Development and Applications of Special Concretes
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Lecture 12
Hot Weather Concreting

Namaskar and welcome back to another lecture in our series on development and applications of special concretes. In this lecture today the focus will be on hot weather concreting.

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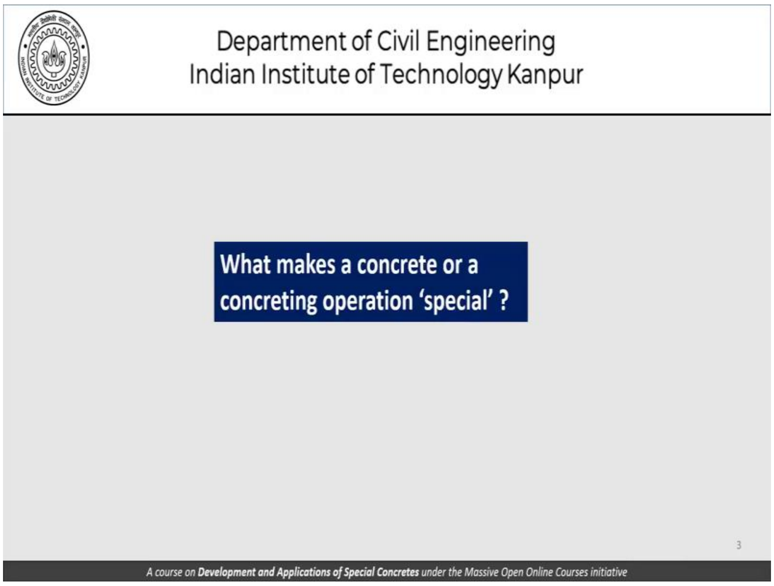

So, what makes a concrete or a concreting operation special.

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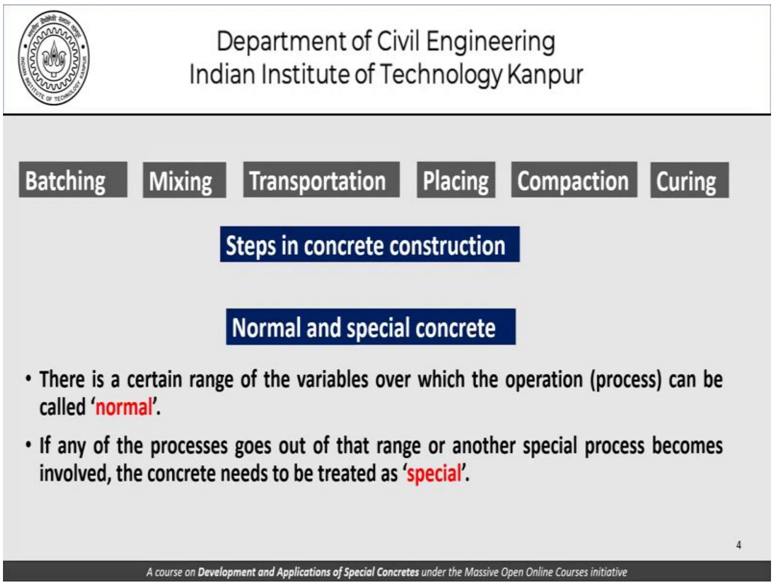

We have already seen that there are different steps involved in a concrete operation or concrete construction; batching, mixing, transportation, placing, compaction and curing. Now as far as normal and special concretes the difference is concerned there is a certain range of the variables over which the operation or the process can be called normal. And if any of the processes goes out of that range or another special process becomes involved the concrete needs to be treated as special and all the other processes need to be readjusted or revisited.

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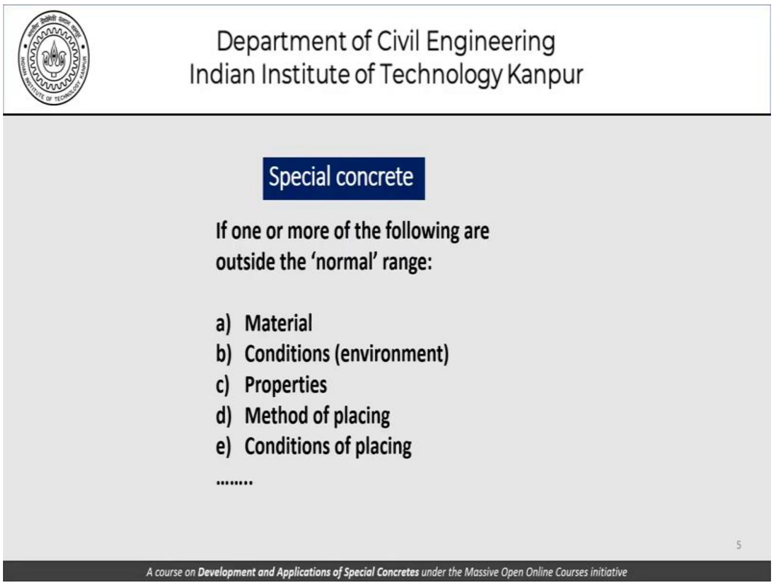

We have talked about this special concretes basically reiteration from the previous slide will be one which goes outside the normal range whether it is in terms of materials conditions or environment properties method of placing conditions of placing and so on.

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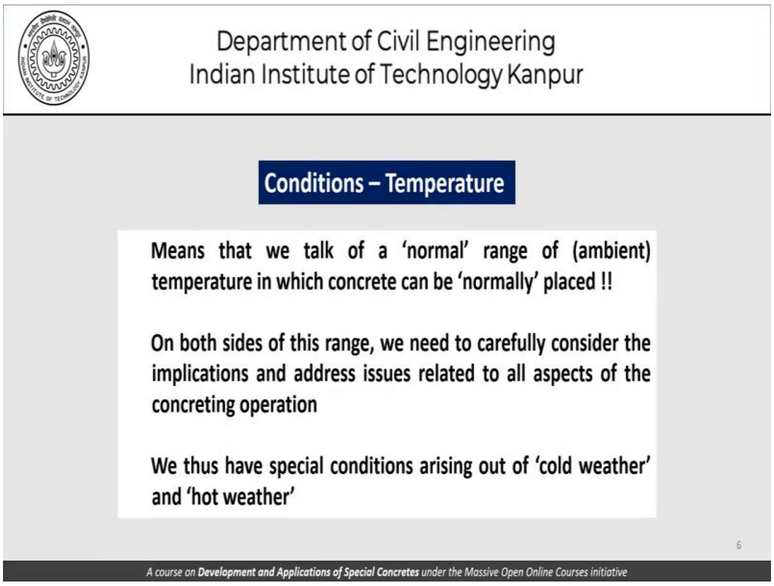

We are talking about the conditions in terms of temperature as of now and there can be a normal range of temperature where we would say that yes concrete can be normally placed. On both sides of this range, we have to be careful and that gives rise to cold weather and hot weather concreting. Cold weather we have already done last time and today is the turn for hot weather.

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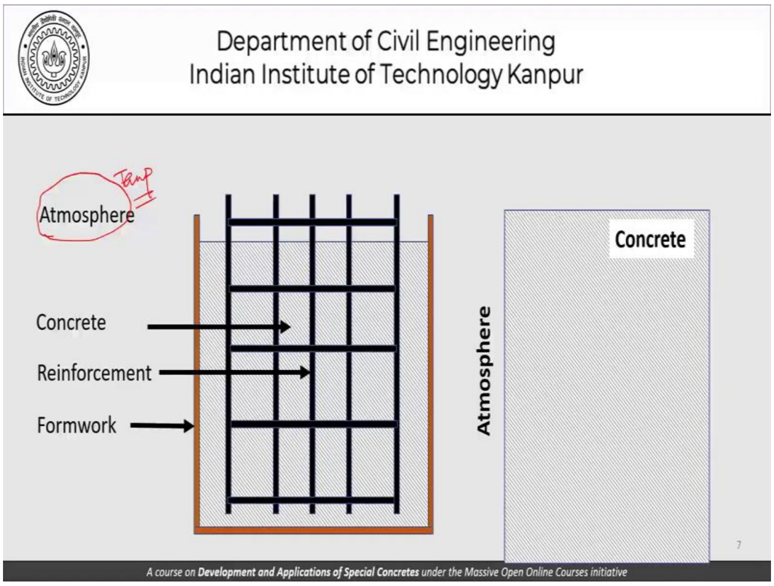

Before we get into hot weather concreting is reiteration of the basic concrete construction process concrete being cast in the formwork. And this atmosphere here is the issue it is not normal. It is not normal because the temperature here is higher as far as our discussion today is concerned. For the sake of simplicity this picture is being modelled by the picture which is shown here on the right-hand side we have removed the formwork and what has to be seen is how does the concrete react or interact with an environment which is higher than normal in temperature.

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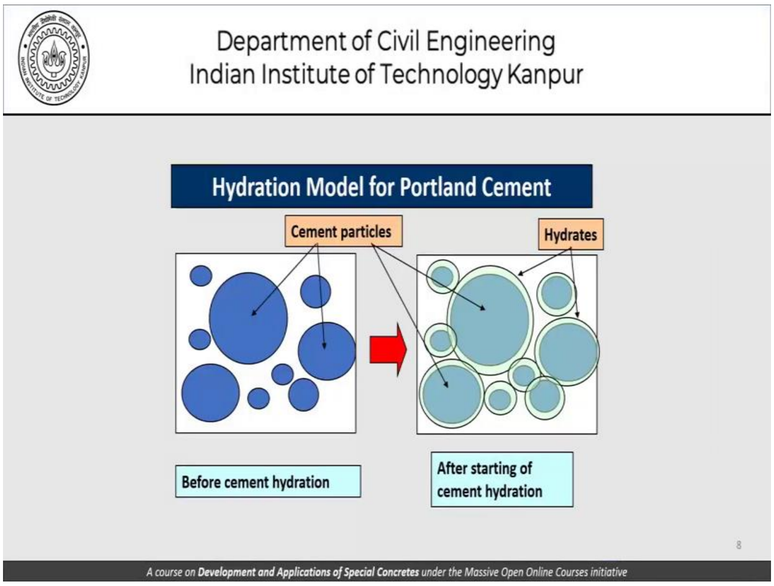

Once again, the coarse aggregate of the fine aggregate being largely inert particles in the matrix the whole thing boils down to the interaction of cement particles more of water. How does the hydration process in Portland cement get affected if the temperature outside is high?

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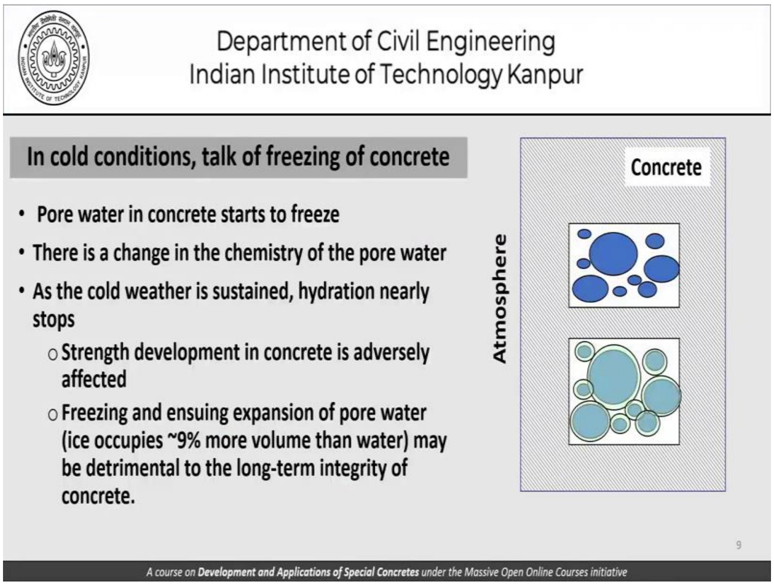

In cold conditions we have talked about freezing of concrete where pore water starts to freeze there is a change in the chemistry of pore water as the cold weather is sustained hydration nearly stops. Strength development is adversely affected freezing and ensuing expansion of pore water may cause detrimental effects in the long-term integrity of the concrete. These are the things that we have talked about in cold weather.

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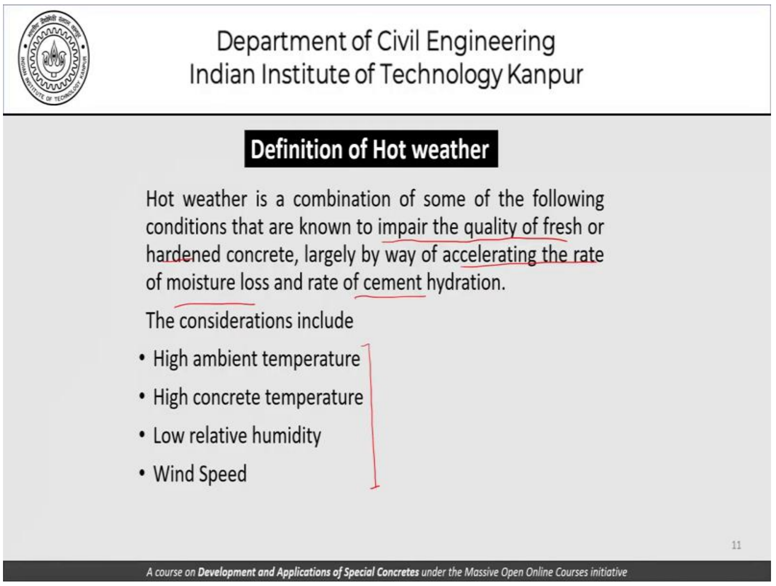

Today is the turn for hot weather we just turn the things around and go to what happens when the ambient temperature is higher than the normal. How does one define hot weather? Hot weather is a combination of some of the following conditions that are known to impair the quality of fresh or hardened concrete largely by way of accelerating the rate of moisture loss and the rate of hydration of cement.

So, we are concerned about the rate of moisture loss from the surface of concrete and the rate of cement hydration having been increased. Now these considerations could include high ambient temperature, high concrete temperature, low relative humidity or high wind speeds. So, a combination of any of these conditions is likely to lead to conditions of hot weather concreting, where we are concerned about an increased rate of moisture loss from the surface of concrete and an increased rate of hydration. How do these two things affect the concrete in the fresh and the hardened state?

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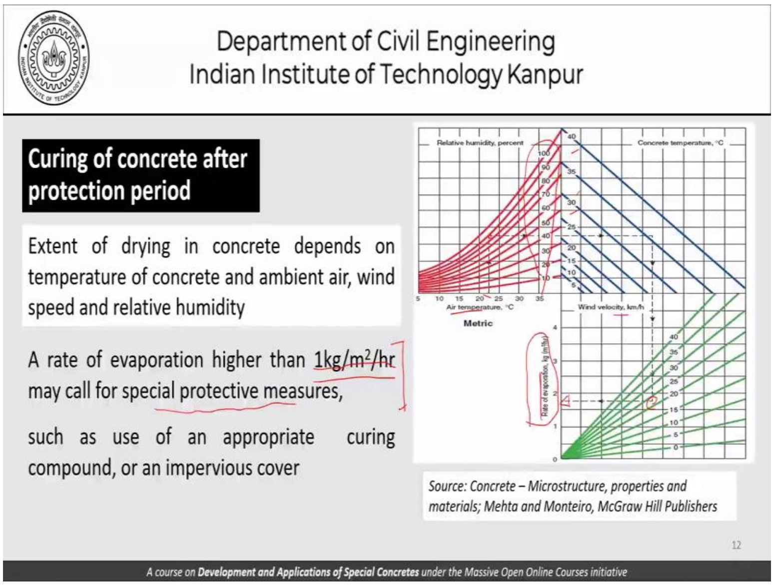

As far as curing of concrete after protection period is concerned that is something which we have seen in the last class. The extent of drying in concrete which is basically the loss of water through the surface of concrete measured in terms of kgs per square meter per hour depends on the temperature of concrete the ambient air and the wind speed and relative humidity. So, we have seen this graph and we had also seen that a rate of evaporation higher than one kg per square meter per hour may call for special protective measures.

Now that is what is the crux of our problem. As far as specifications are concerned as far as the thumb rule is concerned that if the rate of evaporation here measures more than one kg per square meter per hour. We are in the region which calls for special protective measures and we have explained and discussed how we use this particular nomogram? There is a relative humidity given here on this axis which is these numbers.

The air temperature so we enter with the air temperature go up to the relative humidity turn right go to the concrete temperature here which is 40, 35, 30 and so on. Come down wherever you want to and come to the wind velocity and that is when you read off the rate of evaporation. So that is how we use this nomogram and try to come to this number which determines or which helps us determine whether or not we need high weather concreting precautions.

Such precautions would mean use of an appropriate curing compound or an impervious cover. Now the curing compound basically just seals the pores of the concrete and lowers the evaporation rate.

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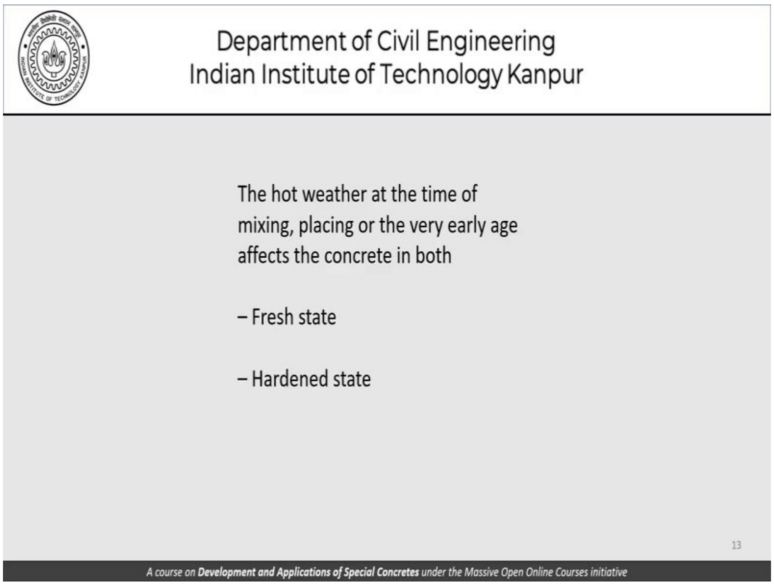

Considerations as far as hot weather concreting is concerned as we have said before affects the concrete in both the fresh state as well as the heartened state.

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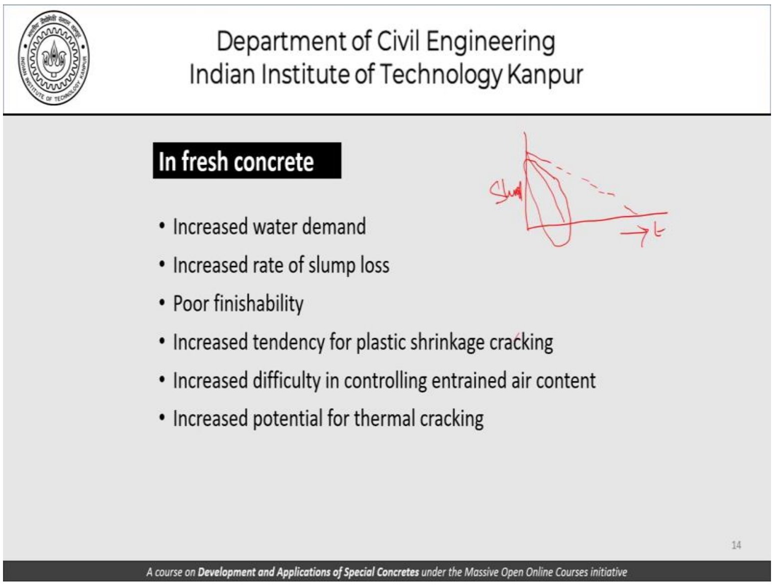

Now what are the effects on fresh concrete? Increased water demand that is you need more water for a particular value of slump, increased rate of loss of slump, we already seen before that in a normal case if we plot time with slump. We will have a certain amount of loss a certain rate of loss. If it is hot weather this rate would become accelerated. So, we will have a more rapid loss in slump.

Poor finishability of the concrete, increased tendency for plastic shrinkage cracking, increased difficulty in controlling entrained air and increased potential for thermal cracking.

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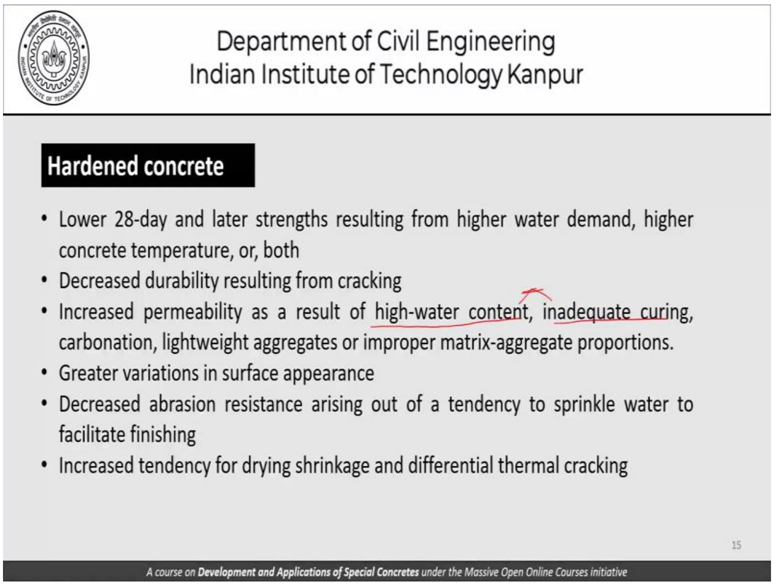

As far as hardened concrete is concerned the effects could mean lower 28 day and later strengths resulting from the higher water demand and the higher concrete temperature or both. Decreased durability resulting from cracking, increased permeability as a result of the high-water content inadequate curing, carbonation, lightweight aggregates or improper aggregate matrix proportions.

So, we are concerned primarily with high water content and inadequate curing because these two things are very critical as far as the health of concrete or as far as the integrity of concrete is concerned. Greater variations in surface appearance decreased abrasion resistance arising out of a tendency to sprinkle water to facilitate finishing. Increased tendency for drying shrinkage and differential thermal cracking.

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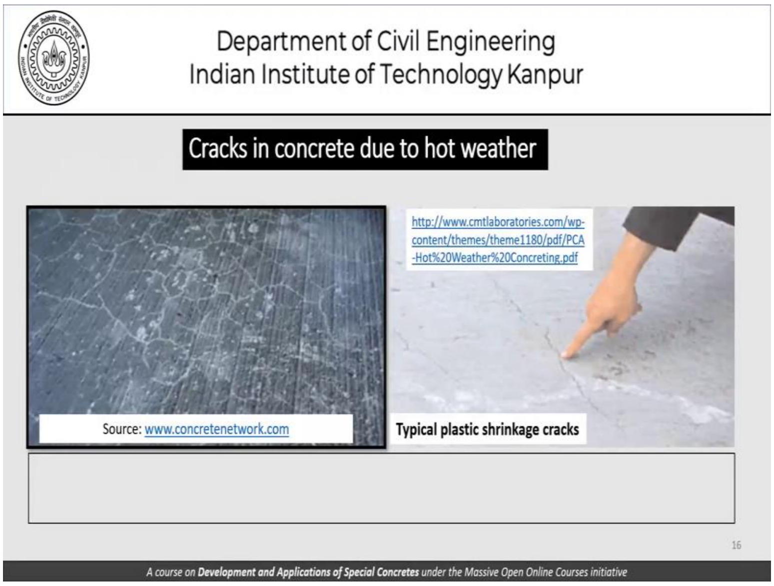

Here are pictures of cracks in concrete due to hot weather. Typical plastic shrinkage, cracks can be seen and we should also note that concrete may stiffen prematurely preventing proper compaction and proper finish or temperature of concrete may rise causing thermal cracking as it cools. So, this thermal cracking part we will visit once again when we try to study mass concrete but that is a slightly different variation of concrete conditions.

Here we are talking of thermal cracking as a result of hot weather or the high temperature of concrete.

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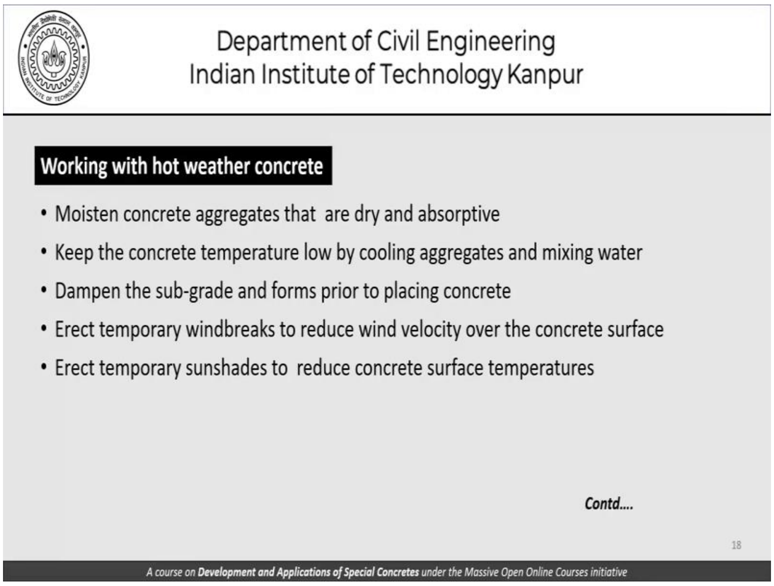

As far as ambient conditions are concerned a concrete temperature of 10 to 15 degrees is perhaps the most desirable to maximize the benefits of mixed properties but it may not be always possible to get these temperatures. It is with this thought that specifications which are basically applicable to certain regions are written keeping in mind the conditions of the region. A study of specifications would reveal that generally it is required that concrete when placed should have a temperature of less than 29 to 32 degree centigrade.

I would encourage you to go and read some literature and find out as far as Indian conditions are concerned what is the maximum temperature of concrete which is permitted? For a pore in India what I am telling you is that generally speaking the concrete temperature should be less than 29 to 32 degrees centigrade and should not be allowed to exceed that. It has been reported that conditions need to be determined on a case-to-case basis and temperatures up to 35 to 38 degrees centigrade may be acceptable in certain cases.

See what happens is that at the end of it an engineer might take a view that given these conditions I will permit a slightly higher temperature in concrete because it is uneconomical. It is technically not possible given the conditions of a site to bring the temperature to this range or this range or whatever it is. So that kind of a discretion of the engineer is always there and is exercised so on a case-to-case basis. The temperatures may be allowed to about 35 to 38 degrees.

Now when it comes to working with hot weather concrete what we need to do is moisten concrete aggregates that are dry and absorptive. Keep the concrete temperatures low by cooling the aggregate or mixing water or both. Dampen the subgrade and forms prior to placing, erect temporary wind breaks to reduce the wind speeds over the concrete surface. Erect temporary sun shades to reduce the concrete surface temperatures.

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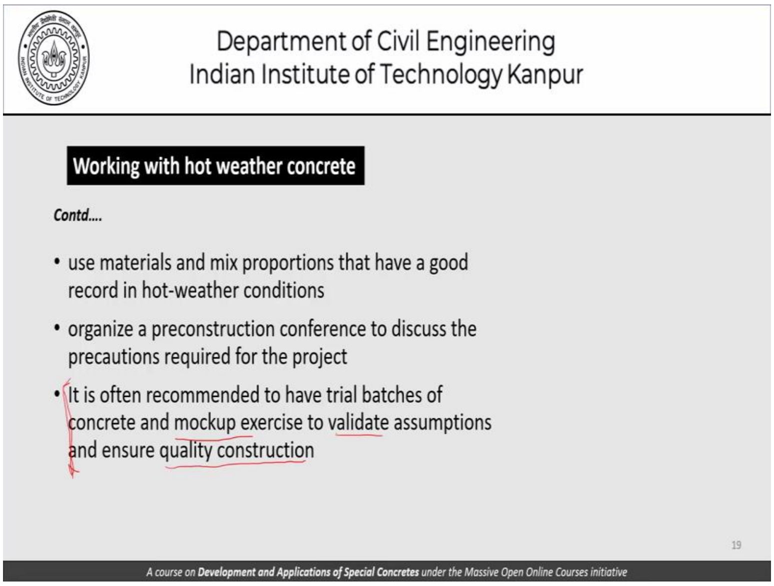

And use materials and mix proportions that have a good record in hot weather conditions, organize a pre-construction conference to discuss the precautions required for the project so that all concerned. The construction people, the design people, the quality control inspection people they are all on the same page and it is often recommended to have trial batches of concrete and mock-up exercises to validate assumptions and ensure quality control.

Now this part of the importance of mock-up exercises to validate assumptions and ensuring quality control is something which is very, very important. As far as engineers are concerned in special conditions and that is what we are trying to deal with in special concretes in special conditions it is not fair for us to expect complete guidance from published material. So, we have to read the published material refer to it of course but use our own judgment to come up with the right specifications the right kind of numbers which will suit that particular site.

That requires mock-up exercises working with actual material at site under those conditions this is something which we are going to take up again maybe in the next class for certain different conditions. But the importance of mock-up exercises in the role of these mock-up exercises in quality construction cannot be overemphasized.

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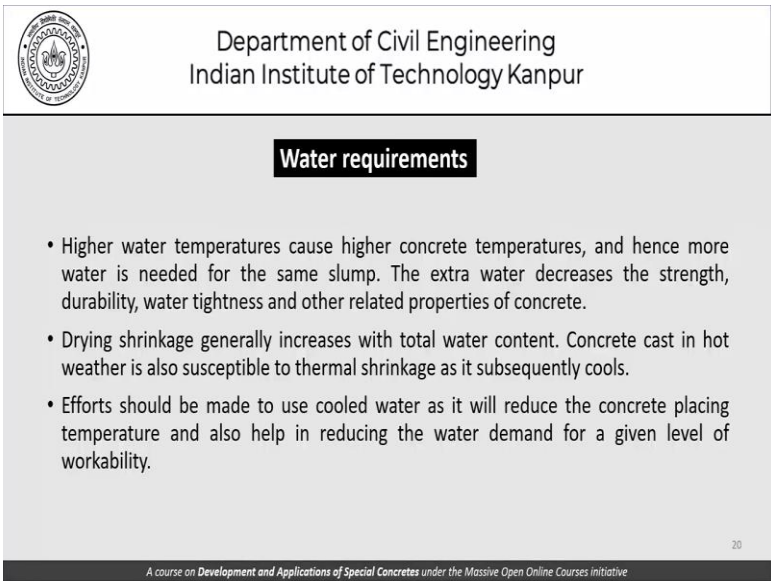

Now as far as water requirements are concerned, the higher water temperatures cause higher concrete temperatures and hence more water is needed for the same slump. The extra water decreases the strength durability water tightness and other related properties of concrete. Drying shrinkage generally increases with the total water content and concrete cost in hot weather is also susceptible to thermal shrinkage as it subsequently cools.

Effort should therefore be made to use cold water as it will reduce the concrete placing temperature and also help in reducing the water demand for a given level of workability.

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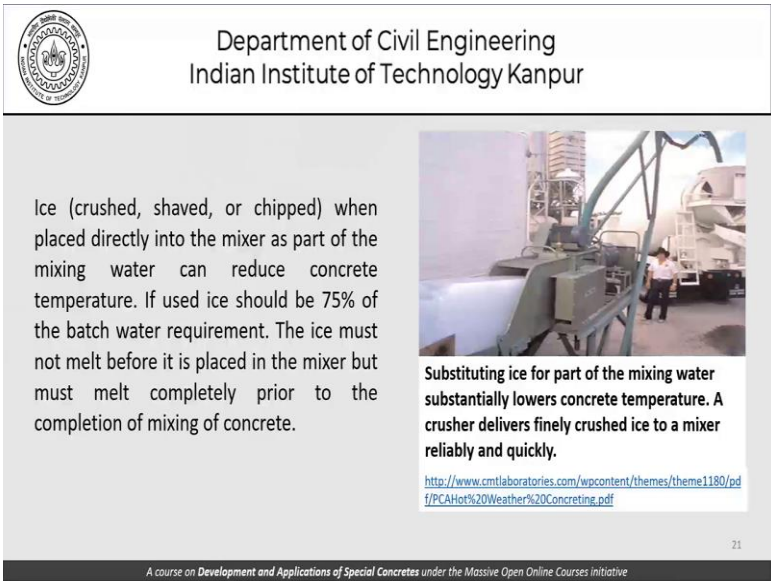

Here is a plant showing ice being substituted as a part of mixing water which substantially lowers the concrete temperature. And a crusher delivers finely crushed ice to a mixer reliably and quickly. So, one has to be very careful when using ice. There are different ways of doing it crushed shaved or chipped dice is what is used and that when placed directly into the mixer as part of the mixing water can reduce the concrete temperature.

If used ice should be 75 of the batch water requirements and the ice must not melt before it is placed in the mixer but must melt completely prior to the completion of the mixing of concrete. It is not acceptable or it is not desirable at all that ice be left in that form after the concrete has been mixed and taken into the transit mixers for placement.

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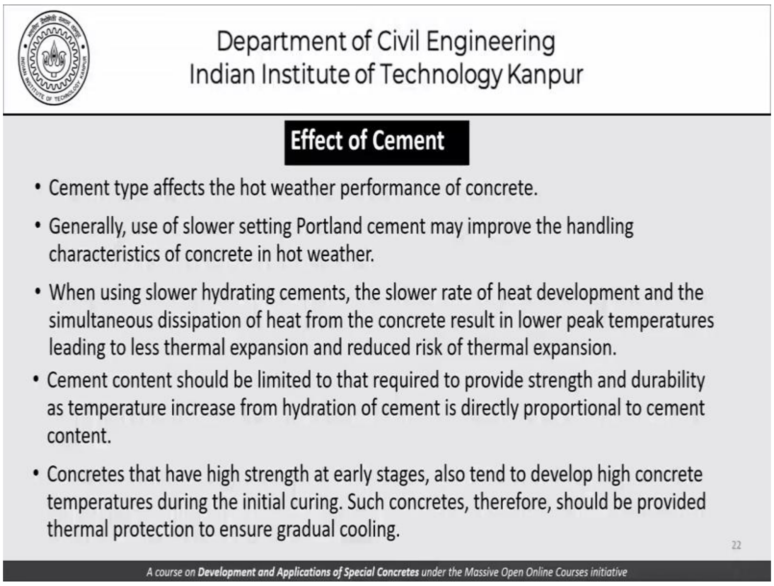

As far as the effect of cement is concerned the cement type also affects the hot weather performance of concrete. Generally, the use of slower setting Portland cement may improve the handling characteristics of concrete in hot weather. You will recall that if you compare our discussion today with the discussion yesterday. A lot of things are just the opposite of what we talked about yesterday and that is exactly what is expected because what is good in cold weather will not be good in hot weather and vice versa.

So as far as the effect of cement is concerned in cold weather, we said we should use cement which is quick setting which hardens early here we are talking of slower setting Portland cement which will improve the handling characteristics of concrete in hot weather. When using slower hydrating cements the slower rate of hydration and heat development and simultaneous dissipation of heat from concrete results in lower peak temperatures leading to less thermal expansion and the reduced risk of thermal cracking.

Cement content should be limited to that required to provide strength and durability as temperature increase from hydration of cements is directly proportional to cement content. What is being said is that we should try to minimize the cement content because more cement means more heat of hydration and that pushes the temperature of concrete. Concretes that have high strength at early stages also tend to develop high concrete temperatures during initial curing such concrete should therefore be provided thermal protection to ensure gradual cooling.

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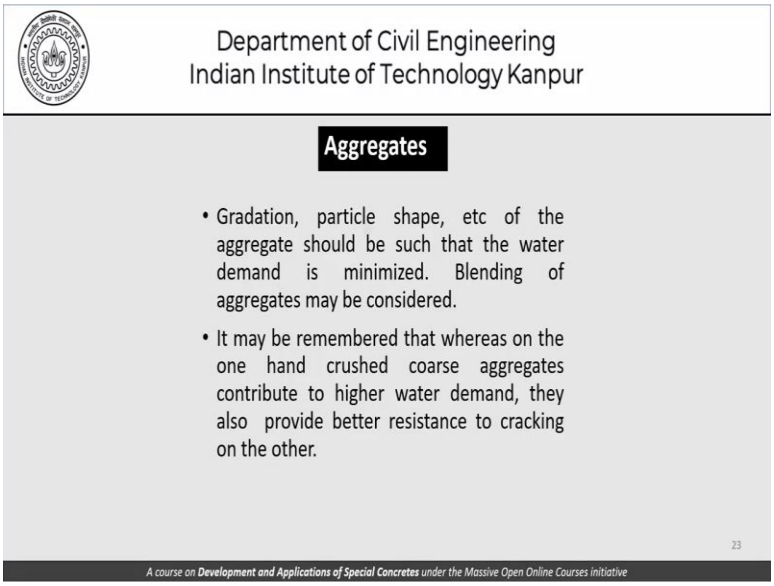

As far as aggregates are concerned, we have already talked about water and cement. Now coming to aggregates the gradation, particle shape and so on of the aggregate should be such that the water demand is minimized, blending of aggregates may be considered. It may be remembered that whereas on the one hand crushed coarse aggregates contribute to higher water demand they also provide better resistance to cracking.

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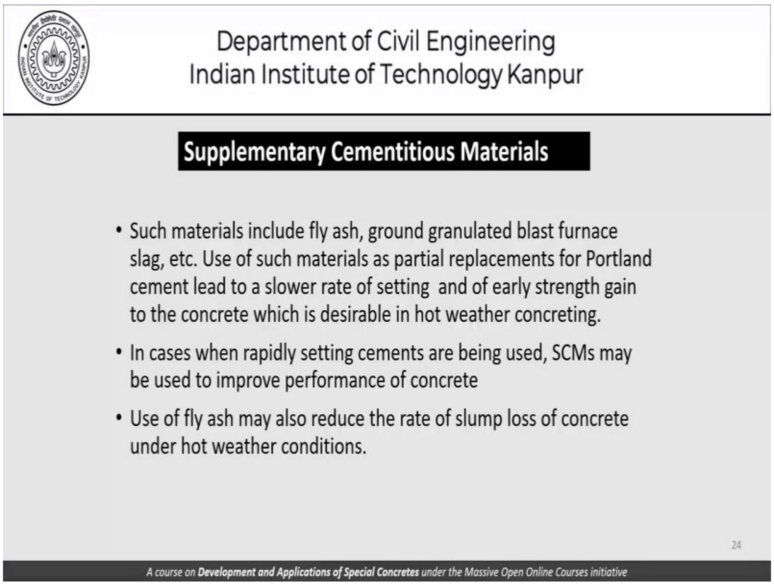

As far as supplementary cementitious materials are concerned. Such materials include fly ash ground granulated blast furnace slag and so on. Use of such materials as partial replacements of Portland cement lead to a slower weight of setting and of early strength gain in concrete which is desirable in hot weather concreting. In hot weather concreting we want the heat liberation rate of setting and strength gain to be slightly on the low key in the initial period.

And that is accomplished by using supplementary cementitious materials like fly ash or blast furnace slag. In cases when rapidly setting cements are being used supplementary cementitious materials may be used to improve the performance of concrete. Use of fly ash may also reduce the rate of slump loss in concrete under hot weather conditions.

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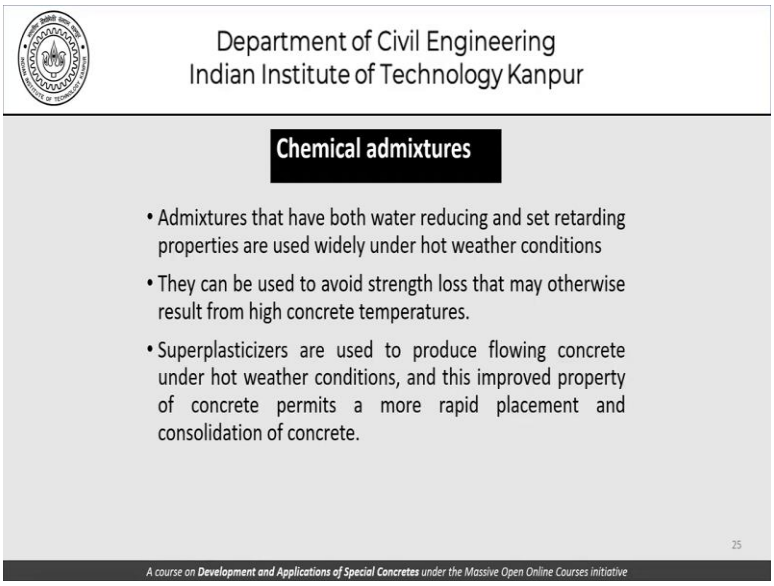

As far as chemical admixtures are concerned admixtures that have both water reducing and set retarding properties are used widely under hot weather conditions. They can be used to avoid strength loss that may otherwise result from high concrete temperatures. Super plasticizers are used to produce flowing concretes under hot weather conditions and this improved property permits a more rapid placement and consolidation of concrete which works to our advantage.

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Now this is a picture which I have taken from the previous discussion. It is a retracted and extended aggregate storage system and that is something which we can use in hot weather as well as in cold weather conditions because at the end of it what we need is to control or kind of engineer the temperature of aggregates. If you want to heat it, we want to cool it, it is better to protect it from the ambient or the outside air temperatures and air effects.

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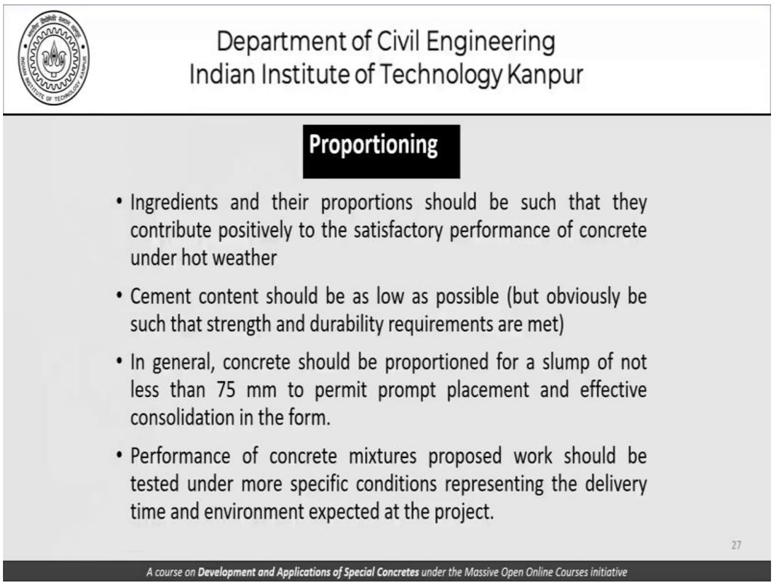

As far as proportioning of the different materials is concerned. Let us have some comments on that ingredient in their proportion should be such that they contribute positively to the satisfactory performance of concrete under hot weather cement. Content should be as low as possible but obviously be such that the strength and durability requirements are not compromised.

In general concrete should be proportioned in a manner that the slump is not less than 75 mm to permit prompt placement and effective consolidation in the form. Performance of concrete mixtures the proposed work should be tested under more specific conditions representing the delivery time and environment expected at the project. This also is alluding to the importance of mock-up which is essentially an exercise carried out to duplicate or replicate the conditions at site and then doing a rehearsal.

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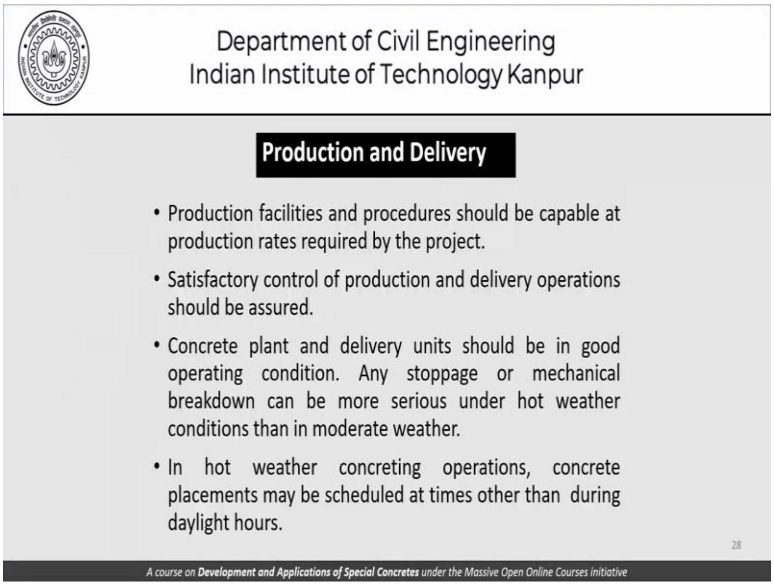

As far as production and delivery is concerned production facilities and procedures should be capable at production rates required by the project. Satisfactory control of production and delivery operations must be ensured. And concrete plant and delivery units should be in good operating conditions. This is especially important because stoppages and mechanical breakdowns can be more serious under hot weather conditions than in moderate weather.

In hot weather conditions or hot weather concreting operations concrete placement may be scheduled at times other than during the daylight hours just because you want to work at lower ambient temperatures to the extent that is possible.

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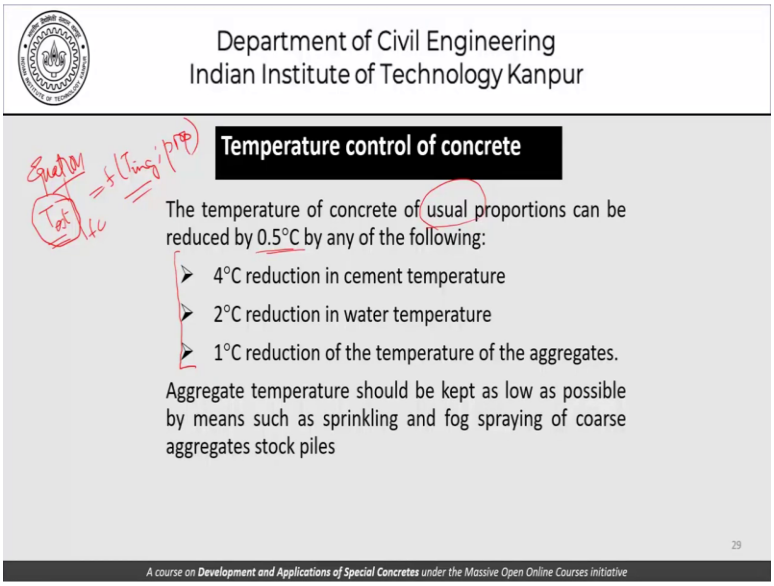

As far as temperature control of concrete is concerned here are some thumb rules. The temperature of concrete of usual proportions. Now here again we are talking of usual proportions we are not talking of some special proportions. Usual proportions can be reduced by 0.5 degrees centigrade by any of the following. 4 degrees reduction in cement temperature, 2 degrees reduction in water temperature or 1-degree reduction in the temperature of the aggregates.

In an assignment in the last class or perhaps the previous one I had asked you to try to look for an equation which allows you to determine or estimate the temperature of fresh concrete given the temperature of the ingredients and their proportion. Now without invoking that equation here is a thumb rule which says that if you want to reduce the temperature of concrete by half a degree here are the steps that you could take and it is up to you which route you want to use.

Aggregate temperature should be kept as low as possible by means of sprinkling or fog spraying of coarse aggregate stockpiles.

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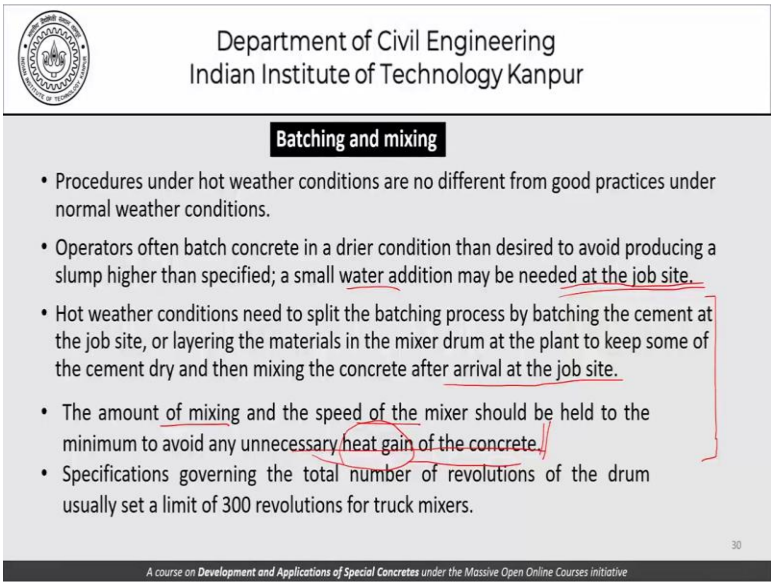

As far as batching and mixing is concerned procedures under hot weather conditions are no different from good practices under normal weather conditions. Operators often batch concrete in drier condition than desired to avoid producing a slump higher than specified. A small water addition may be needed at the job site now. This is where we are trying to deviate from the norm, we are talking of a small water addition at the job site.

Hot weather conditions need to split the batching process by batching the cement at the job site or layering the materials in the mixer drum at the plant to keep some of the cement dry and then mixing the concrete after arrival on the job site. The amount of mixing and the speed of the mixer should be held to a minimum to avoid unnecessary heat gain of the concrete. So, these kinds of statements are very difficult to understand in a technical sense.

Because they are not giving you any specific guidance what is being said is that as far as mixing is concerned try to reduce or restrict the amount of mixing and the speed of the mixer to the extent that you do not have an unnecessary heat gain during mixing because that would push the temperature of concrete that something should be avoided. We are talking in terms of the need to add water at site if it is required.

In fact, continuing further on this discussion the specifications governing the total number of revolutions of the drum usually set a limit of 300 evolutions for track mixers. Now what this text here basically tells us again is the importance of seeing the actual conditions. Looking at your actual equipment and trying to make the most of the conditions that you can in order to minimize the temperature of fresh concrete.

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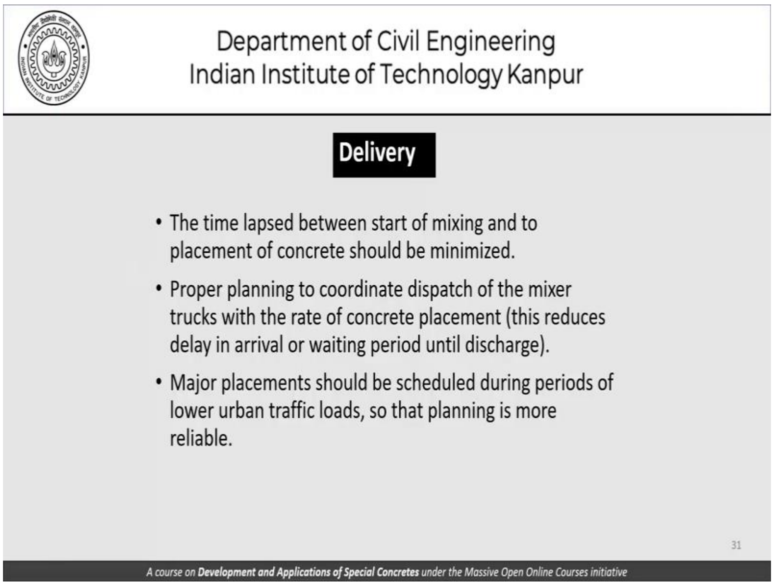

When it comes to delivery, the time lapse between the start of mixing and to the placement of concrete should be minimized. Proper planning to coordinate the dispatch of mixer trucks with the rate of concrete placement which reduces the delay in arriving or waiting period until discharge. Major placements should be scheduled during the periods of low urban traffic so that planning is more reliable.

The bottom line being we need to place the concrete as soon as it is delivered to site. It is not a good idea to keep it rotating in a mixer waiting for it to be placed.

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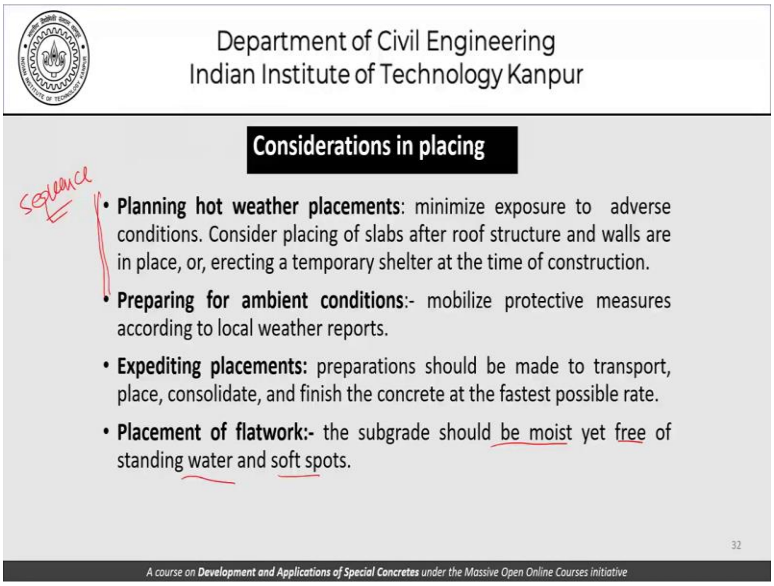

As far as the considerations in placing are concerned, we need to plan hot weather placements in a manner that minimize exposure to adverse conditions. Consider placing of slabs after roof structures and walls are in place or erecting a temporary shelter at the time of construction. So, this basically means that we need to plan our sequence of operations. If we are having a structure where we could somehow do the walls before the slabs.

We could try to do that because those walls will protect the slabs from the adverse effect of winds and so on. Preparing for ambient conditions would involve mobilizing protective measures according to local weather reports expediting placement preparation should be made to transport place consolidate and finish the concrete at the fastest possible rate. Placement of flat work the subgrade should be moist yet free of standing water and soft spots.

Now this is something very important that subgrade should be moist but free from standing water it should not be wet.

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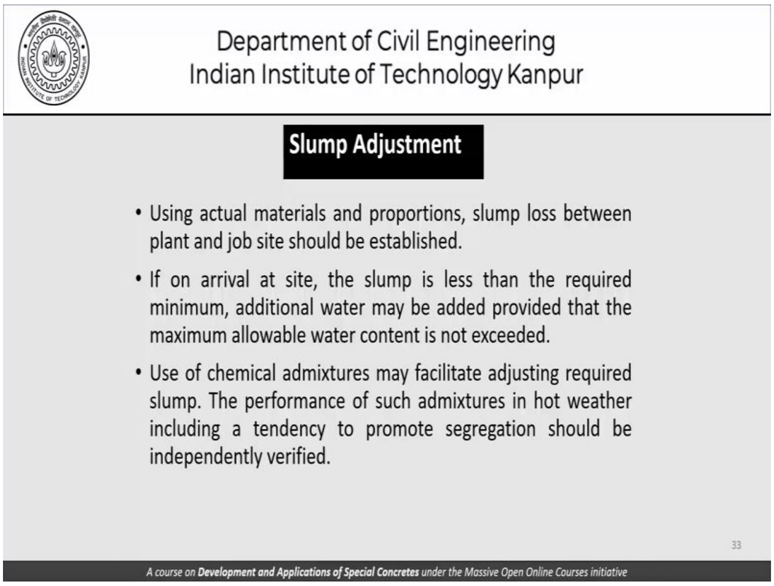

Coming to slump adjustment actual materials and proportions the slump loss between the plant and the job site needs to be established. If on arrival at site the slump is less than the required minimum addition does not lead to the maximum allowable water content to be exceeded. And use of chemical admixtures may facilitate adjusting the required slump. The performance of such admixtures in hot weather including a tendency to promote segregation should be independently verified.

So, what is being said here is you have to read between the lines. The performance of such admixtures in hot weather including a tendency to promote segregation should be independently verified. What it is cautioning you is that if we use chemical admixtures to adjust the slope primarily water reduces the super plasticizers in hot weather there can be a tendency to promote segregation and that needs to be independently verified.

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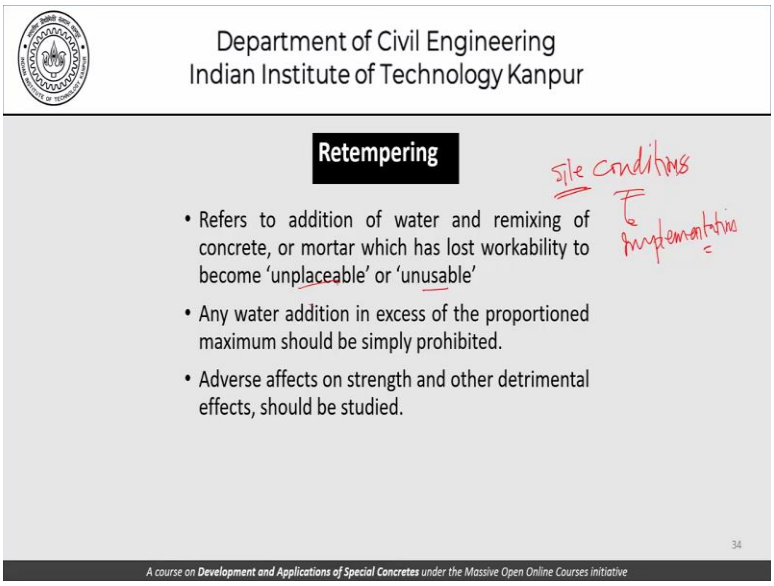

Moving on to the next step in the construction process which is re-tempering. This refers to addition of water and remixing of concrete or mortar which has lost workability to become unplaceable or unusable. In the previous slide also, there was a mention of some water being used at site provided that amount of water or that addition of water does not lead to the water becoming more than the maximum permissible limit.

Any water addition in excess of the proportion maximum of course is prohibited. And adverse strength effects and other detrimental effects should be studied. So, all this discussion that we are having in different slides really points out very importantly to incorporating the site conditions into our planning and also implementing the construction sequence or the construction operations.

If we want to add water at site after the concrete has been brought there for whatever reason we have to study that process there is nothing wrong with it but we need to study it to ensure that there is no adverse effect.

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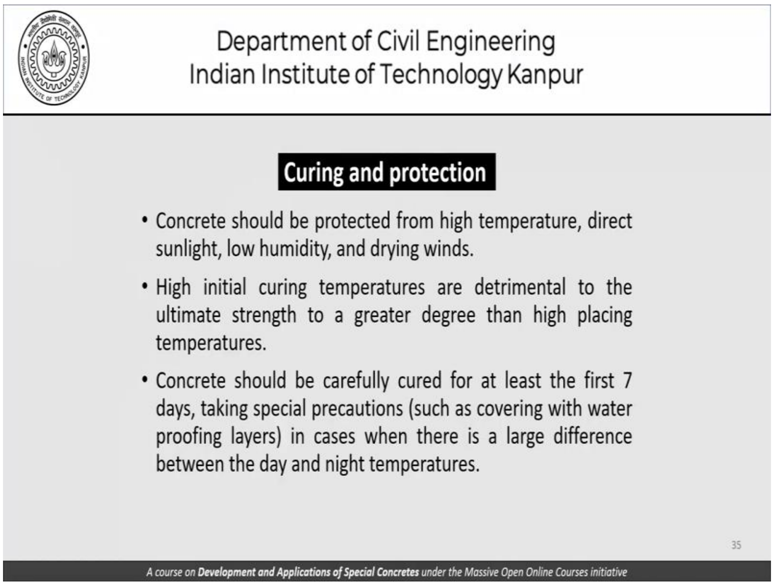

As far as curing and protection is concerned concrete should be protected from high temperature direct sunlight low humidity and drying winds. High initial curing temperatures are detrimental to the ultimate strength to a greater degree than high placing temperatures. Concrete should be carefully cured for at least the first seven days taking special precautions such as covering with waterproofing layers in cases there is a large difference between the day and night temperatures.

So, we have to ensure that the concrete after it has been placed is properly nurtured and taken care of and that is exactly the spirit of curing the concrete.

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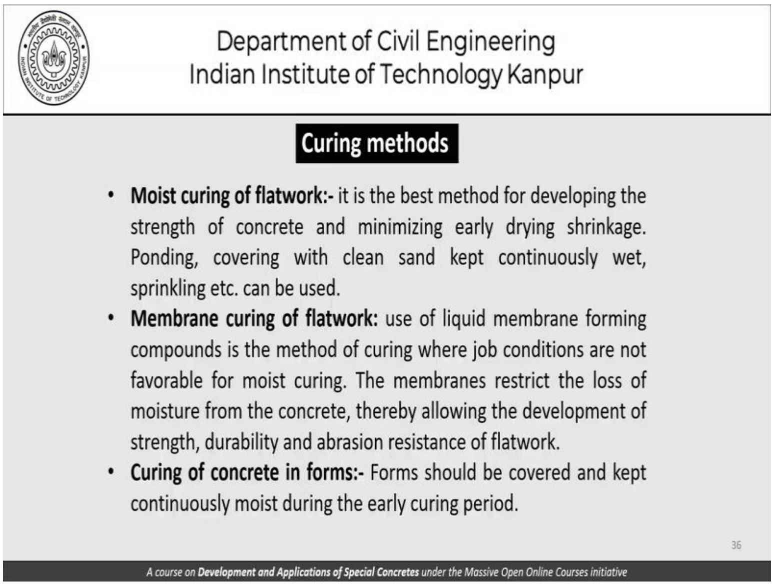

As far as methods are concerned you could use moist curing of flat work which is the best method for developing the strength of concrete and minimizing early drying shrinkage which could include ponding, covering with clean sand, kept continuously wet sprinkling and so on can also be obviously used. Membrane curing of flat work is another strategy use of liquid membrane forming compounds is the method of curing where job conditions are not favourable to moist curing.

These membranes restrict the loss of moisture from the concrete thereby allowing development of strength durability and abrasion resistance of flat work. Once again, I must emphasize that curing what we normally see is keeping the concrete surface wet. Now that surface being kept wet is not so much to supply water for hydration but to ensure that water from the concrete does not escape.

And therefore, the concrete very close to the surface does not become dry and does not contain too much of un-hydrated cement. Curing of concrete and forms one option that you have is that forms should be covered and kept continuously moist during the early curing period rather than removing the forms and exposing the concrete directly to the higher temperatures.

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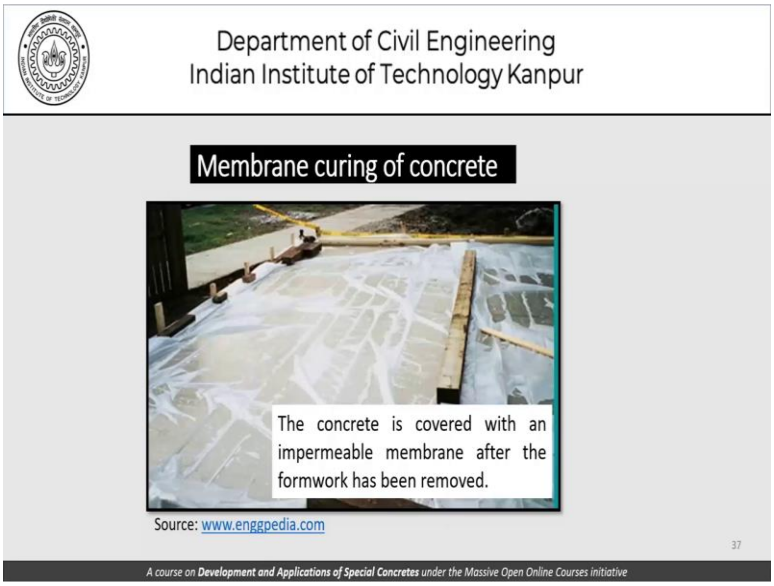

Membrane curing as we can see here concrete is covered with an impermeable membrane after the formwork has been removed.

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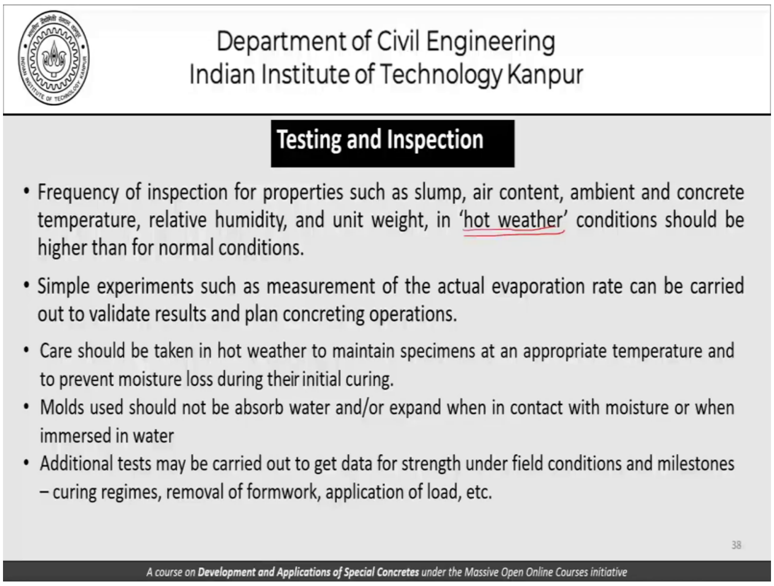

As far as testing and inspection is concerned now that is where we have to see that all concrete and all concrete construction has to be tested and inspected. But the frequency of inspection for properties such as slump air content ambient and concrete temperature relative humidity and unit weight in hot weather conditions should be higher than for normal conditions. Because hot weather is something which is special and the detrimental effects are likely to be pronounced if the weather is hot.

And therefore, we need to be more careful in our inspection procedures which basically include the frequency of testing for slump air content and so on. Simple experiments such as the measurement of the actual evaporation rate can be carried out to validate the results and plan concreting operations. We had that nomogram there which helped us establish or estimate I should say estimate the rate of evaporation.

But if we carry out some simple experiments, we will be more confident of our estimates. We must do that we should try to encourage the site people to do that and learn for themselves as to how much or how accurately those pictures give us real results. Care should be taken in hot weather to maintain specimens at an appropriate temperature and to prevent moisture loss during their initial curing.

Molds used should not absorb water and or expand when in contact with moisture or when immersed in water and additional tests may be carried out to get data for strength under field conditions and milestones in terms of securing regimes removal of formwork applications float etc. So, we are in a situation where we are working with hot weather concrete in fact half of these things that we are discussing now are probably true even in cold weather concreting. There too we need to be more careful when we are trying to inspect and test the concrete.

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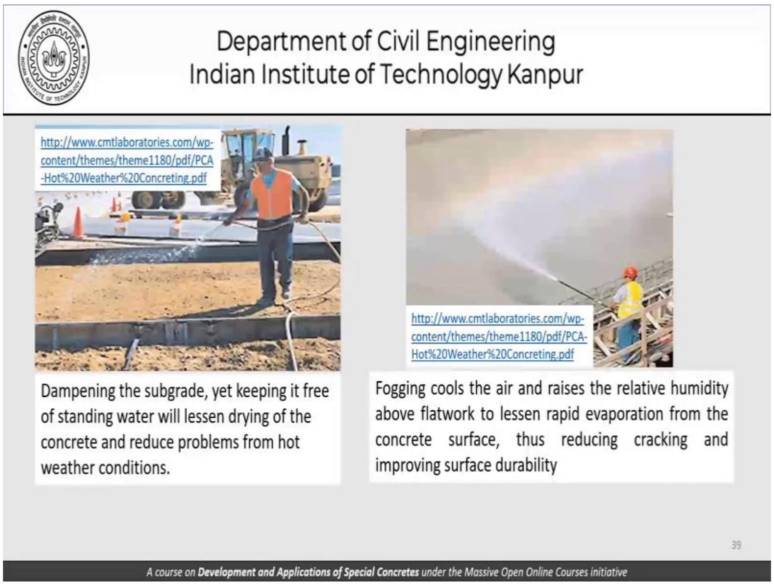

This picture here shows dampening of the subgrade yet keeping it free of standing water will lessen the drying of concrete and reduce problems from hot weather conditions. And this picture here is fogging the cool air and raises the relative humidity above the flat work to lessen rapid evaporation from the concrete surface. Thus, reducing cracking and improving the surface durability.

As you can see from our discussion most of the time in cold weather as well as in hot weather the concern is maximum when the exposed surface area of concrete is large. I am leaving it to you think about it. What is the surface area to volume ratio of normal concretes and a case like a slab or a large pavement structure that we are seeing here, we have that discussion somewhere later on when we try to understand the properties of concrete, in terms of the volume of concrete and the surface area that it has.

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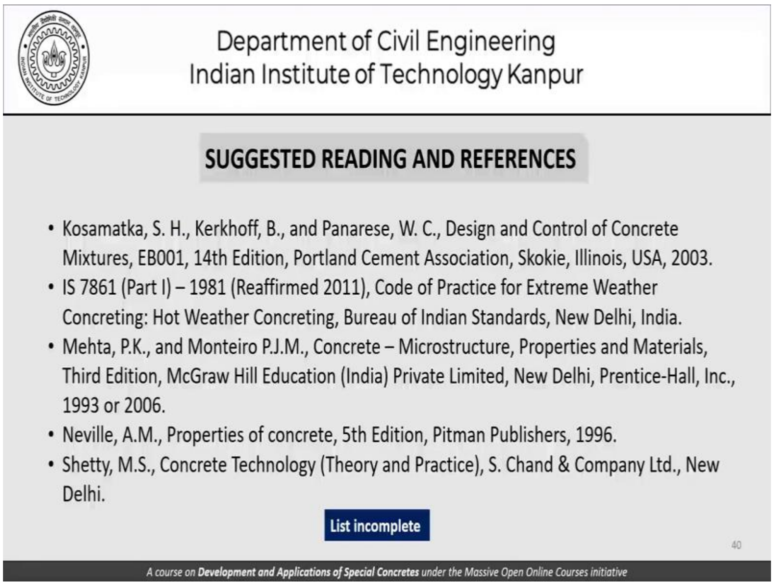

As far as suggested readings are concerned here is a list of references and readings which you may like to go through in order to enrich yourself. As far as understanding of hot weather concreting is concerned something to think about.

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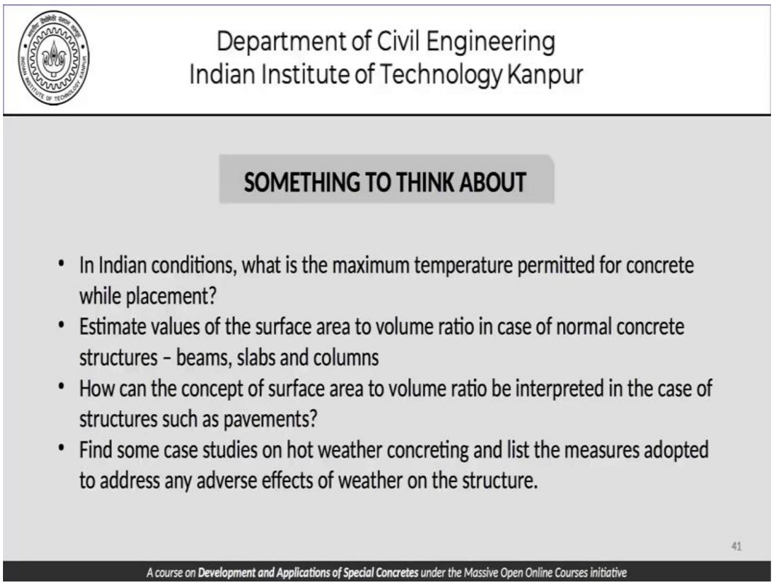

These are the set of questions or directions in which you can think. As you can see some of the directions that I have indicated are basically about getting or reading case studies of hot weather concreting where you would get an idea of the actual strategies adopted in different projects where hot weather concreting was involved.

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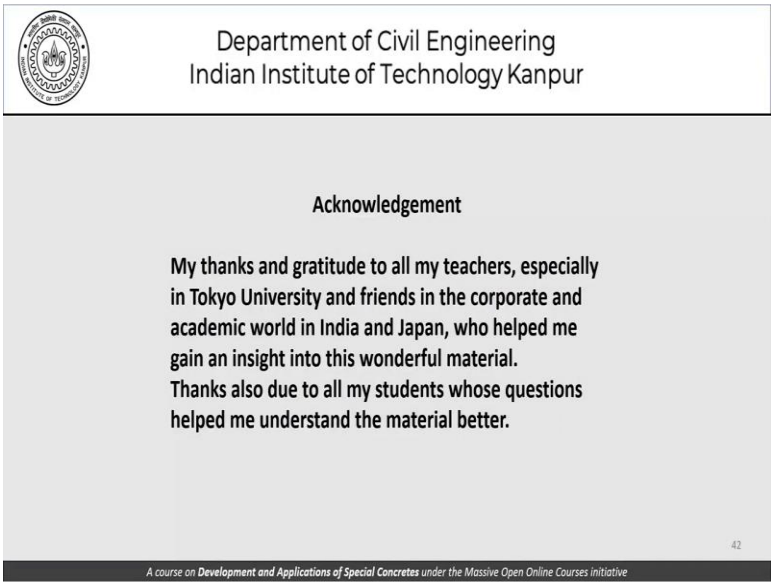

And closing the discussion today my gratitude and thanks to all my teachers the students and colleagues. And with that I come to an end of the discussion today of hot weather concreting. Thank you so much.