in the concrete because of bleeding and they get trapped under the aggregate that leads to a larger void under the aggregate, so you will generally tend to have ITZ. Now, the other aspect that promotes the formation of ITZ or affects the quality of concrete because of differences in ITZ is the type of the aggregates itself.

For example, certain types of aggregates have greater affinity to the cement paste as opposed to other types of aggregates, there may be surface charges for instance on the surface of the aggregate particles that may cause greater affinity, there may be likeness in the elastic moduli which will lead to greater affinity for the paste and so on and so forth. So, the aggregate type can have a large influence on the ITZ and because it does, the aggregate type also exerts a great amount of influence on the properties of concrete itself.

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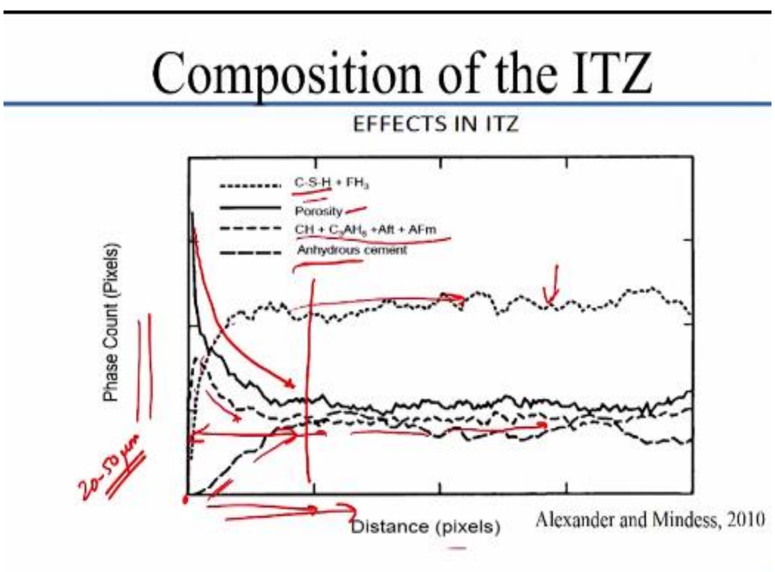

I will show you some of these characteristics but before that let us look at the ITZ itself as it is explored by several researchers, so this is basically, a scanning electron microscope study of the extent of the different phases that are present in terms of the distance away from the aggregate, so here this is at the aggregate surface and here you are moving away from the aggregate surface.

As you are moving away from the aggregate surface, what happens; look at this dotted line first, this dotted line represents the hydrated phases, the hydrated gel basically, so you see that very close to the aggregate its almost zero, steadily rises and then it assumes almost a standard constant value away from the aggregate. Now, in terms of calcium hydroxide plus ettringite and another component, you see that there is a decrease away from the surface of the aggregate until it assumes a somewhat constant value towards the outside.

And interestingly, the amount of anhydrous or unhydrated cement is very low at the aggregate surface and it increases to almost a constant value in the bulk paste, now, why is the unhydrated cement low near the aggregate? Because more waters available, exactly because you have more water available near the aggregate, most of your cement tends to get hydrated, and because of that you have less of unhydrated cement near the aggregate.

Now, the porosity is seen here and you can see that there is a drastic decrease in porosity as you move away from the surface of the aggregate, now of course this distance on the x-axis here is presented in terms of number of pixels but truly speaking in terms of micron's, most researchers have concluded that this zone where you can actively feel the effects of the ITZ is generally between 20 to 50 microns thick.

Most researchers agree that this zone from the aggregate surface extends to about 20 to 50 microns, again that is only by experimental observation there is no clear cut scientific evidence except experimental observation, you cannot really predict this behaviour, which is why a lot of the detractors who believe that ITZ is only an artefact also say that it all depends on the way that I mix the concrete, it all depends on the way that I compact the concrete, that you have or you do not have ITZ.

But for conventional compacting and mixing and transportation and placing purposes of concrete, most concrete seem to show up the evidence of ITZ, most concretes do and you will see that it later helps us to pinpoint certain issues that happen with the concrete, so in other words, it gives us something to blame, we always looking for someone or something to take the blame.

Whatever happens in India is always because of Pakistan that is universally known, whatever happens in concrete is because of the ITZ, now interestingly that statement makes a lot of sense when you look at some of the results that are produced in concrete, no, I was not talking about India, Pakistan, I was talking about concrete. When you talk about concrete, a lot of the properties of concrete seem to rely extensively on the zone of bonding between paste and aggregate.

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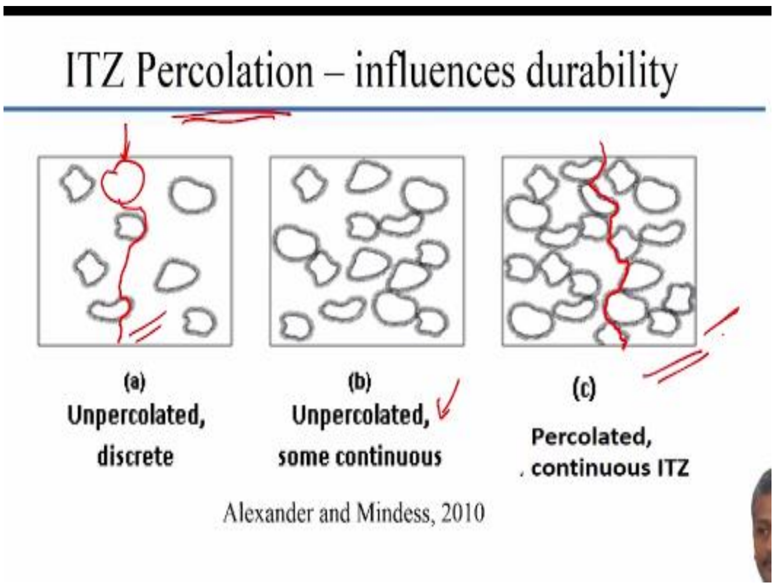

And I will show you some of the examples; one aspect which leads to poorer durability, when you have more ITZ is, this concept called percolation; ITZ percolation, what is percolation? You all make, all had filter coffee, so coffee filters, filters is basically a percolator, so water percolates between the coffee grains and slowly dissolves the coffee, that is basically, a filter coffee.

So, what is percolating here again, water. When water is percolating through a system, it will choose a path that offers the least resistance, and the path that offers least resistance will be the path that is most connected and most porous, obviously, more porosity and permeability the easier the passage of water, so what people have shown is; if you have aggregates that are discretely distributed in concrete verses if you have aggregates that are continuously packed in the concrete.

That means, there is a continuous connection of the ITZ around the aggregates, so what will happen now, it is easy to understand that if water has to enter, it will easily make its way through the connected ITZ and cause a greater permeability in the system, same to do with strength also. In strength if a crack has to actually go through this concrete, will go through the connected ITZ, in this case there is no distinct path for the water to percolate.

But through the paste, until it reaches the surface of the aggregate then goes around again reaches the surface and then goes around, so there is a lot more resistance when the aggregates are discretely distributed as opposed to when the aggregates are very close pack together. So, now what is this trying to convey; that this ITZ connectivity leads you to have a lower strength and durability.

The connectivity of the ITZ leads to you have lower strength and durability and that concept of percolation is the one that most researchers use to demonstrate the effects of the ITZ on different concrete properties, so there are, of course, there can be a situation like this that mostly you have unpercolated but some ITZ that maybe continuous but in this case, most ITZ is continuous in which case it offers a direct path from one end of the concrete to the other.

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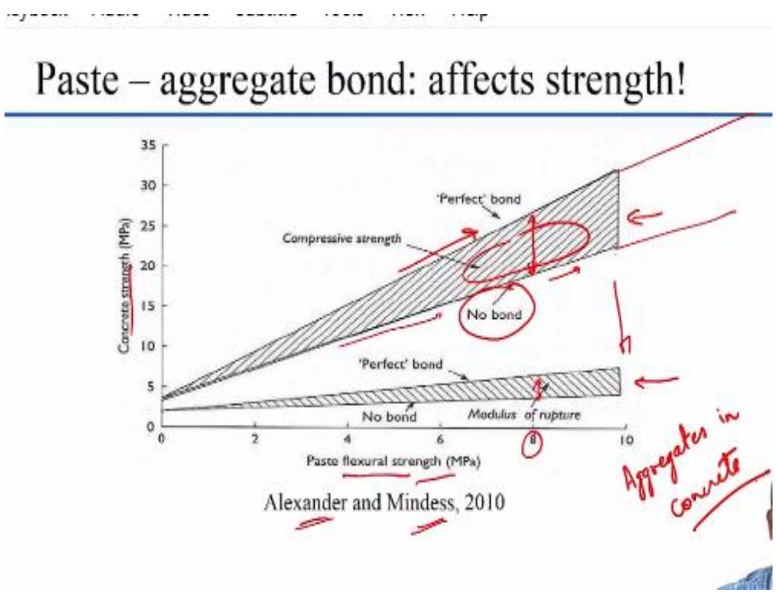

So, how does it affect concrete properties? One first and foremost property is the strength of the concrete and the paste aggregate bond has known to affect strength and people have shown this through several different results, this is a very classic diagram which shows you how the concrete strength and the paste flexural strength are related. Now, why paste flexural strength, why not paste compressive strength, why not, why do not I take paste compressive strength, why do I call flexural strength?

How does concrete failure happen? Does concrete ever fail in compression, no, it happens because of cracking that gets created in your microstructure that cracking generally happens because of tensile strength, so thst is why we are looking at the tensile strength of the phase not the compressive strength and relating that to the concrete strength, of course, concrete strength is your compressive strength.

We are talking about compressive strength of concrete, how it is determined by cracking in the paste, so now if you have compressive strength is here, the flexure strength is here or the modulus of rupture of concrete is here, so if you have an assumption of no bond and that is your line that the strength takes. If you assume that there is no bond between aggregate and paste for a certain type and volume of the aggregate if you keep on increasing the paste flexural strength, your concrete strength increases along this line.

If you assume that there is a perfect bond, that means, there is no third phase, no ITZ, then you get a line that is here, a perfect bond between paste and aggregate leads to a top line, so most concrete obviously do not have either zero bond or perfect bond, they will be lying somewhere in between, so you look here, for example for a paste flexural strength of 8 megapascals, you have a variation in the concrete compressive strength, which is of the order of nearly 10 to 15 maybe around 10 megapascals.

You have a variation in concrete strength that you can expect from different aggregates of the order of 10 megapascals and that is significant that is really large, because if you are moving from one aggregate to another, you can actually change the entire picture altogether because the same aggregate; the different aggregates will give you a different bonding characteristic with the paste.

Now, you see that as this goes higher, the difference will be more and more, in other words when I make the concrete high strength, my aggregate influence will be very large in the concrete and that is very well known that in high strength concrete, the type of aggregate that you chooses can make a lot of difference in the strength of the concrete. On the other hand, the modulus of rupture that flexural strength obviously, we know that it is how much of the compressive strength?

Around 10% or maybe at the maximum about 15% of the compressive strength, so it is definitely at a lower level but the same things happen here, you have a band of strengths that are possible for the modulus of rupture of the concrete based on the paste flexural strength whether you assume a bonded condition or a zero bond condition.

So, these are classic diagram that have been produced after years of research and a lot of work was actually done by Professor Mark Alexander in South Africa and Dr. Sidney Mindess in Canada, so they worked a lot together on this, they actually have a book called aggregates in concrete which explores in detail the role of aggregates on concrete properties. I have that book in case people are interested to go through more details about aggregate, refer to this.

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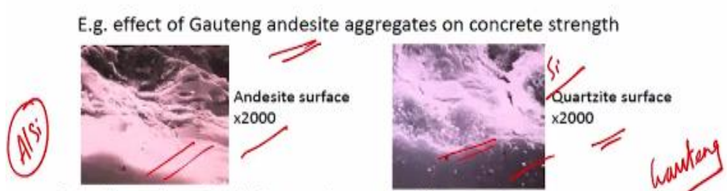

Strength premiums of andesite concrete over quartzite concrete (Alexander & Ballim, 1987)

	Age (d)	Percentage increase in strength for w/c ratio		
		0.83	0.56	0.42
Cube Compressive Strength	28	28%	23%	17%
Indirect Tensile Strength	28	19%	24%	18%
Modulus of Rupture	35	16%	27%	9%

Now, this is an example which has been produced by Professor Mark Alexander about the effect of different types of aggregate on concrete strength and this is the result that led him to work a lot more on understanding this role of the ITZ, this was one of the first studies that he did which explored very different relationships between concrete, so here he was exploring the andesite aggregate and also quartzite aggregates in a region in northern South Africa called Gauteng.

Gauteng is where Johannesburg is located, so it is a province in which Johannesburg is located, so there they have andesite aggregates available as well as quartzite aggregate, what they saw was for concrete with different water cement ratios 0.83, 0.56, 0.42, they saw that there was andesitic concrete, or the concrete with andesite aggregate seemed to give a much higher compressive strength as opposed to the concrete with quartzitic aggregate.

The same thing happened in indirect tensile strength as well as the modulus of rupture; what is the indirect tensile strength? Split tensile strenght. In all 3 strength results, what they found was the andesitic concrete give a much higher strength as opposed to the quartzitic concrete, so they went and did some microstructural analysis of the surface of the quartzite and surface of the andesite, they saw there were some differences in the structural layout.

But more than that the mineralogical composition was quite different, because you know andesitic aggregate will be aluminosilicate, whereas quartzite will be mostly silicate, so there is some difference in the mineralogical composition of andesitic and quartzitic rocks, there is some difference in the textural features that you observe on the surface that leads to this massive change in the strengths.

Indeed, if you look at the mix designs that we do here in South and compare it what is done in Delhi for instance, in Delhi they have again quartzitic type rock and sometimes limestone type rock, their mix designs are very different from ours, when we have to design concrete for the same strength, we find that with our local granitic aggregates, we get much better strengths as opposed to what our counterparts in Delhi can get.

Because of their differences in the aggregate, we never think of that that way, our mixed design also does not seem to address those characteristics because it says that once you have aggregate for concrete, you can use the mix design guidelines anywhere but you will find out that it does not work quiet that easily. The other aspect is the basalt aggregates in Maharashtra for instance, you get basaltic aggregates and there especially, in Mumbai there is a ban on river sand.

So, they have to use the crushed basaltic aggregate as a crushed sand, problem with that is basalt when it crushes; basalt is extremely fine grained crystals, when it crushes, it forms very fine grained particles, so as a result you get aggregate that can absorb a lot of moisture whereas granitic aggregates when you crush them, they do not make too many fines, excess fines are not there, so the kind of effects you get of crushing the aggregate into fine aggregate.

Crushing the rock into fine aggregate are very different depending on the type of rock that you actually start with, so there are distinct benefits to using one type of aggregate or another but you are obviously constrained by what you have available locally, you cannot transport aggregates to a large distance.

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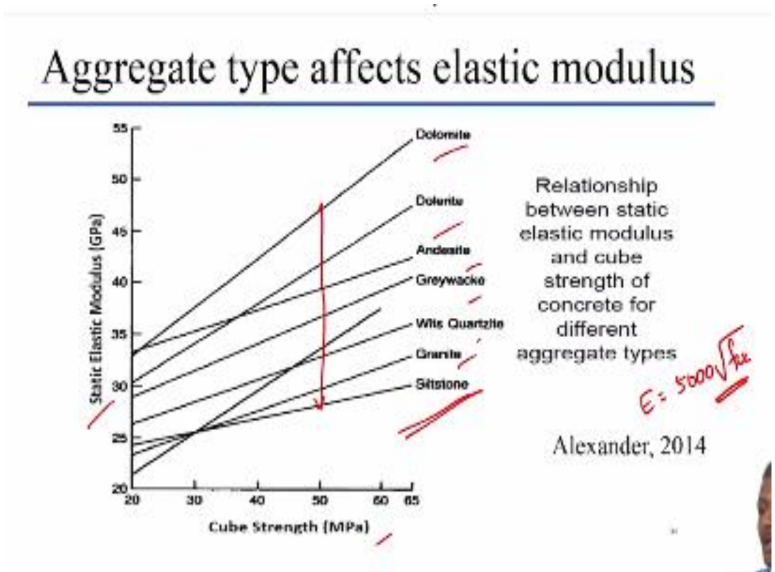

So, again arising out of the work that was started by Professor Alexander, there is now a lot of literature available on the influence of aggregate, so this is the static elastic modulus versus strength relationships. What is the typical relationship that we as assume? Static elastic modulus is equal to 5000 square root of f_{ck} that is our typical IS relationship, but again we do not really specify what type of aggregate that is applicable for.

You can see from this, depending upon what type of aggregate you have, for the same strength, you have such a wide range of moduli that you can actually get which only makes sense because bulk of the concrete is filled with the aggregate, so the concrete elastic modulus will be mostly governed by the aggregate elastic modulus, it is not just the ITZ, it is also governed by the aggregate elastic modulus.

The aggregates that are stiffer will lead to higher elastic modulus, for example dolomite, dolerite, andesite, greywacke, granite, siltstone, these will be the decreasing order of the modulus of elasticity with these aggregate.

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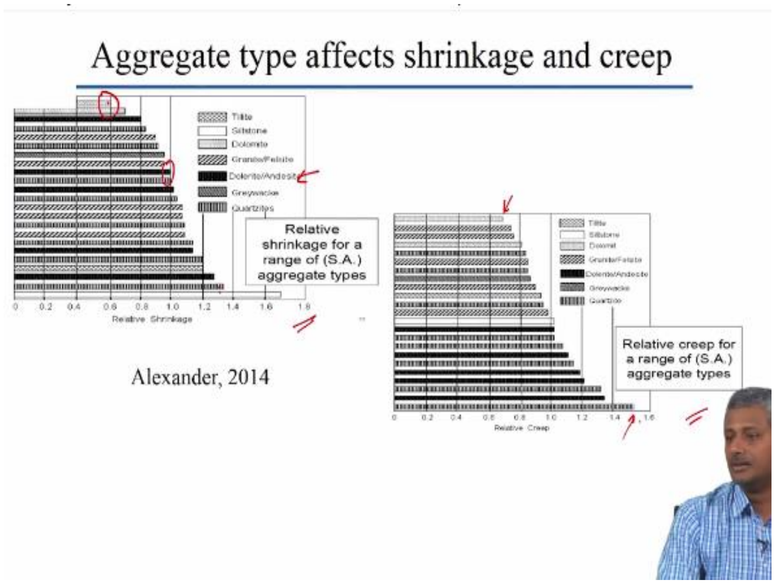

Aggregate type primarily affects dimensional stability shrinkage and creep, and these are relative shrinkages of concrete for different aggregate types, of course, the water to cement ratio of the concrete is fixed to enable comparison across a different range of aggregates, so here you see your relative shrinkage for different aggregate types and a relative creep for different aggregate types.

You can see here that the shrinkage varies from 0.6 all the way up to about 1.3, supposing this one is the aggregate that is the control mix or reference aggregate that is andesite compared to that you can have a variation of 40% or 40% below or 30% above, so very large variation is actually possible in the extent of shrinkage that you get from the concrete. Again, why; why is shrinkage affected by the aggregate?

Shrinkage is resisted by aggregate, which type of aggregate will resist shrinkage more; the ones which have higher elastic modulus, right so again, the dolomitic aggregate which you saw in the previous graph has the highest elastic modulus for a given strength that leads to the lowest shrinkage and so it goes with creep also, with creep also you we will get, lowest creep with dolomitic aggregate and the highest creep probably with quartzite aggregate.

So, creep is again the resistance to loading over a long term period or time dependent deformation because of sustain loading and that creep also is lower, if your aggregate modulus of elasticity is higher because aggregate will tend to deform much lesser, if it is going to be stiffer and that will constrain the entire concrete from changing its dimensions, so again please remember that aggregates mostly we consider as an inert phase in the system.

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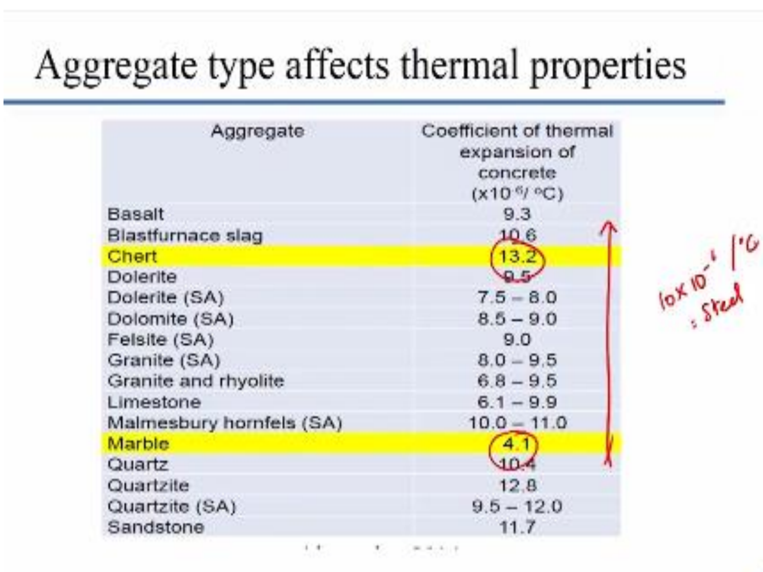

But they lend themselves to very unique properties of the concrete, primarily they effect of dimensional stability because of the elastic properties. Now, thermal properties of concrete can also depend to a large extent an aggregate which is only conceivable because you know very well that aggregates are forming the bulk of your concrete, how much of your concrete is aggregate?

About 70% of the concrete is aggregate, in normal concrete at least 70% is aggregate, so because of that concrete thermal characteristics will be controlled by aggregates, so depending upon the aggregate type, the coefficient of thermal expansion of concrete is vary, the minimum value is 4.1, maximum is 13.2, very large differences in the kind of thermal coefficients that you can actually experience the aggregate.

So, for example when you use a river bed gravel, when you use a river bed gravel, what type of aggregate do you get, what is the mineralogy of the aggregate, when you take river bed gravel? You do not know, you can get a mixture of different things; you can get a mixture of different things because this is aggregate that is weathered and simply carried by the river. So, when you extract river bed aggregate most of it may be of the same type, may be some sedimentary rock.

But there could be different pieces present in it which could have very different characteristics, so that is one problem of using riverbed aggregate is that you may get varied characteristics within the same batch of aggregate, and you need to be very careful about how to do screening to identify the components that could lead to problems. What about steel, what is the coefficient of thermal expansion of steel, it is about 10 multiply by 10 power minus 6, and this is probably the major reason why steel is used as reinforcement in concrete.

Because, it has got a compatibility with the concrete in terms of coefficient of thermal expansion, well, here primarily we are talking about course aggregate because again, bulk of the system is course aggregate, yeah because fine aggregate could as will be river sand because most of these research studies would have been produced with fine aggregate that is river sand.

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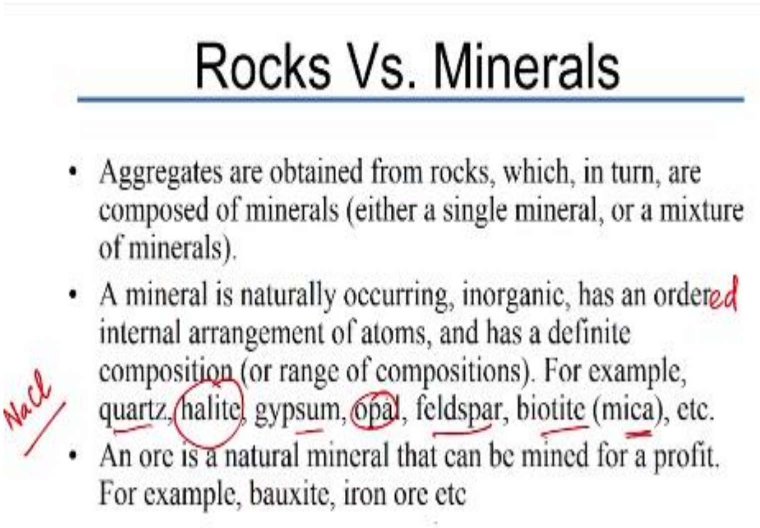

Now, obviously we have understood that the basic impact of the aggregate is because of the kind of mineralogy it has, so let us take a brief look at what kind of minerals actually constitute an aggregate and what property do they bring about in the aggregate that leads to a change in concrete characteristics. So, again you know very well that aggregates obtained from rocks and rocks can be composed of one or more types of minerals.

Mineral obviously, is a naturally occurring inorganic material which has some order or ordered internal arrangements, sorry, has an ordered internal arrangement of atoms and has a definite composition or a range of compositions, you know about different minerals already, you know that quartz is the mineral, quartz is also a rock; quartz is a mineral as well as rock. The rock quartz is formed by multiple numbers of quartz minerals joining together.

What mineral is halite, has anybody heard of halite? You may be actually seeing it on day to day basis but you do not know what it is. Halite is your salt; rock salt, halite is basically the mineral sodium chloride, and of course, you know gypsum very well, gypsum is naturally occurring, it is a mineral; it can also form a rock. Opal; we use a lot in ornaments and jewellery, but opal is also part of your sedimentary rocks, one of the type of sedimentary rocks.

Feldspar; where do we get Feldspar, which rock gives you, which rock has Feldspar as a main constituent, rock you are all familiar with? Granite; granite is the local rock and feldspar is the most common mineral in granite, you have biotite, which is micaceous minerals, these are micaceous minerals. Again, you have learnt these before, I am not going into an extensive treatise on geology but something that you need to recall.

Because many of these minerals define the characteristics that the aggregates will have, now of course, you know very well that an ore is different from mineral and ore is essentially a natural mineral that can be mined for a profit like, you have bauxite or iron ore, what types of iron ore are there; hematite and magnetite, the oxide composition of iron is different in hematite and magnetite.

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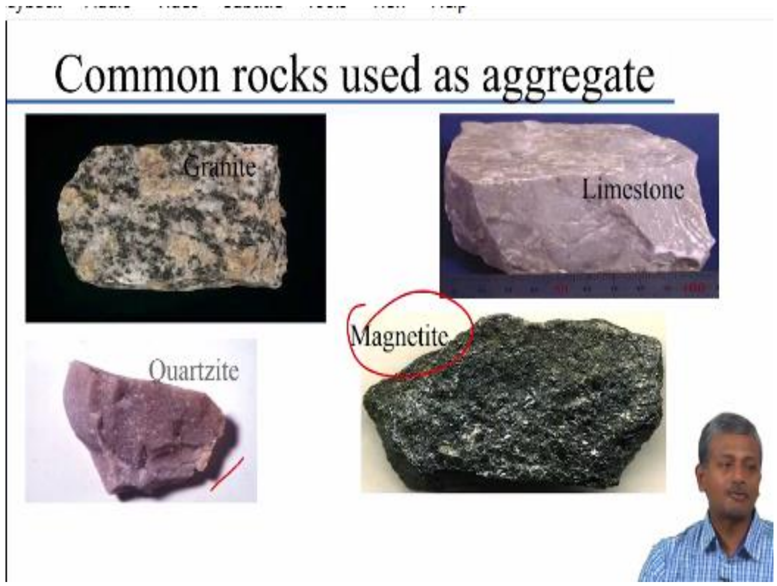

The common rocks that are used as aggregate you know very well, granite, limestone, magnetite, and quartzite, where is magnetite used as aggregate? For high density concrete because magnetite is iron; made with iron because of that it lends a very high density to the aggregate which contributes a density to the concrete and where do you need high density concrete? For nuclear radiation shielding, it is used only in nuclear reactors for radiation shielding purposes.

But of course, you can also develop other usages of high density concrete primarily for designing underground walls for instance, you can design underground walls, bunkers and so on but people do not use that as much as high strength concrete, so the high density concrete can also be utilised in other locations but mostly it is used for nuclear radiation shielding. Quartzite; now from a basic look at the surface characteristic itself, we can tell that there is a major difference between the different types of rock, which could be used as aggregate.

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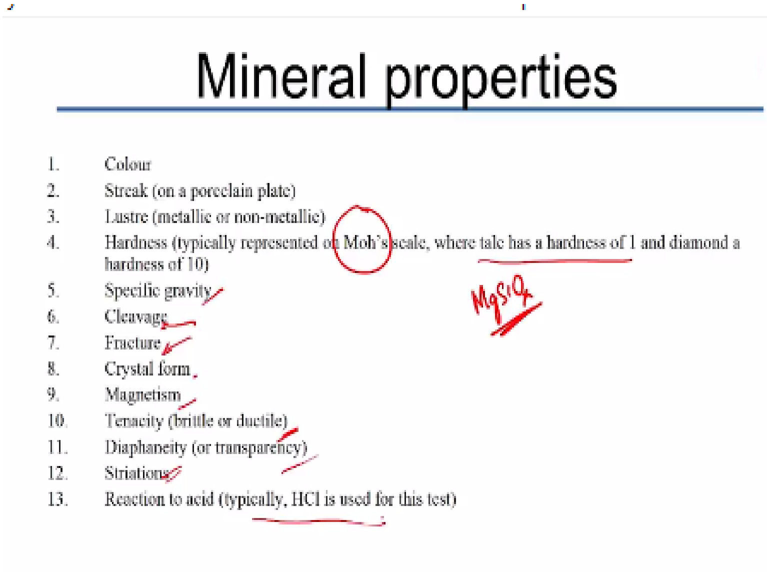

So, what are the mineral properties that are of importance, you have done these tests sometime before probably, when you studied geology in your college, of course, the colour of the mineral, streak that means you take this mineral and rub it on a porcelain plate, the streak or the line that is left behind is characteristic of different types of minerals, you have the lustre, which the shine on the mineral.

Then, you have the hardness; hardness is the random scale that we use from 1 to 10 is called the Moh's scale, where the lowest hardness is talc, which is hardness of 1 and highest is diamond which is hardness of 10. What is talc, what material is talc? Talc is basically the magnesium silicate, talc is magnesium silicate, and of course, you know very well, where it is used for creating very fine powders for instance.

So, hardness is a scale that is not really quantitative that means when you go from hardness of 1 to 2, it is not the same as going from hardness 2 to 3, what is the hardness of steel on the scale, about 6.5; 6.5 is a hardness of steel, limestone or calcite have a hardness of around 3, and concrete which is essentially made with the same component, a little bit more than 3, is between 3 and 4 generally, that is the hardness of concrete; a concrete or cement paste rather.

The other important characteristics of the mineral is specific gravity, then you have cleavage, fracture, these are important in describing the way in which the aggregates will fail or the rocks will fail, when you apply a load to them, the form of the crystal that is there that means, whether it is cubic, orthorhombic, triclinic monoclinic and so on. Magnetism, obviously this is important for the minerals that are bearing what; iron, yeah.

Minerals that are bearing iron, tenacity or ductility of the aggregate, transparency or diaphaneity of the aggregate, not aggregate; mineral, striations whether they are having some striations present on the surface and reaction to acid, where is this used, what type aggregate can you distinguish by a reaction to hydrochloric acid, so when you drop the acid, what will happen from the aggregates surface?

You will see bubbles coming out, what were those bubbles? CO_2, so obviously those are only there for carbonate aggregates, the limestone and dolomite if you sprinkle acid on it, it will effervesce carbon di oxide, granitic or siliceous aggregate will not have the same effect, so that is one test that is effectively used to distinguish carbonate aggregates from the others, so we will resume from this in our next class.