Advanced Concrete Technology
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Lecture – 05(A)
Cement Classification – Part 1

So let us not go there, we will come to something that civil engineers have to deal with on a day-to-day basis that is specifications for cement as per different standards, which are existing around the world. Now, I am not talking about all standards, but I am talking about some prominent ones like ASTM and EN, Euro Norms and of course since we are in India we will of course also talk about BIS or Bureau of Indian Standards.

Now ASTM standards classify cement into 5 different types, you have type 1, 2, 3, 4 and 5. Type 1 is called General Purpose cement.

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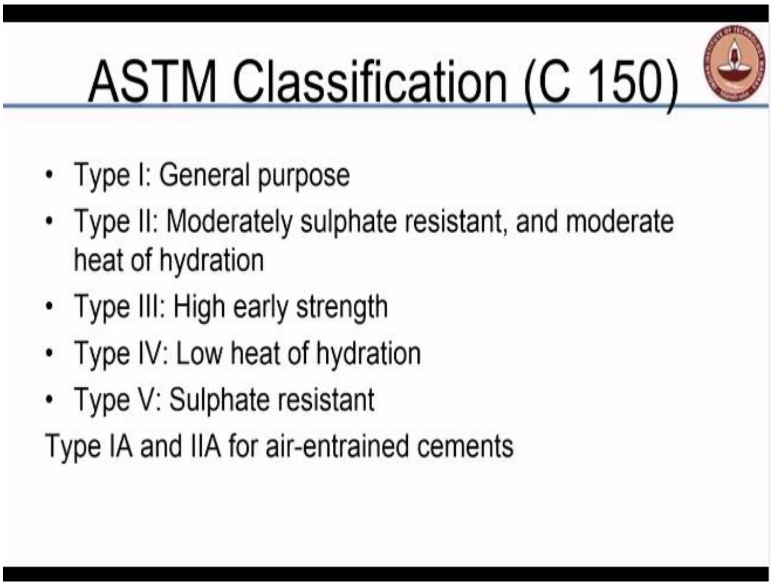

In India of course we simply call this as OPC, Ordinary Portland Cement that is what we would called this as in India. The second one is Moderately Sulphate Resistant and moderate heat of hydration. Now this is something which we do not have in India, okay. We do not have a cement like this which is neither OPC nor sulphate resistant nor low heat, this is somewhere in between.

And, type 3 is high early strength cement and in India again we call it as Rapid Hardening Cement, I will talk about this later. So type 3 is high early strength cement when you want the structure to gain strength very fast. Type 4 is Low heat of hydration cement or low heat cement, in most other countries it is called low heat cement and type 5 is Sulphate resistant cement or SRC.

So, these 4 cement types that is OPC, rapid hardening cement, low heat cement and sulphate resistant cement probably you will find in every standard around the world, okay, but this type 2 moderately sulphate resistant and moderate heat of hydration is something you will find only in the American standards, okay and American standards also allow you to have air-entraining cements.

What does that mean? The air-entraining compound, the air-entraining chemical is added during the cement manufacture itself to produce cement which already has these compounds in it. So you can have either type 1A or type 2A, air-entraining cements also which can be used in very specific purposes. Now let us look at what are the properties of these in terms of the composition.

So type 1 is ordinary Portland cement, so again the composition is similar to what we discussed earlier. For a general Portland cement we expect the C_3S to be the primary constituent about 50% or more. So C_3S is definitely of that order here.

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Typical Composition

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

C_2S, I am sorry that the headings of the table are shifted a little bit. So C_2S on the other hand is about 20-30% as I was saying nearly half of that was C_3S, C_3A is 8-12% and C_4AF of 6-10%. Type 2 or moderately sulphate resistant and moderate heat of hydration, the primary difference is that it has got a lower C_3S content and a lower C_3A content as compared to type 1 cement, that is the only difference of type 2 with type 1.

Now of course when you lower C_3S, what will go up, C_2S because generally the balance of aluminates and silicates are the same in every cement. So if you lower the C_3S, your C_2S goes up. If you lower the C_3A, the C_4AF of course up. Now type 3 cement has a higher C_3S content because we want a higher early strength and in general it will also have a higher fineness.

We are finely grinding the cement to a specific fineness, to make it more reactive all we need to do is grind it finer. So when you grind it finer it becomes more reactive. You also have to remember, when you grind something finer because of the reactivity, you are also increasing what? The heat of hydration, exactly. When you increase the heat of hydration, you are causing more possibilities for thermal cracking to exist in your system, okay.

So type 4 cement or low heat cement, what do you need to do, you need to reduce the amounts of compounds that are creating the maximum heat, which are those compounds? C_3S and C_3A. So again you see C_3S content is very low, and C_3A content is also low. So both these contents are reduced when you have low heat cement. So in another words you care causing C_2S to be much higher, and C_4AF of course is higher as compared to the ordinary Portland cement.

Mainly the C_2S content is what is very high. So this kind of a cement I talked about the fact that C_2S does not gain strength very fast and gain strength very slowly. So if you are able to cure this concrete prepared with the cement for a very long period of time your strength gain will continue for a very long period. Whereas an ordinary Portland cement we say that potential strength gains stops at what age? we say 28 days.

In reality it continues much further, but by 28 days you get the potentially maximum strength that you can get out of the OPC. Now the faster the cement reacts, the quicker that potential strength gets obtained. With rapid hardening cement or with type 3 cement you many actually get that strength gain as early as 7-14 days, but beyond that there is not going to be a significant improvement in your strength.

The faster you make the system react, the quicker the potential strength is reached, and this may actually end up producing a structure in the compound or in the concrete, which may not be as durable as the cement that reacts slowly. So the old adage of slow and steady wins the race happens here also, but nobody really is bothered to worry about that today we want our concretes to be very rapidly strength gaining.

We want to complete our construction projects early, but there is a price to pay, which I will talk about when we discuss the structure the cementitious compounds that actually forms or hydration products that actually forms and later we will link that to durability of the concreter and you will see that, generally higher temperature cured systems are prone to more durability problems as opposed to lower temperature cured systems.

Alternatively, higher reacting systems are more prone to durability problems than lower reacting systems. Which is probably one of the reasons why many of our older structures do not show much signs of damage in spite of 40-50 years of service. In spite of the lower grades of concrete that were used. Of course, we can also say that the designs were very conservative, we had very high factors of safety.

In India we were using the working stress design principles for a very long time which meant that your concrete was never subjected to more than one third of its potential strength levels. So, there are several factors obviously that lead to performance of older structures much more than modern structure, but one of the critical aspects is that we now have concretes that are expected to gain strength very fast.

And that comes with the host of problems that need to be looked at carefully. The aspect of cracking is probably the most important problem that we need to pay attention too today in modern concrete technology and that is something we will be touching upon quite often during the course of the semester. Alright, so type 5 cement, that is sulphate resistant primarily owes it is resistance to lowered quantity of C_3A, 0-4% C_3A.

And we will discuss as to why this happens when we talk about the reactions that are involved in cement chemistry, for now you can understand that the sulphate resistance is bought about by lowering the content of C_3A. So again this is just putting into words what I have already discussed, type 2 has marginally lower C_3S and C_3A in comparison to type 1 cement.

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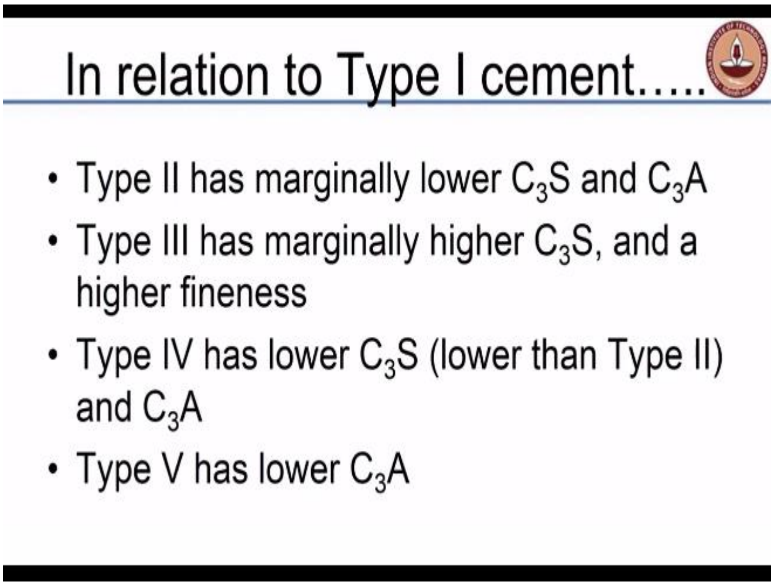

Type 3 has marginally higher C_3S and a higher fineness. Type 4 has lower C_3S and C_3A and type 5 simply has lower C_3A as compared to type 1 cement. So some results that you can see from your text book also.

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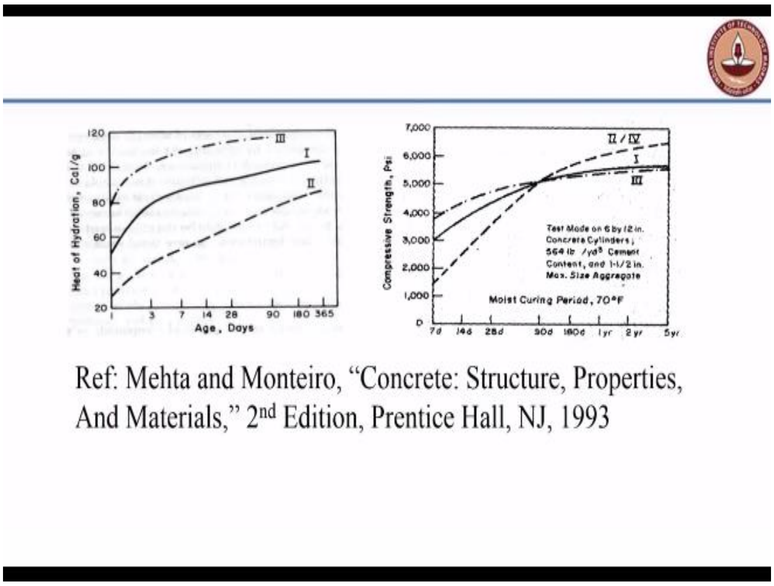

The one by Mehta and Monteiro of course these are pictures that have been photocopied from an older edition of the same textbook. So here you see type 1 cement, heat of hydration of type 1 cement. So this progressing rapidly in the beginning and then it starts slowing down. Type 3 cement progresses very rapidly then it slows down and probably comes to a asymptotic sort of a system where you do not see a major increase.

Type 2, which is moderately sulphate resistant and moderate heat of hydration you see that the heat is continuously increasing. Now this is the heat of hydration, that means you are reacting each and every compound that is present in the system. Whenever each and every compound reacts, each gram of compound reacts you liberate some heat. So continuous development of heat of hydration implies what?

It implies that the reaction is continuing. You have a continuous reaction that keeps on happening. When the heat of hydration becomes asymptotic that means your reactions are stopping. Of course this also means that your strength is continuously growing, again that is showing in this picture here on the right and here you have type 1 systems which are starting off at high strength and then tapering off by about 28-90 days.

Type 3 cements are starting off at a much higher level, but then they taper off much faster, you do not gain strength much longer even in spite of continued curing. Type 2 and 4 cements which are higher in C_2S you see that they start off much lower, but then the rate of strength gain is almost continuous for a very long period of time. This is actually real concrete specimens that have been subjected to curing over 5 year durations.

You can imagine that the extent of data that they have actually generated right from 7 days to 5 years, they measure the strengths of concretes with different types of cement and most of this work was done in the past in the Portland cement association in the US, Portland cement association, okay, that is of course, it does not function as a Portland cement association anymore.

It is probably a private company now, but the Portland cement association is responsible for lot of interesting data, long term data about concrete that was published in the 20th century and the other establishment that you will often hear about is the British establishment called BRE, it is called Building Research Establishment, it is in UK and they have also produced a lot of interesting data. Much of the work that has been done by PCA and BRE actually finds its results implemented in standards and specifications around the world.

You will see IS 456, we have got several different tables that relate to the properties of the cements desired and how much minimum strength and maximum water cement ratio that is desired to obtain durability, all that is coming from the long term work that has been done by these 2 primary establishments which have looked extensively at concrete research. Maybe one more thing you can hear often is the US army corp of engineers.

They have also done extensive amount of work. So PCA, US army corp of engineers, building research establishment in the UK, these are all really landmark, they have done landmark research that has led to a lot of developments in concrete technology today. Blended cements in ASTM are covered in different standard, of course we have talked about the regular cement classification that is covered in C150.

I urge you to take a look at these standards, to get an idea about how these cements are actually classified, what are the different properties that have been mentioned and so on. And then we go into ASTM C595, that is the specification for blended cement in ASTM.

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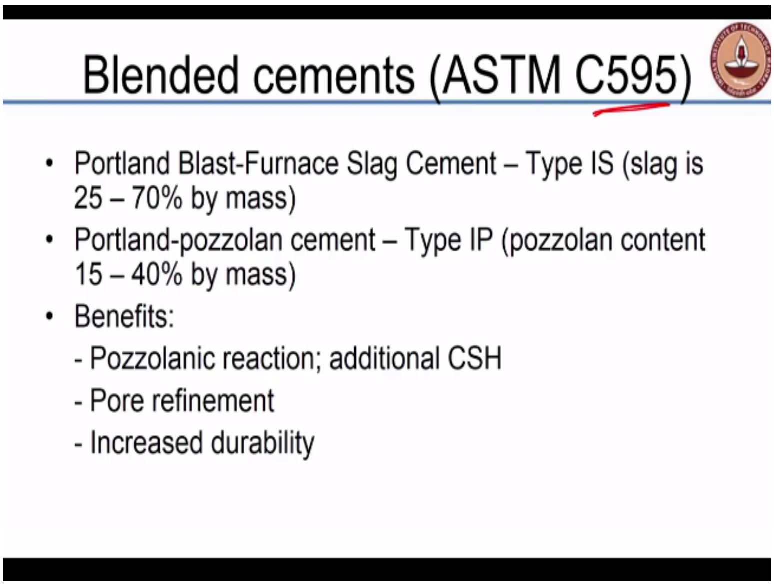

Now the blended cement, primarily there are 2 types, one is Portland Blast-Furnace Slag Cement, it is called type 1S and type 1P for pozzolanic cement or Portland-pozzolan cement which we have in India also we will call it as PPC. In India we call this a PSC of course and this is PPC. Slag content in the Portland blast-furnace slag cement is about 25-70% by mass.

So you can actually have a cement, slag cement in which you have 70% slag, 25% clinker and 5% gypsum. So that is an acceptable cement in terms of a blended Portland slag cement. In the case of a pozzolan cement which is type 1P you have 15-40% by mass of the cement is a pozzolanic material. Now in India, PPC is almost entirely containing what pozzolan? fly ash.

In India Portland-pozzolan cement is essentially fly ash based cement, but in the US or countries that follow the ASTM standards the pozzolan could be fly ash, it could also be naturally occurring volcanic ash, that is also permitted as a natural pozzolan or calcined clay, that is also a pozzolan as per the American classifications. So pozzolan content in this system is 15-40% by mass.

Now the reason why we have only lesser levels of substitution possible with pozzolan as opposed to slag is because slag is actually considered to be one of the hydraulic cements itself. Slag is actually a hydraulic cement because on it is own slag can still react with water. Although this reaction takes forever to happen, it takes a very long time to happen, but slag can eventually react on it is own with water.

In the presence of cement slag gets activated and reacts much faster. On the other hand, pozzolanic materials cannot react on their own with water. They need the presence of cement because cement generates calcium hydroxide upon hydration or lime upon hydration. This lime is reacted with pozzolan to produce CSH in the pozzolanic reaction. Again we will talk about this detail a little bit later, but essentially your pozzolanic systems cannot work on their own without the presence of cement.

So that is why the pozzolan content in PPC is much lower as opposed to the slag content in PSC. There are several benefits that you get from this, you get additional calcium silicate hydrate formation by the pozzolanic reaction which refines your pore structure that means it reduces the size of your pores present in the system and of course if you reduce the pore sizes you also are going to reduce the interconnectivity of the porosity and that leads to increased durability.

We will talk about this in more detail in the subsequent chapters, but for now Portland-pozzolan cement and Portland slag cement lead to an improved durability of the concrete. All this is assuming that you do adequate curing, one aspect that many of us tend to forget, at least in practice when we do concrete construction that we forget that the pozzolanic and slag systems without appropriate levels of curing cannot be brought to levels of the same structure as ordinary Portland cement.

So you need to cure it substantially longer as compared to ordinary Portland cement to obtain the benefits that are listed here. So again this is showing some examples again from the text book, which tells you how the heat of hydration actually reduces when I increase the pozzolan content in the cement.

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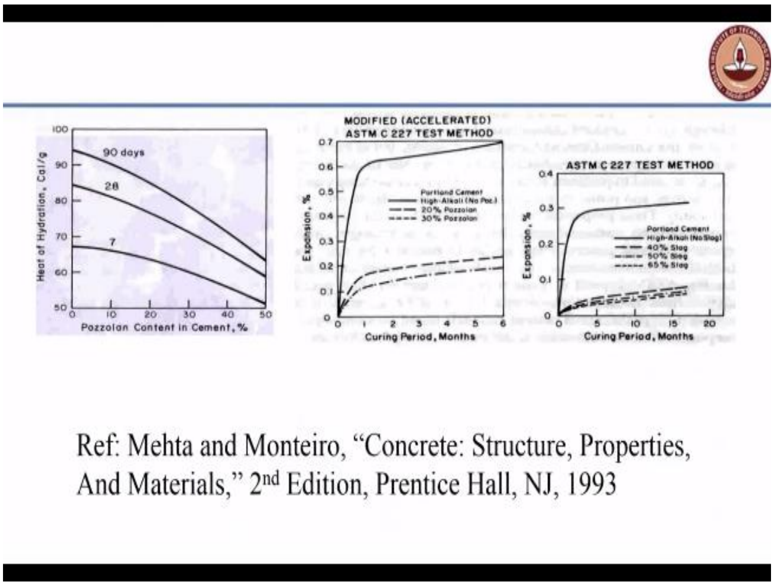

So that is a direct benefit, that you reduce the amount of heat that is liberated during cement hydration, the other aspects that you tend to improve are the performance of concrete in alkali silica reaction. Now this is something that is presented from there, you see the top curve looks at the expansion of concrete or of mortar made with ordinary Portland cement when subjected to a very high alkaline environment.

Or when subjected to conditions that favour alkali-aggregate reaction for example when you have a reactive aggregate, in the same case when you have pozzolanic materials you are bringing down the expansions significantly. So later we will discuss about alkali silica reaction in more detail and the best and most elegant solution to this problem is to simply replace the cement with pozzolanic materials.

And you can really cause massive reductions in the expansions that occur. Again this is also showing you with slag. This one is with pozzolan and this result is with slag. So you can see that the expansions due to alkali silica reaction are reduced significantly when you replace cement with pozzolanic materials and slag. Very commonly we call slag also as pozzolanic, we should not do that. Slag is actually a hydraulic cement on its own.

It is not a pozzolanic material it is a cement replacement material yes, but it is not pozzolanic, it does not react like the others, it can react on it is own. It produces its own hydration products also. Now an interesting rather new development with the American standards is the introduction of the performance based standard for cement.

Now again this is something which we will discuss again about what is performance based as opposed to what is prescriptive. Now when we saw the earlier standard C150 and C595, they were prescriptive. They said that your cement should have so much C_3S, so much C_2S, so much C_3A and so much C_4AF. The performance based standard tells you that you do not need to have any of these.

You can produce anything as long as you can meet my performance requirement. That is what the performance based standard tells you. So there are no compositional restrictions.

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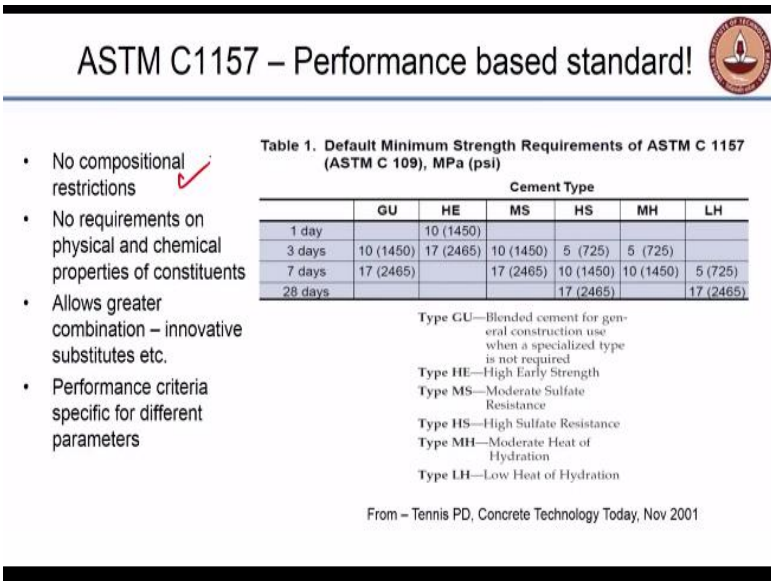

There are not requirements on physical and chemical properties of the constituents, which is interesting because now you have the option of playing with several different types of cement replacement compounds, of course if you have to look at the standards to realize that you cannot use anything that you want, but it permits you a very wide range of compounds as cement replacement.

So you do not have any strict norms on what your cement should have, it allows greater combination and you can actually work with innovative substitutes for example you do not need to substitute cement with only one replacement material, you can actually work with combinations of replacement materials given the kind of synergies and kind of chemistries that they can exhibit in a cementitious system.

And one such example that we will talk about much later is the ternary blended cement like a Limestone Calcine Clay cement that is something we will talk about in our discussion of mineral additives to concrete. And the performance criteria can be specific for different parameters. So one example of course is this table that has been reproduced from the standards.

So you have here the requirements of strength for different types of cement you see here. Names are given as GU, which is blended cement for general construction use. Type HE is high early strength cement, type MS is moderate sulphate resistance, type HS is high sulphate resistance, MH is moderate heat of hydration and LH is low heat of hydration. Now again if you compare this with ASTM C150, again it is showing you the same types of cement.

Like something similar to OPC, something similar to type 2, type 3, type 4, type 5 like that, so here instead of saying that my cement should have so much C_3S, I am saying that the general use cement should develop at least so many megapascals of strength at 3 days and 7 days. The high early strength, the strength requirement is much greater at the early ages itself, at 1 and 3 days itself.

For the low heat cement obviously my strength requirement is lower. I require only 5 megapascal by 7 days and 17 megapascal by 28 days. Now again this is only the strength requirement, apart from the strength requirement you may also have other requirements, for example, for the low heat of hydration cement, there should also be a requirement for the heat of hydration obviously.

You need to have a requirement for the heat of hydration, so you also need to have an appropriate technique by which you measure the heat of hydration. So it is not as simple at it seems to use a performance based cement because the requirements of performance also dictate that you have to do the appropriate tests to get that requirement satisfied. So then again you need to be familiar with these tests.

You need to be having the equipment to do these tests and ensure that you are producing the result with the cement as to the standard which is dictated here. So, it just does not mean that you swap together any combination of materials and produce cement and call it GU or HE or whatever. There are performance requirements that need to be met with very specific test methods.

And these test methods have to be available in your laboratory to actually prove that you have met the required standards. So please go through these standards, it is available of course on the IITM library website you have access to all the American standards because IITM is the subscriber so you should be able to get a copy of the standard, it is quite interesting to see the kind of requirements that are there and later when we discuss concrete durability one of the aspects that we talk about will be performance specifications.

And you will see that, in concrete specifications also, one of the common problems that we face today arises because we are prescriptive in nature. We give very strict boundaries as to what composition the concrete can have and that sometimes lead to very inefficient type of concrete mixes that we have to deal with in engineering practice.

So very often we can overcome that by performance specifications and that is something we will discuss in quite a bit of detail in our durability chapters. Moving on to BIS classification, again I am not going to do the very specifics of different types of cement, I am just listing the more generic types that are there as per BIS, so you have ordinary Portland cement.

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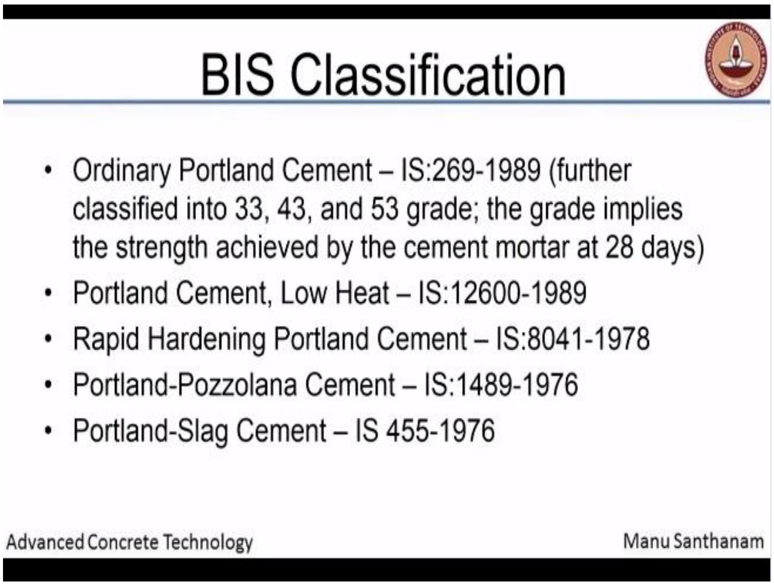

Which is further classified in terms of the strength grade. In India, we have 33, 43 and 53 grade cements, okay, and the grade implies the strength achieved by cement mortar at 28 days. So obviously at 28 days, the 33 grade cement obtains the strength of 33 megapascal plus a certain standard deviation that you need to overcome to look at the variability also in the system, 43 has to reach a 43 megapascal strength, 53 has to reach 53 MPa strength.

Now tell me something, does this mean that if I prepare a concrete with these cements, I will also get the same strength? No, obviously not, because concrete have to design for the strength grade that is required in the concrete, so if I have to design an M30 concrete in other words concrete that has characteristic compressive strength of 30 megapascals at 28 days, which cement should I choose? 33, 43 or 53 grade? 53 would be more ideal.

Why do you say 53 would be better? 53 will be more reactive obviously because the cement is producing greater strength at 28 days, so 53 is more reactive, but does that mean I cannot use 33 or 43, no it does not mean that, I can use any cement, I only have to design my concrete mixture appropriately, that is all.

But again in concrete my strength demands are for 28-day strength. The cement that get you the fastest growth to 28-day strength for a certain quantity is 53 grade cement. If I have to use let us say 360 kilograms per cubic meter of 53 grade cement for a particular strength in the concrete when I use 43 grade cement, I may have to raise that cement content to about 400 because I need more reactive material to get me the same level of reactivity at 28 days.

And I may need still greater contents of 33 grade cement. Of course today you do not have a choice, you do not get 33 grade cement anymore. It is not produced because there is a vast difference in the performance requirements of 33 and 43 or 53 grade cements. So today we only get 43 or 53 grade cements in the market. So there is not tremendous difference in the performance levels but the strength gain levels of 43 and 53 grade cements will lead to different cement contents for the same grade of concrete.

So when you do a design of the concrete mixture to obtain a certain strength the type of cement makes a difference because your strengths are dictated by what you get at 28 days. Now if that were not the case, if you could talk about the ultimate strength potential of the concrete then would it make a difference, if I go with 43 or 53. If I continue to cure this concrete for indefinitely long period of time, will it make a difference?

It would not make a difference as to what cement type I choose in the beginning because finally if all the cement reacts the composition is not all that different in these systems. Of course there will be minor differences because 53 grade cement may have higher C_3S as oppose to 43 or higher fineness which may lead to a difference in the extent of reactivity that is possible from these compounds, right.

So all that may happen, but potentially I may not get any difference in the extremely long term strength of my concrete irrespective of the type of cement that I have. So this is only pertaining to the 28-day strength. When I want to design concrete for 28-day strength the higher the grade of cement that I choose, the more likely I am to get that strength target met with the certain quantity of the cement.

Now why 33, 43 and 53? Where are these numbers coming from? Is it per centimetre square converted, no, but why not 30, 40 and 50? There is no answer to that, even I am not sure what the answer is, if you go to Europe they say 42.5 and 52.5, I do not know what, at least 43 and 53 are better than 42.5 and 52.5, but still there is no clear cut understanding.

Probably in the early days when they were looking at standardizing these materials with the kind of materials that were available with the cements that were produced in those days they were mainly approaching these levels of strength development. If you are able to find the answer to this please let me know, I have also been trying to find out why 43, 53, but I am not been able to get a handle on that.

It is possible that when you convert this to pounds per square inch you may get somewhat of a more rounded thing, for example 43, I think will approximately be 6000 pounds per square inch, 6000 psi, whereas 53 will be about 7500 psi, so maybe that maybe one of the reasons that the original standards were 6000 and 7500 pounds per square inch and when they were converted to megapascals it became 43 or 42.5 and 53 or 52.5.

But anyway if you find the real reason let me know. It is not important anyway so, we have to deal with the cements on a day-to-day basis and so 43 and 53 grade cements are the strength grades and why is the strength of the cement measured on a mortar? why do not we measure just on cement paste? We say it is a cement strength, right, why do we measure it on mortar?

Why cannot we measure the strength on cement paste itself? Cement paste would tend to shrink, there is no way that can keep its dimension carefully right properly. So if you make 7 cm cube like we do in India we would not get all 7 cm when we test because the shrinkage will be tremendous.

But more importantly you want to test a mortar because of something else, because of the function of the cement paste in concrete. The function of cement paste in concrete is to bind the aggregate. So if you test it on an appropriate mortar you get a much more better understanding of what the cement is capable of doing in concrete, so it is a binding strength of the cement that we are addressing with the test on cement mortar.

We use standard sand for testing, however there will be a lot of variability associated with the standard right, 43 and 53 because the standard sand also may vary, water may vary. So we are practically assuming that standard sand does not vary from one location to other because in India for example the BIS has a very specific standard sand. Right now it is collected from Ennore, is north of Chennai and that is the one which is cleaned, packaged and sold in different fineness grades as the standard sand.

So as long as we use that in every laboratory in the country it is fine. We do not expect any variations to occur because of standard stand, because it is all centrally produced and distributed, for example if you go abroad also ASTM standard sand is available which is again a very well classified sand. So that any 2 laboratories using the same sand should not show any variability because of the sand.

And then all the cement tests are supposed to be done at controlled temperature and with the certain quality of the water. So as long as that is maintained you should not expect variabilities to arise from that, but what you said is right, although several cements classify from this for the same grade like 43 or 53 very often we get very different results from these cements.

So there is no, if you look at our specifications carefully there are minimum requirements but there is no maximum requirement. For example, the fineness, if you look at the fineness standards for 43 and 53 grade cements it tells you that the finest should be minimum of 225 square meters per kilogram, it should be at least 225 square meters per kilogram, but it does not tell you how much is the maximum level.

So if you get 2 different cements with vastly different fineness ranges then you may actually have a very different performance in terms of the strength development as well as the performance in concrete. So you can get very different performances, but not just the fineness sometimes even the type of the kiln operations that produces the compounds can end up producing very different morphologies of the C_3S and C_2S that leads to a large difference in the way that the heat is produced.

A large difference in the way that the strength is attained. So again you can get massive variabilities between cements that are coming out of different plants. To give you an example sometimes from the same brand of cement you are not sure as to what performance you are going to get, to give you an example Coromandel cement, one of the prominent South Indian brands, so they have several of what are called grinding units.

Now that is something I did not cover during cement production, not all cement plants have full-scale cement plants located at every location. In several places they simply put grinding units. So grinding units means, these are units which are capable of only of the final stage of cement manufacture that is inter-grinding the components. So what they do is they get the clinker from the cement plant.

And all the other materials that need to be ground are also available at these grinding units like gypsum, fly ash like lime stone or slag if you are producing slag cement at the grinding unit. So at the grinding unit what they simply do is inter-grind all these components together. So cement, the same brand of cement can sometimes be made from clinkers that are coming from 2 different locations.

So if a grinding unit is based in Chennai there are 2 possibilities of getting clinker, one is from Andhra which is a place called Tadipatri, that belt is basically very rich in lime stone, Kadappa region it has got lot of lime stone and that is where many cement plants are located. The other belt which is close to Chennai is down south near Trichy in the Ariyalur district that is why you have lot of cement plants located because they have very good lime stone availability there.

But the quality of the lime stone that is available in these locations can be quite different, while you have much higher grade lime stone available close to Kadappa, you do not have that level of lime stone available in Ariyalur, so clinker that you ultimately get from these systems can be massively different in how it actually works in concrete or how it works as a cement.

So what we have seen by our research experience is that the cements that are made with the Andhra clinker are producing much greater strengths as compared to cements that are produced using the Ariyalur clinker. Now this is the same cement mind you, like Ultra Tech or Coromandel or other companies that are producing these cements they are selling the brands as the same cement brand.

But you do not know what clinker you are getting so very often the performance can change which is why in concrete you have to keep testing there is no other way. So there are quality controlled test that are done whenever cement is delivered to a job site. Now today in addition to that we must also do some studies or some minor studies at least on the compatibility of these cements with chemical admixtures.

So that is where this hurts the most, when you have different cements coming from different productions you can actually get vastly incompatible combinations of cement with superplasticizer halfway through the project. And you may not get the required strength development with the mixed designs that you have been using.

So you may want to change that also. So there is a lot of dynamic changes that you need to do to encounter the issues related to different clinkers to produce the same kind of cement, so that is something you have to keep at the back of your mind. Sometimes the problems on site are inexplicable, I mean for many months the construction goes on without any problems, all of the sudden the source changes and you have all kinds of problems happening.

So you must realize that this could be something related to the cement also because of the kind of production that is being done for the cement. Of course we cannot blame the cement companies because the grinding units obviously have to get the demands met or they have to ensure that they produce enough to satisfy the demand in their area and to satisfy this demand they maybe actually calling for clinkers from different locations. So that is something you cannot avoid in practice, okay, so we will stop at this today.