Advanced Concrete Technology
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Lecture - 01
Cement Production - Part 1

Welcome to the first chapter in our course on advanced concrete technology. Today, we will be talking about cement production and as I was indicating earlier I have also highlighted the sections from the textbook which have the relevant information. I hope that some of you have been able to procure the textbook already and those of you have not done so already I hope that you will be getting it soon.

So it will help if you read this content before you come for class, so that you can participate actively and contribute to the class discussion. As I was indicating earlier, this textbook has been written very well and it is written in a language that is easy to understand without using too much very highly technical or research oriented jargon, it is probably intended for massive use as a textbook all over the world.

So the content that you find in these sections will be very relevant to what we will talk about in class.

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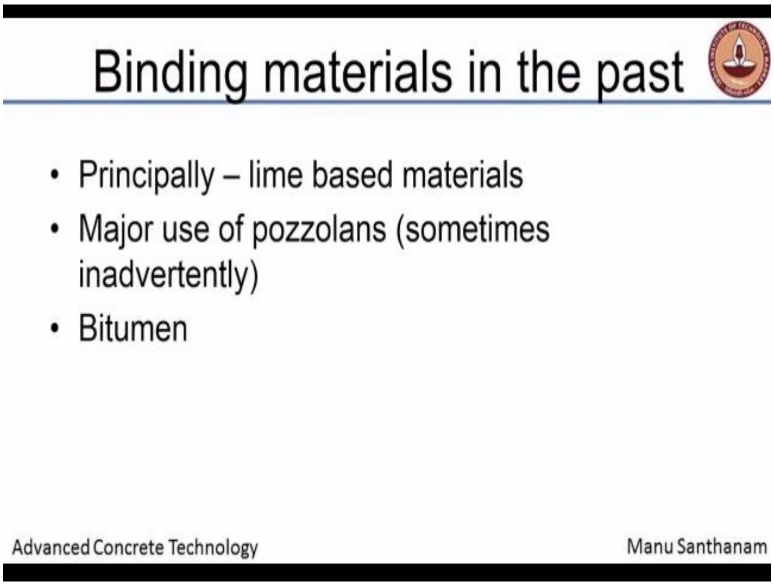

So, without further ado, let us first talk about what were the binding materials that were used in the past. Now this is something that you know very well, most of our ancient heritage monuments if you think about them have different types of binders which are binding the different masonry units.

Mostly, lot of our heritage monuments are in stone and brick and these masonry units were bound typically by binders which were based either with lime or some binders were based on gypsum and sometimes even Bitumen has been used in the past quite significantly, and in some cases the use of pozzolanic materials was also quite prevalent in the past. Now of course today we have very specific categories of pozzolans and how they are supposed to be used in concrete, how they are processed.

There is a very clear cut understanding of how the system actually works, but in the past people had used pozzolans quite inadvertently. For example, in Greece and Italy there were several examples of the use of volcanic ash as an ingredient to the lime mortar and the people who were using it found that the use of volcanic ash gave the lime mortar very good properties in terms of improved strength and applicability and so on.

So, because of that there was inadvertent use of pozzolans in the past but today of course when we look at, think about pozzolans, there are several different pozzolans that come to our mind today. Can you give me some examples of what types of pozzolans are there today? **"Professor - student conversation starts."** Silica fume, fly ash, rice husk ash, one more prominent type is, calcined clay.

We sometimes call it Metakaolin, slag yeah slag is also mineral admixture **"Professor - student conversation ends."** But once we talk about cement composition and cement chemistry you learn that slag is not truly classified as a mineral admixture, it is more of alternative cement itself, alternative hydraulic cement, okay, but these are pozzolanic materials that we commonly use today for most of our blended cements and also for concrete which contains mixtures of cement with these blending materials.

Now, we have gone several steps beyond the use of these simplistic mortars because these were based primarily on ingredients that were found and could be obtained in the form of engineering practice based on very minimal processing, for example gypsum is naturally found also you do not really need to process it. Bitumen again naturally found, you do not need to process it and lime based material of course were derived from limestone.

Limestone is calcium carbonate and when you burn calcium carbonate you remove carbon dioxide and get calcium oxide which is your quick lime which serves as a binding material, right. So now this obviously was a precursor to the development of Portland cement, and there are several people who have used different variations of cement in the past, okay. Now one first name that comes to our mind is that of John Smeaton.

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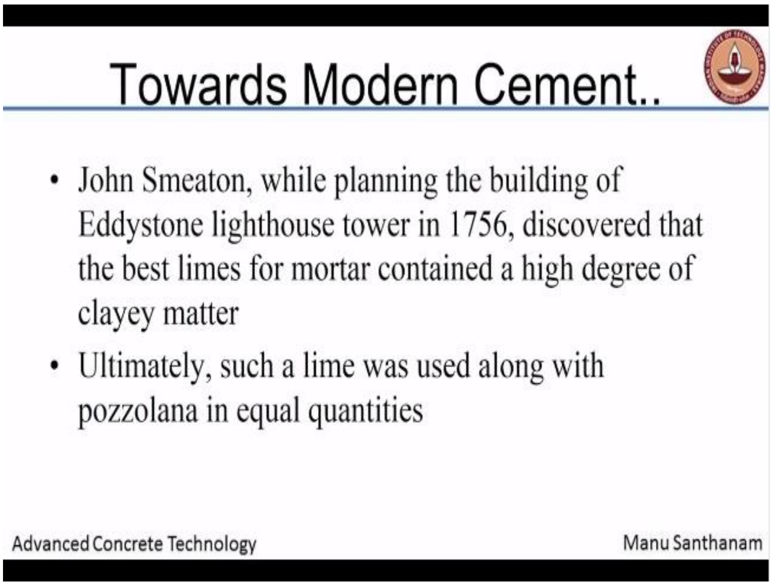

Now how many of you have heard the name John Smeaton before, some should have heard John Smeaton okay. What was specific about John Smeaton apart from the fact that he built the Eddystone lighthouse tower which is already there in the slide. So no marks for that, so what is special about John Smeaton? **"Professor - student conversation starts."** This is a quiz question, I mean not the quiz what you write, this is Trivia quiz basically.

John Smeaton, any guesses, you were saying something. No, no, no that was a different person, that was Aspdin. I will come to him in the next slide. John Smeaton was essentially the first civil engineer. Why do we say he was the first civil engineer? Okay what is meant by civil? Which is not military exactly, so he was a first non-military engineer to do building construction that is why he was called the first civil engineer okay **"Professor - student conversation ends."**

He can be coined as a father of civil engineering and whatever that means anyway, so John Smeaton was a first civil engineer, because he was the first from nonmilitary background to actually do building construction. So he planned the building of this Eddystone lighthouse tower in the 18th century and he discovered by accident that he had different sources of lime to prepare as lime mortar.

Can you found that the ones which had a large proportion of clay matter as an impurity, those were the ones which actually gave him best properties as a lime mortar. So, again we know today that cement is the mixture of lime stone and clay which is burnt together under very controlled conditions but in the past, right from the 18th century people have been using some form or the other of cement.

So ultimately what John Smeaton did was used this kind of a lime along with pozzolana in equal quantities to produce the lime mortar which is required for the Eddystone lighthouse tower.

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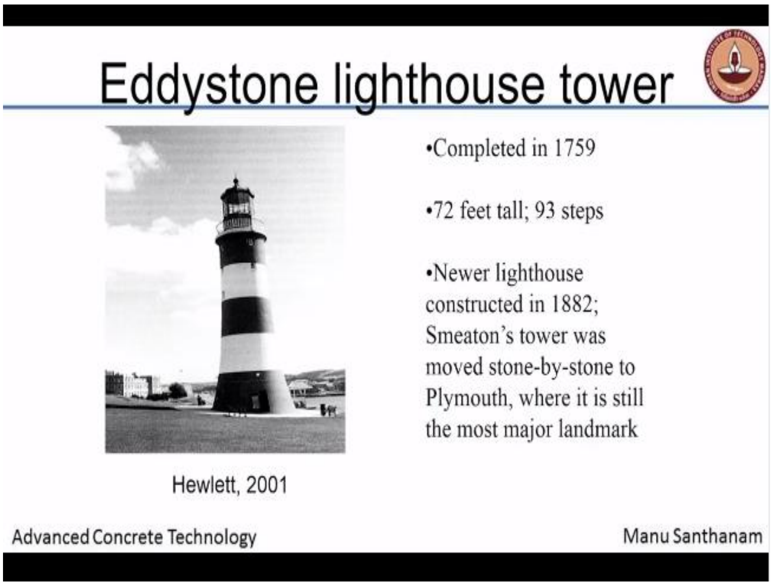

This is the photograph of Eddystone lighthouse tower, of course this is no longer an active lighthouse tower, but it is still a prominent national landmark in the UK because it is in the memory of John Smeaton, so because of that it is still a permanent landmark okay. There is a new lighthouse that was constructed about 100 years after this and this entire lighthouse tower was moved stone by stone to another location where it is still a major landmark.

Anyway, so proceeding further what were the steps that led to the development of Portland cement, as somebody was saying the person who first coined the term Portland that was actually Joseph Aspdin but before him there were several other scientists who were working on different types of cement okay, different types of ingredients that were similar to what we commonly call today as cement.

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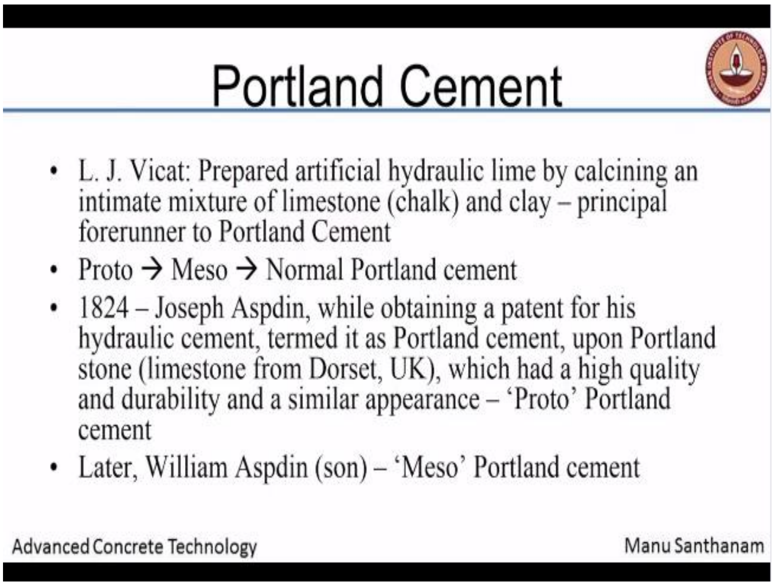

So now, Vicat, another name that you are all quite familiar with, where does Vicat come, in Vicat apparatus correct, you would have all used Vicat apparatus to determine some properties of cement like the consistency of the cement, initial and final setting time and so on, okay. Now this Vicat was also a French scientist who in the laboratory developed an intimately calcined mixture of lime stone and clay that was probably the first precursor to your Portland cement that we know it as today.

Now in the development of cement there are many stages and researches spent to classify these in terms of 3 different types, you have the proto-Portland cement that means the first few variance that probably was associated with the work that was done by Vicat and probably Joseph Aspdin in the beginning and then later Meso, that means towards the beginning of the 20th century, the kind of cement that started coming into prominence that was essentially attributed to William Aspdin who was Joseph son.

So he was the one who really pioneered the art of modern cement manufacture and today we have completely different product, we call it modern Portland cement. The requirements of cement have changed quite a bit in the last 100 years. Now what is the primary necessity from cement? **"Professor - student conversation starts."** No, of course binding, even the past binding was the primary necessity but why is cement different today compared to the past?

It is more C_3S okay more C_3S why because, we want faster setting and faster strength gain. Primarily, we want high early strength so most cements today are engineered to obtain a very high early strength. **"Professor - student conversation ends."** In the past, it was not this case I mean in the past people were willing to wait for a longer period of time for their structures to come up, which is actually a very positive attribute.

But today we moved from the test match generation to the T20 generation, so we want everything quickly. So while in the past people were willing to cure concrete for 28 days and today we have curing done for 3 days, probably no curing at all, people want the concrete to be ready right after it is poured so anyway the upshot is that cement has undergone massive changes in the past 100 years and because of that today it is a completely different kind of material.

Now of course you know the story quite well that it was named Portland cement because once cement hardened and set after reacting with water, it had an appearance which is similar to Portland limestone in the United Kingdom, it has got nothing to do with the city of Portland. It is actually some stone which is called Portland limestone in Dorset, United Kingdom.

And based on that Joseph Aspdin actually patented the name Portland cement. It is interesting to see that this patent even after nearly 200 years is still active. Although, the patent has run out several years ago, the name is still used, right. If you go to somebody and try to sell them ordinary cement, they will not buy it but if you call it ordinary Portland cement, then there is some mark of authority.

You say that okay this is the Portland cement and you are trying to sell Portland cement, so Portland cement is something which is actually having no meaning today because the term Portland is no longer valid right, the patent ran out several years ago. So now it is just ordinary cement but we still call it Portland cement because of the power of the brand, okay. Again a common example I give everybody is Xerox.

Xerox was the name of the one of the first companies that came up with the photocopying machine but today I challenge you to find a Xerox machine in any of the photocopying shops, only you will find some Japanese makes Minolta, Sharp, Canon and so on. You will not find a Xerox machine anymore okay but we still use Xerox as a noun, as a verb and everything possible right. We say that I am going to Xerox these notes okay, we do not say I am going to photocopy these notes so that is again the power of branding.

So the name Xerox stuck on for several years even after the machine actually ran out, they stop making any profits I guess, but today we still call it Portland cement and that is because of the patent that was there for several years and the name somehow stuck with being associated with the quality of this material that is today produced in large quantities.

So this was work done by some researchers who tried to figure out what was the original cement like.

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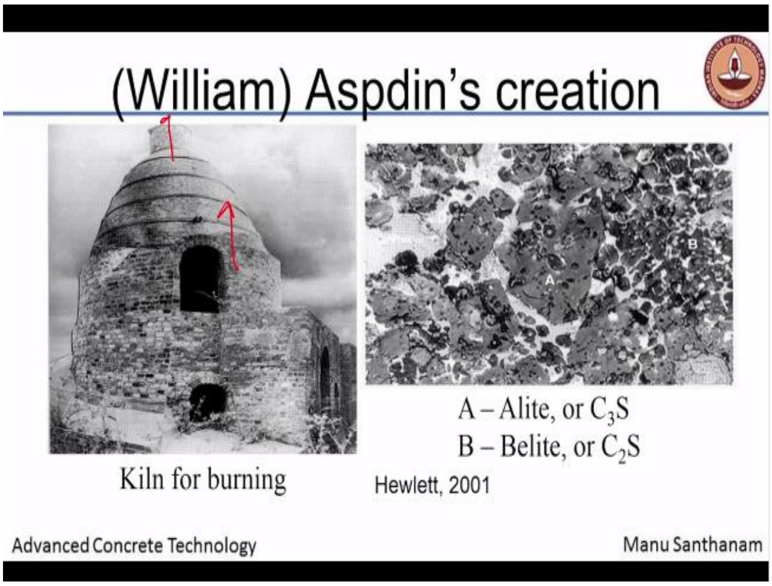

So they went to the kiln that was used by William Aspdin for burning and you can see that this is the type of kiln that was used. Since this is a shaft which is quite similar to what we have for typical limestone kilns. So this is actually called a vertical shaft kiln, so you feed in the material at the bottom and it is getting heated and the carbon dioxide goes up from the top and ultimately you essentially get calcium oxide which is remnant or quick lime.

And this quick lime was again processed probably with additions of several other components to get your cement. Now of course that the quicklime is obtained in a limestone kiln but in the cement kiln, what Aspdin would have done is mix the limestone and clay together and fed in as charge and then heat it for a certain amount of time after which the material was pulled out and then you would have obtained the Portland cement clinker from that.

So now you know that, these kinds of kilns are no longer used. **“Professor - student conversation starts.”** What types of kilns are used today? We use rotary kilns which are basically very large drums which are rotating at a very slow speed and the advantage of that is you feed in the material at one end, it comes out at the other end without the need for any additional energy input.

And secondly since it is a continuous process because the material comes in at one end, leaves at the other end so you can continuously keep feeding the material. **“Professor - student conversation ends.”** In a vertical kiln like this obviously you have to wait for entire burning to take place, remove your material from inside and then again have the next batch placed in, so the amount of material that you can produce in a vertical kiln is quite limited.

And on the right you have this microscopic image of the sample of clinker that was actually collected by researchers from this kiln and you can see from this that the kind of components that we see in modern cement are still there, A is basically Alite or tricalcium silicate C_3S, B is Belite or dicalcium silicate C_2S. Now there is a certain difference in the kind of Alite’s and Belite’s that are actually there.

I will tell you later as to what the primary differences are in terms of the crystal sizes and the reactivities that was found in the older cement and how it is different from the modern cement.

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Comparison of PC – then and now

Parameter	Aspdin clinker	Modern clinker
Relative burning rate	Slow (poor)	Quick
Alite size	60 μm	10 – 40 μm
Belite size	5 – 10 μm	20 – 60 μm
Cooling rate	Slow (poor)	Quick
αC_2S	Nil	10 – 20%
Kiln	Vertical (beehive)	Rotary

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So coming to that, how is the modern clinker different from what William Aspdin first made in his vertical kiln, okay. So if you compare different properties and composition, so this is what it looks like. The relative burning rate that means the speed at which the burning happened obviously that is going to be different for a vertical kiln versus the rotary kiln. In the case of old clinker, the burning rate is quite slow because again the material is charged and then you have to wait for a certain period of time and then the material gets removed.

In the modern clinker, the burning is rather quick because the entire time that the material spends inside the kiln is only 30 minutes. The material comes in at one end and goes out at the other and traverses the entire distance of the kiln that is nearly about 60 to 70 meters sometimes in the matter of 30 minutes. So the burning is rather quick, okay, and because the entire material is going through the same temperature phases, the burning is a lot more uniform in a rotary kiln that is why you get much better burning in today's clinkers.

The size of the Alite crystal that is C_3S crystal in the clinker that was produced by Aspdin was nearly about 60 microns whereas today you get clinker sizes or Alite sizes in clinker between 10 and 40 microns. What it does tell you about the reactivity? You get more reactive Alite in modern cement clinkers, correct. On the other hand, Belite sizes are rather small in the previous clinker.

But today Belite sizes are little bit larger because the burning is a lot more uniform and complete as a result of which you get larger crystal sizes of Belite. You will find later when we discuss cement chemistry that for the most part this component of Belite remains unreacted in the first nearly 7 to 28 days of hydration. Only very long term hydration tends to react this Belite that is actually available.

Because it is a very slowly reacting material okay and again we will relate that to the kind of crystalline shape and the impurities that are available in Belite which cause it to have rather a low reactivity, okay. The cooling rate once again in the past you have to actually remove it from the vertical kiln, allow it to cool naturally but today we have specialized clinker coolers about which we will learn later in this chapter which are used to actually cool the clinker that comes out of the kiln because of which you can actually get a very rapid cooling rate.

Certain form of C_2S or Belite, alpha C_2S which is one of the polymorphs of Belite is found in modern clinkers but it was not there in the older clinkers, okay, and of course as the kiln as we already discussed is the vertical or beehive kiln in the past and today we use the rotary kiln because of its greater efficiency and much higher output as compared to the vertical kilns.

So let us now come to the production of Portland cement. Before we discuss the individual steps of production, I want you to realize these things.

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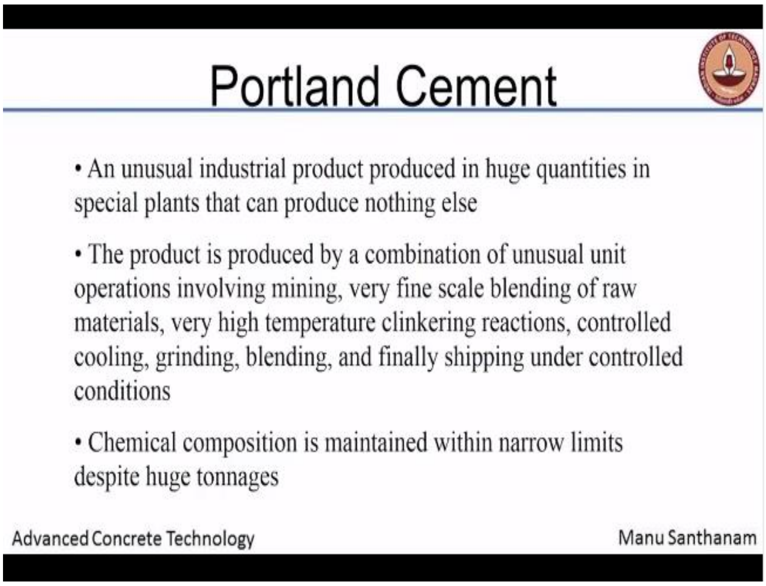

One is Portland cement is an unusual industrial product which is produced in huge quantities and special plants that can produce nothing else. **"Professor - student conversation starts."** and do you know how much cement is produced around the world or a nearly basis, annual basis, any idea, any guesses, sorry, any number, throw out some number don't worry, it may be right.

No, you are talking about effect of cement production but how much cement is actually produced? Related to that we can, I do not think you can back calculate, no, so how much cement is produced, any numbers? How many million tons? 1400, 200 all over the place, all wrong, it is more than 4000 million tons, okay. The amount of cement produced in the world is around 4000 million tons or even more out of which nearly 35 to 40% is produced in china, right **"Professor - student conversation ends."**

And like everything, India is second to China in cement production. India is second to china in cement production, India is second largest producer of cement in the world and we have an installed capacity of nearly 300 million tons but our current production is probably about 260 or so okay. We produce 260 million tons per year. Of course, much of the cement is used within the country.

We are also exporting cement to several other countries and somebody was raising an important point that cement production contributes to nearly 7 to 8% of carbon dioxide emissions around the world. Why? Yeah, obviously it was a primary raw material for cement manufacture is calcium carbonate. When you are burning this calcium carbonate, the carbon dioxide goes out.

So for every ton of calcium carbonate that is burnt, around 400 kilograms equivalent of carbon dioxide actually goes out in the atmosphere but apart from this you also have burning fuels, okay some of these are coal based fuels right some of these are other alternative fuels but overall because of burning of fuels also there is additional charge of carbon dioxide that goes out into the atmosphere.

So it is estimated that for every ton of clinker that is produced, an equivalent of one ton of carbon dioxide goes out into the atmosphere. So you can imagine the kind of impact cement production has on the carbon dioxide emissions that is why it is leading to about 7 to 8% and overall I think the building industry itself is contributing nearly 20% of CO_2 emissions around the world.

That is because not just cement, the other components of concrete production like aggregate, aggregate crushing, aggregate production and then your transportation of the concrete, the job site activities that relate to building construction, all those involve the consumption of energy. So when energy is consumed obviously that accounts for some burning and this burning also accounts for CO_2 emission.

So, there is a large amount of emission that goes out from the construction industry and the maximum part of that is from cement production. So today there is a major emphasis on not just LC3 but technologies that can reduce the amount of cement that is used in concrete to produce a given quality of the concrete.

So coming back to this perceptive that cement is produced in plants that can produce nothing else, the product is produced by combination of unusual unit operations involving mining, very fine scale blending of raw materials, very high temperature clinkering reactions, we have temperatures of nearly 1500 degree Celsius which is reached during this process of clinkering, controlled cooling, grinding, blending and finally shipping under controlled conditions.

And all this has to be done keeping in mind that the chemical composition should be maintained in a very narrow range. The tonnages are huge, we just discussed 4000 million tons around the world and you still have to do this with the kind of quality control that produces chemical composition which is within a very narrow range, because then you do not want variability to happen with cement, right.

Typical plant costs are very high; I mean this is probably a number from several years ago 250 million dollars but I am sure that today this number must have doubled, okay. The plant must also produce continuously to pay off capital cost because this is a very large investment. So if you don't produce 24 hours a day, 365 days a year, you are not going to be able to maintain the cement plant or pay off the loans that you would have taken to actually build these cement plants.

3 shifts per day and again if you stop the kiln operation for even one shift, the problem is your material variability will increase. If you have the kiln running continuously, you will have the same level of composition or rather the range of compositions will be kept to very constrained and narrow ranges if you are able to operate the kiln continuously. The moment you stop operating it and restart it, it will take a long time before you can actually come back to you regular cement production.

So, again you need to do it on a continuous basis, 3 shifts per day and there are several environmental constraints also because you know that there is CO_2 emission first of all, but since you are burning different types of fuels there are also other emissions SOx and NOx, you must have heard about different forms of sulphur oxides and nitrogen oxides and these are also emitted in the atmosphere and depending on where you are in the world the constraints could be very stringent or probably somewhat less stringent.

But nevertheless they are very much there and you need to ensure that you are keeping these things in control while you are doing your burning of the raw materials inside the kiln.

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All this must be done to produce a commodity product that sells for 6 to 8 rupees a kilogram, okay, I think our 50 kilogram cement bag is about 390 rupees. **“Professor - student conversation starts.”** Interesting question again why 50 kilograms? Why is the cement bag weighing 50 kilograms? Easy to handle, have you tried handling 50 kilograms? For labours it is easy to handle, believe me it is not, one person lifting 50 kilograms can be a back breaking exercise.

Even 2 people lifting it can be a fairly difficult one, why 50 kilograms? The equivalent cement bag weight in the United State where they use still an old system of units, pounds, it is 94 pounds okay, our’s is not as bad 50 kilograms. We are not using 46 kilograms; it is conversion of 94 pounds. Why 50? Some basic thing must be there? Why is it 50? No, that depends on the mix design and today we are doing mix design mostly by weigh batching.

So does that give you some idea why 50 kilograms, because in the past volume batching was used and if you go to several sites where volume batching is still done you find this cubical looking bucket that they used to measure the ingredients if you fill up one cement bag, it will exactly fill that bucket, so it is approximately one cubic foot right, that bucket is approximately one cubic foot and that one cubic foot is filled up by about 50 kilograms of cement. **“Professor - student conversation ends.”**

So instead of measuring cement in the bucket, they can now put bags directly in volumetric batching. So, in volumetric batching you have proportions like 1:1:3, 1:2:4 and so on, right. So in that case only the sand and stone need to be measured with this volumetric bucket. The cement taken directly used as bags, so that is the advantage of having this 50-kilogram bag.

Now if you read the standards carefully, cement can also be packed in other weights but then they want to maximize the amount of packing so that they can minimize on the transport costs of the cement. Apart from bags of course you know that cement is also available in bulkers, when it is supposed to be transported in huge tonnages especially to ready mix concrete plants and so on, they obviously have to send it in bulkers.

Bags are still preferred for trade construction, for regular construction in the market, but for large construction infrastructure where they can set up their own silos to handle the cement obviously they will be getting it in bulkers. So all this is done at a cost which is significantly low okay less than bottle water, so imagine the kind of constraints and the kind of operations that go on the cement plant, how well they need to be controlled.

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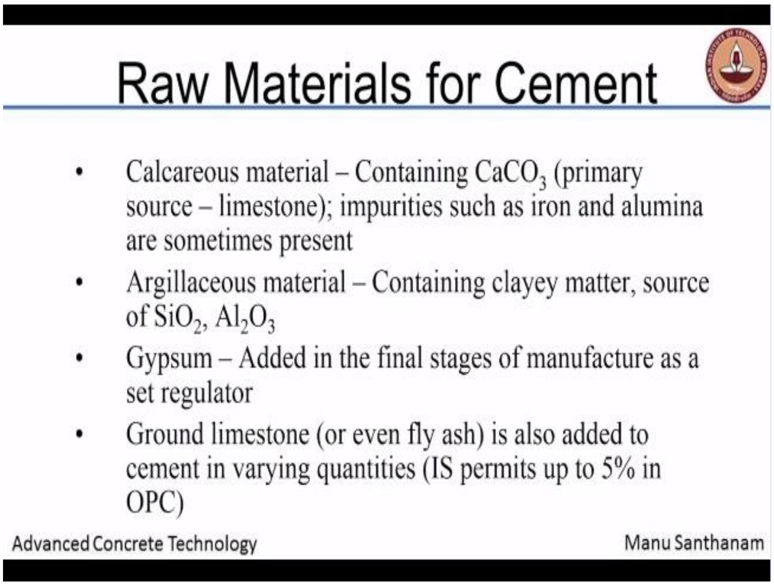

So coming to the raw materials for cement production, we know that the primary raw material is the same that was previously used for lime that is calcium carbonate. So it is essentially calcareous material, it need not be just the limestone, it could be other forms of calcium carbonate which have certain impurities also. I will talk about that in just a minute. The source of your lime may also have some impurities in the form of iron and alumina.

It is not going to be entirely purely limestone. Then, you have a clayey material or argillaceous material which has primarily a source of silica and alumina because clay is basically aluminosilicate right, clay is aluminosilicate. Now if you think about it, about 80% or more of your cement is essentially limestone, 80% or more of the raw material for cement is actually a limestone.

The clay is only a very minor component which may even be present as an impurity within the limestone itself because when you do mining of limestone there is obviously clay to be found as an over burden or between layers of limestone. **“Professor - student conversation starts.”** How is limestone formed? Any idea? How is calcium carbonate formed?

It is a sedimentary rock but sediments from where? From where these sediments coming from? What are these sediments? Calcitic sediments, so most commonly found where? Skeletons of shelled organisms, sea creatures mostly right. So because of the weight of the sea water on top, the shelled organisms which died, basically the sediment started breaking and recompacting under pressure. **“Professor - student conversation ends.”**

And these layers probably would have formed over hundreds or millions of years. So if you visit a limestone quarry you will see that there are distinct layers of deposition. So each layer of deposition is one geological event, okay and what will happen is after that layer of deposition you might find a layer of clay which may have been the overburden during that time, okay or sand or other things which are mixed, the soil which was mixed.

So it is a very interesting scenario, I will show you some pictures later on when we actually move to the segment on aggregates. So concrete even though we are using it today is also a very historic material right because we are obtaining the raw materials from materials that were existing millions of years ago or materials that were formed millions of years ago.

So even when you are not dealing with stone, when you are making cement or aggregate also you are dealing with extremely old material and this has been processed to make something totally new. Gypsum is another raw material that is used in cement manufacture and it is added in the final stages of cement manufacture as a set regulator. We will talk about how this affects the cement chemistry and it does a major effect on cement chemistry.

And today if you look at the standards for ordinary Portland cement okay anybody knows the number for the standard. **“Professor - student conversation starts.”** Anybody has referred the standard for Portland cement? 269 is the correct number but have you referred the standard? Okay you should refer, make sure that you do refer these standards because ultimately a lot of the properties of cement are very clearly given in the standards. **“Professor - student conversation ends.”**

We need to understand the implications on actual concrete mix design also, okay IS269 is the standard that pertains to Portland cement and you will see that it allows you up to 5% of a material called, performance improver. So any cement that you buy today is not purely Portland cement. The Portland cement may have up to 5% of a performance improver. **“Professor - student conversation starts.”** No, today the new 269 covers all grades of cement.

The older one was 33 grade and 12269 was 53 grade but today the modified 269 covers all grades, correct. So, up to 5% of your cement you are allowed to put in a performance improver and the most common performance improver that cement companies like to put is limestone itself. So all you do is same instead of processing a limestone, take your raw material limestone and grind it along with the cement clinker to produce the cement, up to 5% can be used.

Instead of limestone, if fly ash is available that is also a good performance improver. Now why is it called a performance improver, what performance is that improving? Durability, well it is questionable we do not know whether it is increasing durability or not, 5% of fly ash may or may not do anything but what is it doing? What performance is that improving? 5% is the hard sell, you think about it, 5% improving anything?

Exactly, so essentially you are improving your performance by reducing the energy and the costs. **“Professor - student conversation ends.”** Your ground limestone is ground and simply added to the cement, you are not burning it anymore, so 5% of your energy is reduced. Fly ash which is collected from thermal power plants is already a waste or a byproduct, you do not have to process it further, you can directly use it as 5% replacement for the cement clinker.

So that is where you are reducing your energy and cost and that is why these are called performance improvers. Of course, they may marginally improve performance, for example the ground limestone which we will learn later can also have a reactive side to it like what is there in LC3 or limestone calcined clay cement. We will talk about that later. There may be some marginal improvement in properties, some maybe workability, maybe strength maybe durability.

But essentially these performance improvers are intended to cut down the net energy emission in the cost from the production of the cement and today there is a new cement coming in which is called Portland limestone cement. Of course in India it is new but in the western countries Portland limestone cement is already been there for several years. Portland limestone cement will have up to 15% of the clinker replaced by ground limestone, up to 15%.

So again the idea is the same that we want to reduce the amount of energy required to produce a single ton of cement, by replacing material that has to be burnt at very high temperatures with something that is directly ground. It does not need to be burnt at all, so that is the major reason why we want to shift towards Portland limestone cements.

And, of course because of the other issues involved with cement production, very high CO_2 emissions, we want to shift increasingly to blended cements. So we will talk about blended cements in the later parts of this chapter also. So what are the sources of these raw materials? There are different types of carbonate materials available on the earth's crust.

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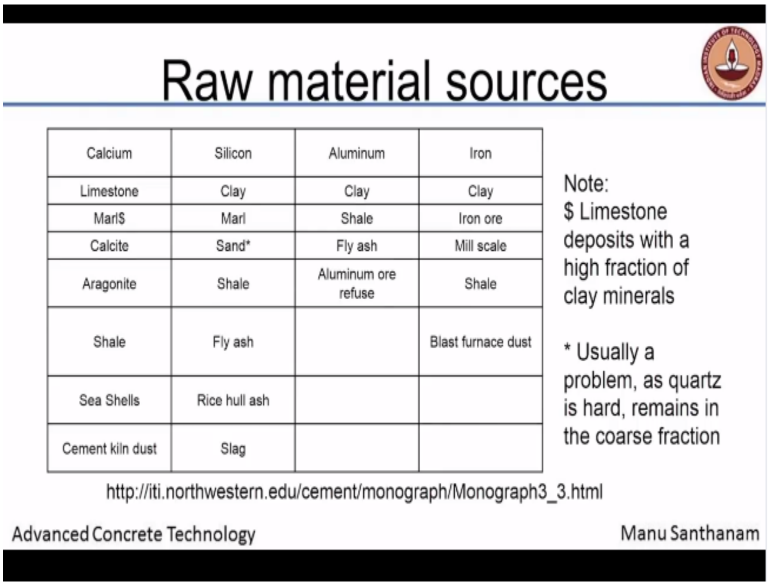

The most common ones that are used are limestone, marl. Marl basically is a limestone deposit with the high fraction of clay minerals. Marl is a very interesting material because it gives you a fairly high quantity of clay also along with the limestone. So you do not really need additional clay to produce cement. Then, you have calcite and aragonite which may be available in the natural mineral form itself.

And you have shale, sea shells directly, cement kiln dust, the dust that comes out of the cement kiln which is not collected as cement, the lighter part that flies out that can still be collected and that can be a raw material for the next cycle of cement production also. Silicon, you are getting it from clay, marl, sand, shale, fly ash, rice husk ash or slag. So these are some alternative sources of silicon that may be added to get a desired proportion of silicon dioxide in your system.

Aluminium is coming obviously from the clay and from other forms of clay and shale and fly ash and may be sometimes aluminium ore. If your clay does not have sufficient quantity of aluminium to contribute, you may want to get it from aluminium ore itself. Iron again from different forms of the impurities in clay. Otherwise, we may need to add iron ore, mill scale, blast furnace dust and so on to increase the content of iron to the desired limits.

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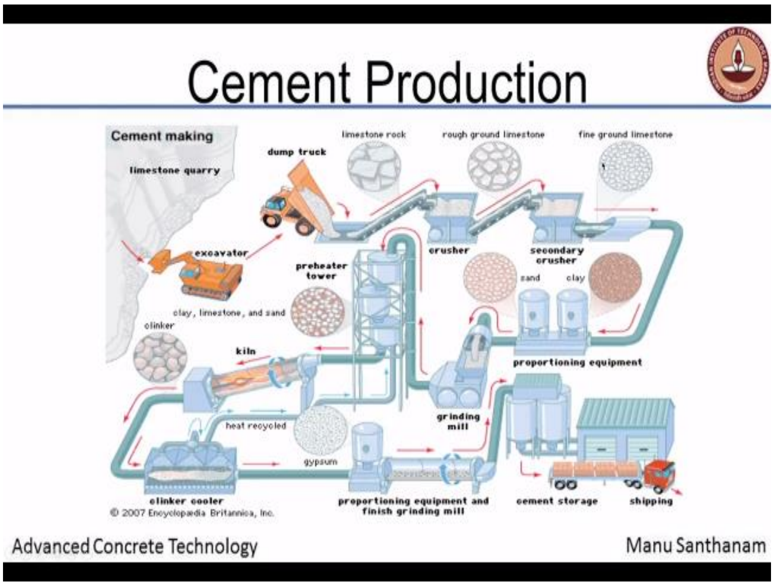

Now this is the simplest schematic depiction of a cement production process. It is not that complicated as it looks, there are too many activities here but we will further refine it by looking at each activity separately but overall this is what is happening. You have your cement limestone quarry here. The excavation of the limestone is done and it is brought to the crushing unit.

There is some primary crushing that goes on to reduce the particle size or to reduce the large boulders into small stone sizes, and this primary crushing these to rough ground limestone that is ground through a secondary crusher that leads to a fine ground limestone. **"Professor - student conversation starts."** Now why do we want to grind the raw material? It is going to easily blend and burn, okay, it is going to easily blend with the other raw materials and burn in the kiln when you reduce the particle size. **"Professor - student conversation ends."**

So then we have temporary storage spaces silos and so on where we have other materials also like sand and clay which may be added to get the desired composition, right, and these are again sent to a grinding mill to ensure that they are ground to very fine particle sizes to improve the blending and burning capabilities. Then, all these are sent together to what is called a preheater tower.

The idea of a preheater is to try and remove any moisture that may be there in the raw materials because all these raw materials are getting naturally mined, right. So there is obviously moisture that is coming in, this moisture has to be driven out if you want to drive everything out in the kiln process it may be a very difficult thing to do because the kiln has a certain limited length.

And if most of the length is spent in trying to drive out the moisture, you will not get an efficient formation of cement. So in most cases before the kiln operation you have the preheating tower, okay, which is basically preheating or subjecting all the raw materials to a heat of about close to 700 to 800 degree Celsius and from this preheater the material is then coming into the kiln.

So this is the typical layout of the kiln where the fuel source or the burning source is at the lower end of the kiln and the material comes in at the higher end. So since the kiln is rotating the material that comes in at the higher end simply moves by gravity to the lower end and since the fuel source is on the lower end, the temperature gradually increases from the input end to the output end.

And the material that comes out of the kiln goes through what is called the clinker cooler, okay. Now please remember that this material is coming out at very high temperatures, 1500 degree Celsius, you are cooling it down to almost normal temperatures or close to about 100 degree

Celsius. So the remaining heat is still something that can be utilized for further production processes.

So this heat is actually captured from this cooling process and recycled into the preheater tower. There is lot of heat recycling that goes on there to ensure that you are not losing all this energy that heat recycling actually enables supply of heat for preheating once again, okay. So beyond the clinker cooling, the material is then proportioned with gypsum in the final stages and sent to the grinding equipment.

In the past, people were using ball mills but today there are more efficient grinding units available. So anyway this is the picture of a ball mill, once again ball mill is quite simple, it is a rotating cylinder which has very heavy steel balls inside. So you put in your cement clinker and gypsum, the steel balls collide and impact against each other crushing the cement clinker and gypsum together in the process.

So you are crushing and blending at the same time, okay, inside the ball mill and from here it goes into the temporary storage, from there it goes into the packing facility to be sent out either in bags or in drums or in bulkers or whatever the case may be okay. So this is the overall layout of the cement production process.

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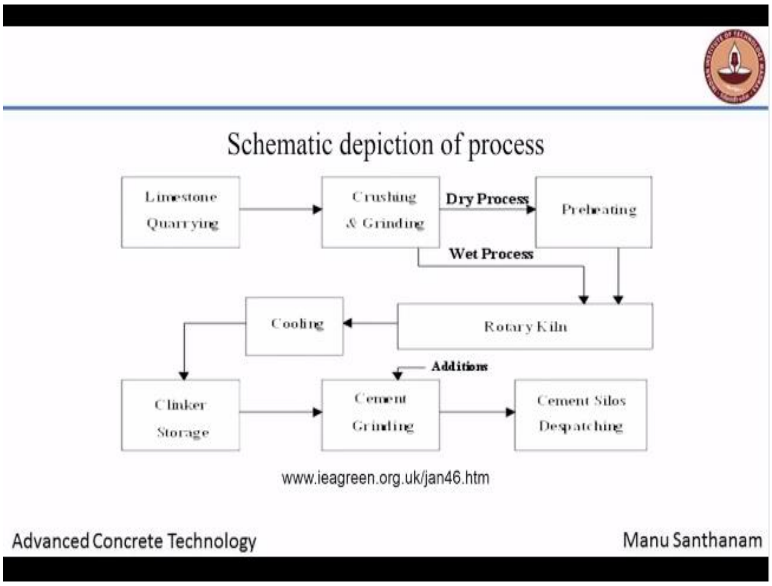

This is again a schematic depiction of this process which tells you the same essential things. You have the limestone quarrying followed by crushing and grinding, the preheating and then the rotary kiln. Now it turns out that in the past there was also an alternative process used that was called the wet process. Now this was used when the raw material which was sourced from the natural mines had a very high content of water inside.

So, supposing your raw material is so wet that nearly 20% of it is water, then probably this preheating may not be efficient in removing that water entirely and then your kiln burning may not be as efficient as you want it to be, so what you would like to do in that case is simply add extra water and blend the raw materials as a slurry, okay, and then send the entire material into kiln directly.

But the problem obviously is that majority of the length of the kiln will now be used to drive off the water, it will be used to drive off the water. So because of that wet process kilns that we used in the past were nearly 100 meters long, today with the help of a precalciner or preheater the kiln lengths have actually come down to nearly 30 to 40 meters. So significant reduction and since that is the most massive piece of equipment in your cement plant the capital cost associated with the kiln will be the highest.

So, people have increasingly moved to combination of the preheaters with the dry process kilns and nobody uses a wet process anymore barring a few plants that have not really shifted to these. In India, I do not even know if there are any wet process kilns available. I think most of the kilns are dry process kilns. So again from the rotary kiln the material is coming to cooling, storage of clinker then final grinding where all the additives come into the cement and then cement silos for dispatching.

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I will just walk you through a cement plant layout just to show you all these operations from a natural cement plant for those of you have not been to cement plants, okay. So this is from a cement plant in Chhattisgarh which is owned by Lafarge. Of course, in the past it was Lafarge, now Lafarge has been sold off to a company called Nuvoco okay, the new name of Lafarge in India is Nuvoco.

There is no longer Lafarge cement available in India, so this is actually the limestone stacking yard, you see here the limestone stacking yard, on the right of this image you see the limestone stacked. There are several conveyors which are bringing the limestone from the quarry or from the delivery unit to the limestone stacking yard, okay. From the stacking yard, this limestone will go towards the crushing unit.

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And this is the conveyor which is taking the limestone from the stacking yard towards the crushing unit.

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The next picture shows a typical crusher.

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Again from the crusher, the material is stored in a temporary silo, and there will be other temporary silos for other raw materials which you want to add during this process.

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Now I do not know how clear this image is. This image is that of a preheater tower. Why is it called a preheater tower because there are several preheater modules connected to one another vertically. So you can see that this is nearly 8 to 9 storeys high and there will be at least 6 to 7 preheaters connected in series to one another so that the material gets thoroughly preheated, all the moisture is removed.

And in fact today we even use it as a precalciner, so not just preheating precalcining that means we are able to burn off a significant quantity of your limestone in the preheater itself. So, that further brings down the necessity for large energy input into the kiln and you can still reduce the length of the kiln further.

So it is called a precalciner when you are actually having a fuel source also inside the preheater which tends to remove the carbon dioxide from the limestone quite effectively, nearly 60, 70 probably even 80% of limestone gets decarbonated or carbon dioxide gets removed and then this material comes to the kiln, you can reduce further the size of the kiln.

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From the preheater tower, the materials come into rotary kiln but of course you see 2 different tubes here. The rotary kiln is here on this side, okay. This tube here is the heat recovery tube which is actually taking the heat from the cooling process back into the preheater. You see it is sloping the other way, so from the preheater the kiln has to slope in this direction. So this is the kiln which is sloping in this direction and I will have clearer picture of the kiln.

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So this is the rotary kiln here. That's your rotary kiln and this is the heat recycling tube that is actually taking up the extra heat and conveying it back to the preheater tower. So the rotary kiln, please remember it is a very long cylinder nearly 40 meters in most dry process plants if not more, okay and what you also have to imagine is it is made with steel and steel cannot withstand extremely high temperatures.

What is the temperature range up to which steel can be okay, probably 500 to 600 degree Celsius, beyond that it cannot withstand that heat. So what you have to do is line the interior of the kiln with heat resistant bricks okay, typically heat resistant bricks are used to line the interior and sometimes you can use special cements like calcium aluminate cement which are extremely good against very high heats.

So you are lining the interior to kiln with these heat resistant bricks, different types of heat resistant bricks are used in different segments of the kiln depending upon the temperatures that maybe experienced in the kiln. So this is your rotary kiln, the other end of the rotary kiln is where the fuel source is located.

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So again this is the picture from the left side so that is the preheater tower that is the rotary kiln. You can see that the slope is very gentle, the slope is extremely gentle because the material should come in at a fairly controlled speed, okay, and at this end that is at the lower end of the kiln, is the fuel source.

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I will show you a picture, yeah this is the fuel source and that is where the burning is actually occurring at this end of the kiln.

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The operations are very well controlled. Today, it is a completely computer controlled process. There is no manual input anywhere, everything is perfectly controlled and most Indian cement plants are probably state of the art plants because they were set up towards 80s and 90s only and we have the best equipment possible in most of our cement plants.

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This is the clinker that is coming out of the cooler. You can see the clinker looks like a very nodular almost like an aggregate, right, and that is basically your clinker which is fused together at high temperatures and after cooling it comes out like nodules.

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These nodular clinker is then sent to the ball mill, okay, after temporary storage it is sent to the ball mill, in the ball mill you have the other additives that go in or added, either you add your gypsum anyway then you may be adding fly ash or limestone as a performance improver and supposing you are producing other types of cement like Portland pozzolan cement PPC, in that case the larger quantity of fly ash will go in.

If you are producing Portland slag cement, larger quantity of slag will actually go into this grinding unit to grind all the materials together. It is not just grinding; it is also intermixing all the materials properly.

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So the material then comes out and stored in the silos and finally dispatched.

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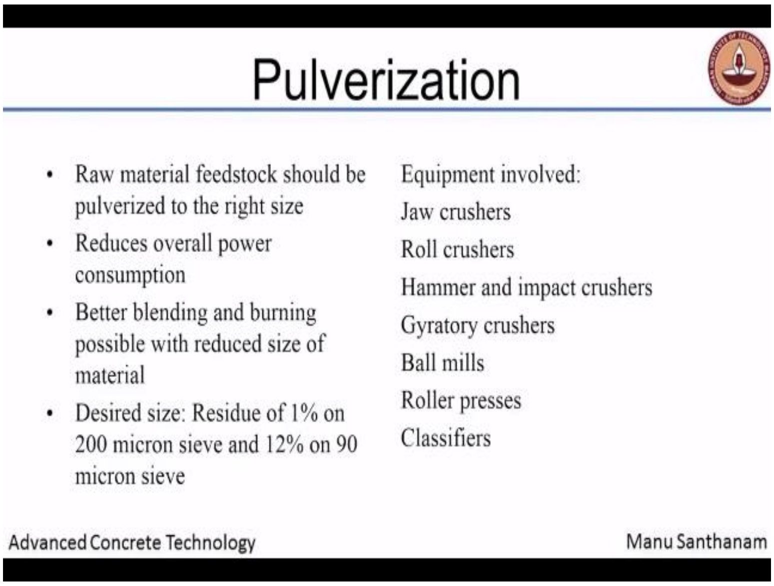

Now, we will talk now about the individual processes and what are the challenges involved in these processes. You know that the first important process is the pulverization of the raw material. The feedstock of the raw material should be pulverized to the right size, again as you rightly said for proper blending and burning of this material. So if you are reducing the size, it reduces the overall power consumption to get a certain quality of your cement.

There is definitely better burning and blending possible with reduced size of material and what size do you really want and typical desired size is that you want a residue of 1% on the 200 micron sieve and 12% on the 90 micron sieve, that means most of your material is between 200 microns and 90 microns. So that is the particle size range that you are grinding it down to.

You remember that during quarrying you are actually getting the limestone in very large boulders, some of these boulders maybe even a meter in size and you are actually then crushing it down to just a few microns, only 100 microns or so in average size. One more thing I want you to remember is that not all of the limestone that is mined is suitable for cement manufacture, not all of the limestone.

In fact, it is estimated that nearly 60% or probably even 70% of the limestone that is actually mined is not useful for cement manufacture because it has got way too high an impurity content. So the overall net charge of calcium oxide that is possible from the limestone may be limited because of that large chunk of your limestone is not usable. So if you go to a cement plant you will see these mountains of the waste material that happens anywhere.

Now wherever mining is there we produce mountains of over burden, we produce mountains of material that is not distinctly usable. Again clay mines are a lot more drastic in that regard because only very high grade clay, very white clay is sort after by the paints industries and ceramic industries, all the other clay which contains lot of iron impurities that is just junked.

All this material simply lies as waste, so any mining produces a lot of wastage and same thing happens with limestone mining for cement manufacture. Much of this limestone is not utilizable. So what we have to ensure is we know what to do with this kind of the waste also and this is something again that we will talk about later when we look at blending materials for cement manufacture.

Now there are certain equipment I am not going to go through how these work, you can find enough information on these different types of equipment are involved for crushing, you have jaw crushers, roll crushers, hammer and impact crushers, gyratory crushers, ball mills, roller presses and then of course you have classifiers to ensure that you are classifying the smaller particles and the larger particles.

So that the smaller particles can be taken forward in the process, the larger particles that are there need to be fed back into the grinding system and then send back to this process.