Development and Applications of Special Concretes
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Lecture-28
Using Polymers in Concrete

Namaskar and welcome back to our series of lectures on development and applications of special concretes.

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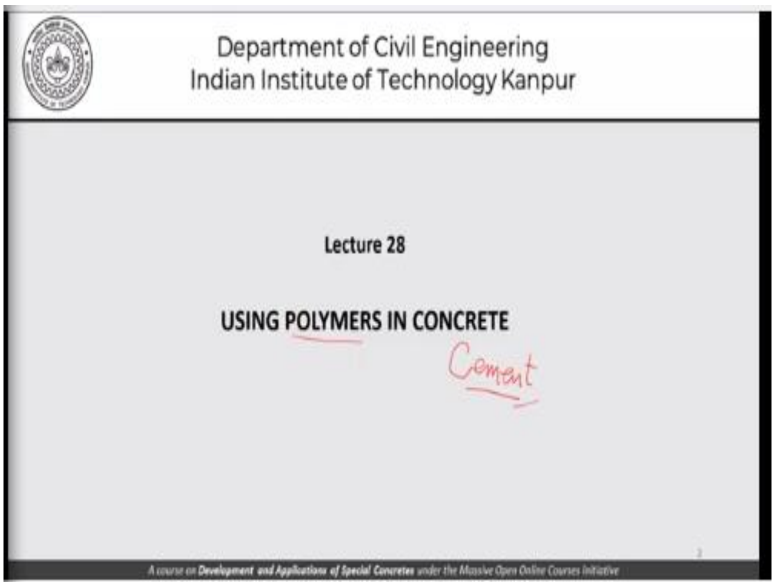

So, today we start our module 8, that is the last week in this series of lectures and we start with a very different kind of topic using polymers in concrete. So, far we have dealt with concretes all along which had cement as an essential ingredient. Today we will be talking of concretes which do not have cement or even if they have cement, they have cement yes but in conjunction with polymers. So, today we will concentrate on using polymers in concrete as far as this discussion is concerned.

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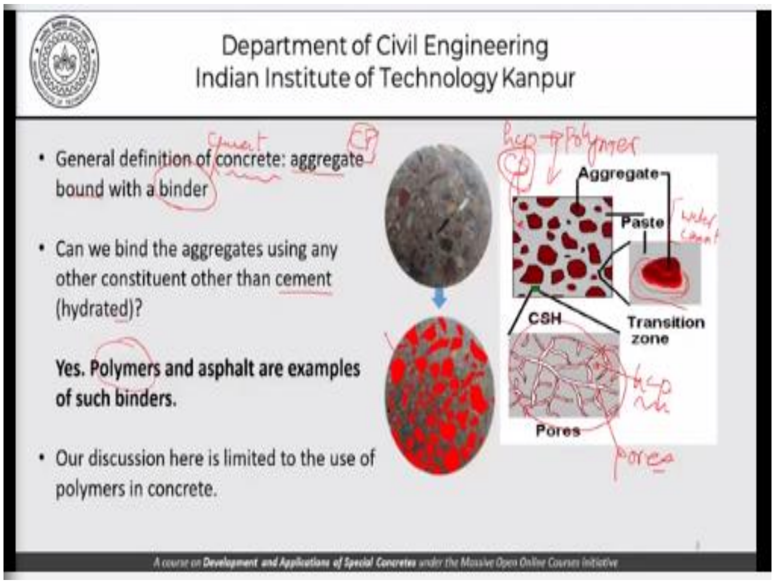

Let us look at this picture once again from this point of view. And what we have seen so far is that the aggregate is bound with a binder. And this binder in the normal concrete that we have talked about, cement concrete I should be more specific at least for today, this binder has been cementing paste. Now, we have these aggregates here suspended in paste which is cement and water, hydration products made out of cement and water.

Extended to this diagram or this schematic sketch of the model these aggregates surrounded by cement paste, cement paste having this kind of a pore structure where this is necessarily the hardened cement paste or the hydration products of cement. And these are the pore spaces as we have seen multiple times before. And we have this intermediate transition zone formed in the neighbourhood of aggregates because of the separation of water and cement.

So, the separation of water, bleeding in other words causes this part of the paste to have a slightly higher water cement ratio, and that has implications in terms of strength and so on and so forth. Now the question that we want to ask is can we bind the aggregates together using any other constituent than cement, of course when we say cement it is the hydration products of cement. The answer is yes, polymers and asphalt are examples of such binders.

So, today we largely concentrate on polymers we leave out the asphalt concrete discussion for some other time. And our discussion as I have said is limited to the use of polymers in concrete.

So, we will be talking of a situation where this binder which used to be cement paste or hydration products made with cement that is HCP will be replaced at least partly or fully by some kind of a polymer. Now how does that polymer find it is place? In the cement matrix is something which we need to investigate and try to be clear about as far as this lecture is concerned.

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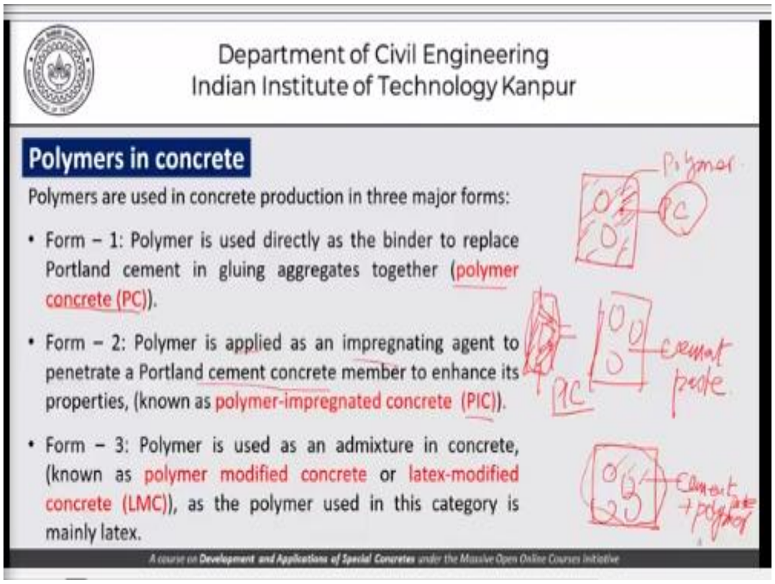

Polymers in concrete they have three major forms that we talk about these days. One is polymers used directly as a binder to replace Portland cement in gluing the aggregates together and that is what we get polymer concrete. So, polymer concrete is one where the polymers have completely replaced the Portland cement as a binder and they provide the binder for the aggregates. In the second form polymer is applied as an impregnating agent to penetrate a Portland cement concrete to enhance it is properties.

And then we have a product called polymer impregnated concrete which is the PIC. The third form is polymer is used as an admixture in concrete and known as polymer modified concrete or the latex modified concrete or LMC, as the polymer used in this category is largely a latex polymer. So, what we have essentially is the fact that if we look at aggregates being bound by the matrix or aggregates bound in a matrix, in polymer concrete, we have this entire matrix as polymer.

In PIC what we have is, we have the normal concrete matrix here, this is my cement concrete that is this part is cement paste. So, in the pore space here which I often draw like this, we apply a polymer layer here and this polymer impregnates into these pore spaces and what we get is PIC polymer impregnated concrete.

In the third case, the polymer is mixed along with the cement at the time of mixing itself and we get in the cement paste, we have some polymer as well. So, we have cement paste and polymer as part of the entire paste matrix here. This does not happen in PIC, because the PIC has impregnation which could be limited to a certain depth alone. In the case of LMC which is the latex modified concrete the polymer is all over the place as far as the concrete is concerned.

And in polymer concrete we have completely replaced the cement hydration products with the polymers. So, these are the three forms in which we talk about polymers in concrete.

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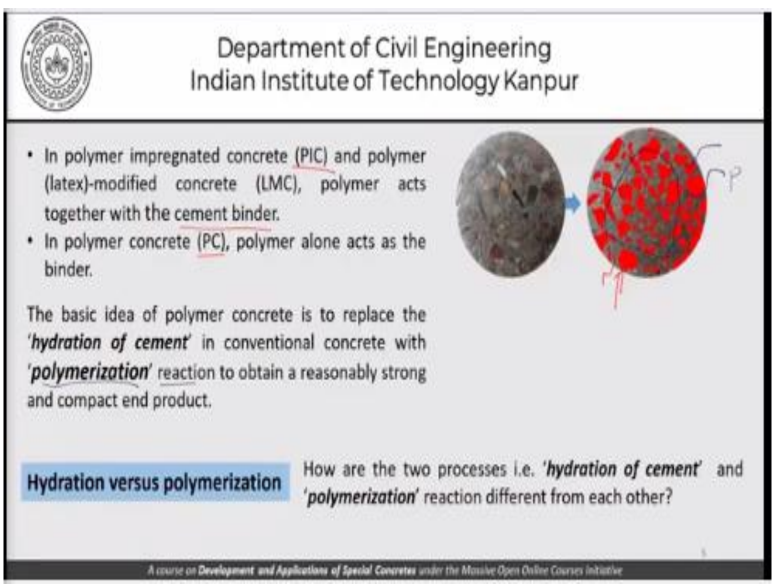

In polymer impregnated concrete and polymer latex modified concrete that is LMC or PIC, the polymer acts together with the cement binder that is what we have talked about just now. In PIC it is largely limited to the surface, in LMC it is the entire body of concrete, in polymer concrete polymer alone acts as the binder, so that is what we have talked about. And this picture can be seen as a reminder that**,** if we replace this complete thing here with polymers, we will get polymer concrete.

We have only a surface layer here which has been impregnated by polymers from outside after this concrete has hardened. Then we get polymer impregnated concrete and as far as LMC is concerned, the concrete has polymers all over the place. So, the basic idea of polymer concrete is to replace the hydration of cement in the conventional concrete with polymerization reaction. So, how do we get polymers in the concrete is something which we will just touch upon today.

And we learn about the polymerization reaction to obtain a reasonably strong and compact end product. In that sense we can try to compare the processes of hydration and polymerization to better understand. The properties of polymer concrete in the framework that we already have and we have a fairly strong framework as far as the understanding of cement concrete is concerned, and we will use that framework to understand the properties of polymer concrete.

So, there are 2 processes basically the hydration and polymerization and how are they different from each other. So, as far as Portland cement concrete is concerned that is the hydration process.

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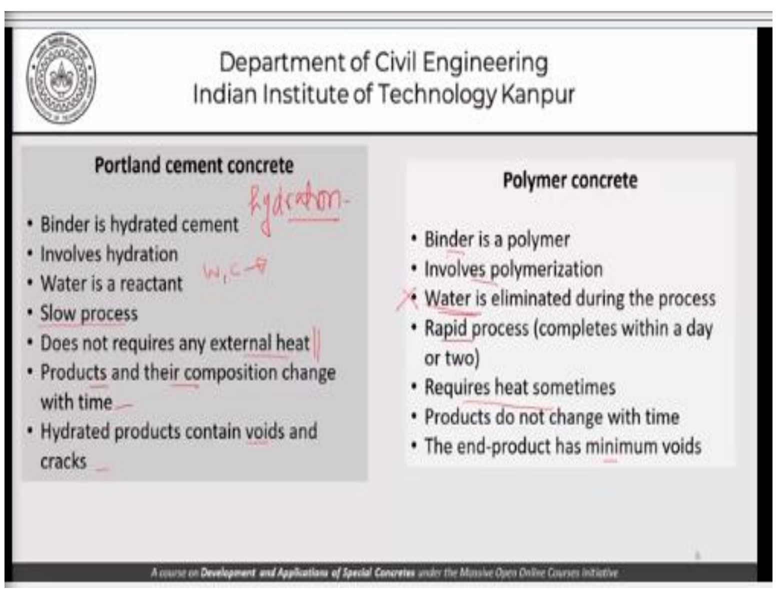

We have discussed at length and in fact it has been at the bottom of our heart as far as this particular course on special concretes is concerned. The binder is hydrated cement, involves hydration reaction, water is a reactant in fact water, and cement are the only 2 chemically reactive products which are there in concrete, the rest of it is fillers most of the time. The process is slow, hydration goes on for a long period of time does not require any external heat.

In fact, hydration generates heat it is an exothermic reaction does not require any application of heat basically unless you are talking of something like steam theory. Products and their compositions change with time, so these products of hydration, their composition changes with time and hydrated products contain voids and cracks. So, this is basically the characteristics of hydrated cement paste or Portland cement concrete.

As against this if we talk about polymerization and polymer concrete, the binder is polymer, involves the process called polymerization, water is eliminated from the process. So, there is no water which is required for polymerization it is a rapid process as against the slow process of hydration. The polymerization is a rapid process, and completes within a day or 2, requires application of heat at times, products do not change with time.

As against the hydration products which change over a period of time and the end product has minimum voids as against hydrated products in cement which has certain amount of voids and cracks. Having said that, there are problems with polymer concrete and that also we shall see at the end of our lecture today. So, but let us move on and try to understand a little bit about the polymerization process.

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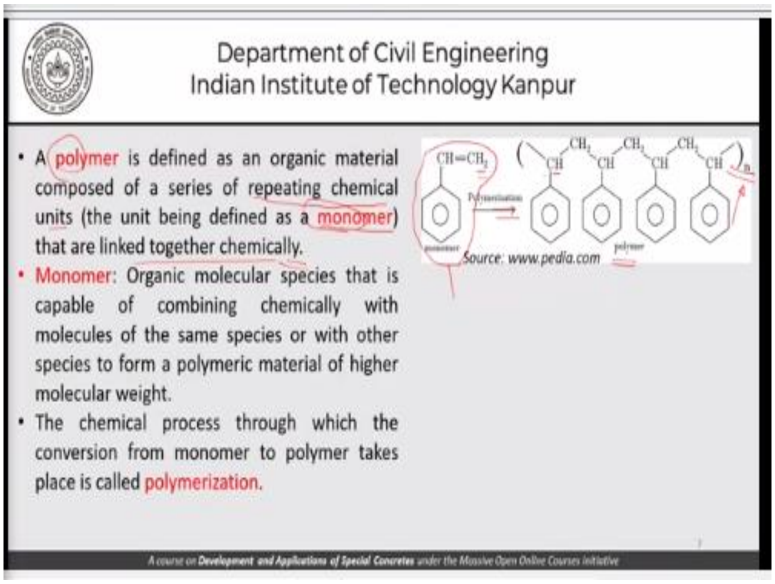

A polymer is defined as an organic material composed of a series of repeating chemical units, the unit being defined as a monomer. So, against the monomer we have the polymer, and these polymers are basically having repeated chemical units which are linked together chemically. So, what is happening here, that is the representation of the polymerization process and the whole relationship between monomer and polymer?

So, this here is a monomer, so this is a single unit and when it polymerizes it gives rise to this polymer which has the same unit here. The CH is coming from here the CH 2 has moved on the top here and is shared between 2 CH, one coming from here and this goes on and on and there are n such units. So, we have to understand how to control this n if we can, and what is the rate at which this polymerization process happens?

How does this polymerization affect the molecular weight of the polymer which is coming from the monomers? And how does the weight or the molecular weight effect or impact mechanical properties such as the strength of that polymer? So, these are some of the things that we need to understand a little bit as far as polymer concrete is concerned. We will not necessarily go into all these details but just give you a bird's eye view of this process.

A monomer is an organic molecular species that is capable of combining chemically with molecules of the same species or with other species to form a polymeric material of higher molecular weight that is what we discussed just a minute before. The chemical process through which the conversion of monomers to polymers takes place is called polymerization.

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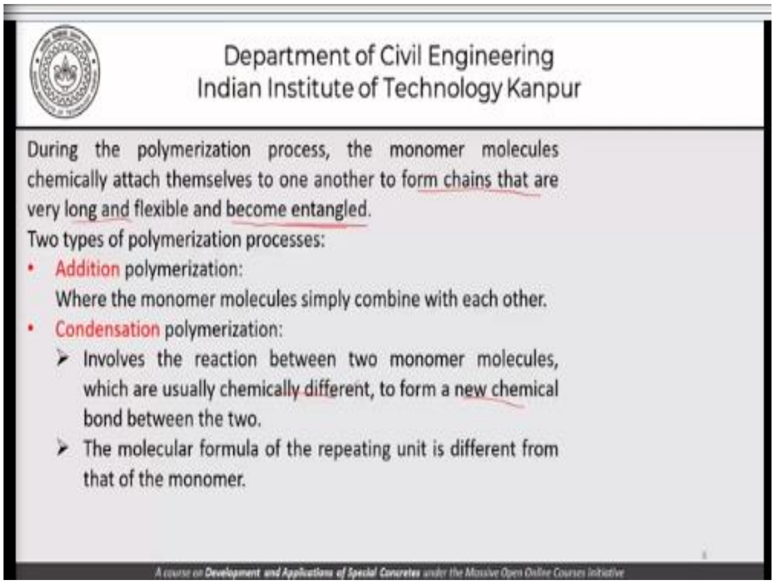

During the polymerization process the monomer molecules chemically attach themselves to one another to form chains that are very long and flexible and become entangled. So, this entanglement is something which gives them some kind of stiffness as far as mechanical properties is concerned. There are 2 types of polymerization processes, let us are talked about a literature, one is addition polymerization, now what is additional polymerization?

Where the monomer molecules simply combine with one another that is addition polymerization, the molecules are just adding to themselves or adding 2 molecules of the similar type. Condensation polymerization on the other hand involves the reaction, between 2 monomer molecules which are usually chemically different to form a new chemical bond between the 2. The molecular formula of the repeating unit is different from that of the monomer.

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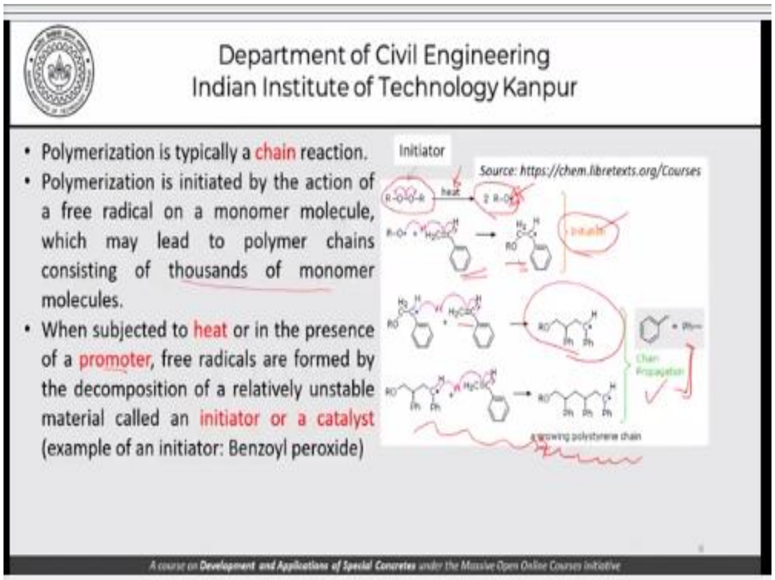

So, polymerization is typically a chain reaction and involves initiation by the action of a free radical or a monomer molecule which may lead to a polymer molecule chains which could be thousands of molecules long. When subjected to heat or in the presence of a promoter, free radicals are formed by the decomposition of a relatively unstable material called the initiator or catalyst, a typical initiator is benzoyl peroxide.

Now this process is represented here in this picture, this is the initiator and we can see that this is what is formed upon application of heat as far as the initiator is concerned. So, this initiator which was not a very stable compound has this element here which makes it kind of reactive. Now, this attacks this double bond here leading to this formation here and this is what is the initiation of polymerization?

So, this monomer molecule has now become more reactive and this attacks the next monomer molecule forming something like this. And, this reaction goes on, and we have a growing polystyrene chain and this is what is the chain propagation. So, this is the initiation reaction, and this is the chain propagation of polymerization, in this case for polystyrene.

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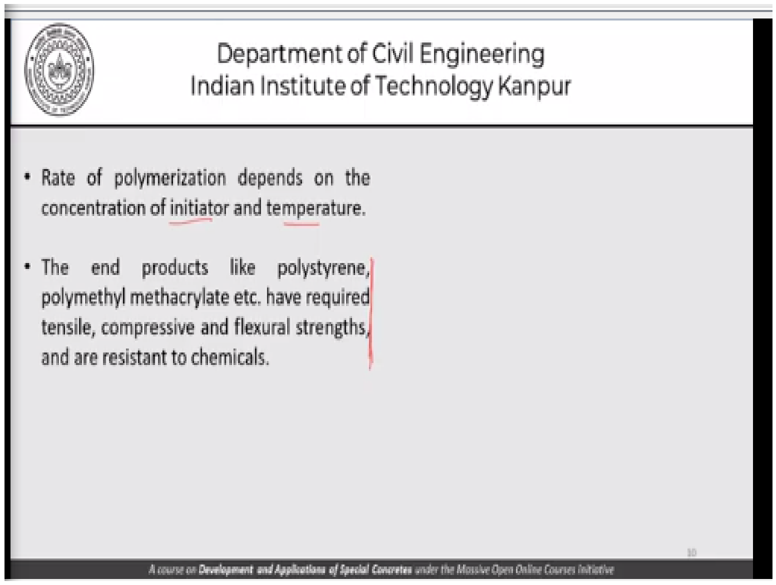

Now, the rate of polymerization depends on the concentration of the initiator and the temperature. The end products like polystyrene or polymethyl methacrylate have the required tensile compressive and flexural strengths, and are resistant to chemicals. And we have kind of mastered the art of controlling the polymerization to the extent of achieving the right amount or the desired kind of tensile compressive or flexural strength at least to some extent. Now moving forward, let us talk of polymer concrete.

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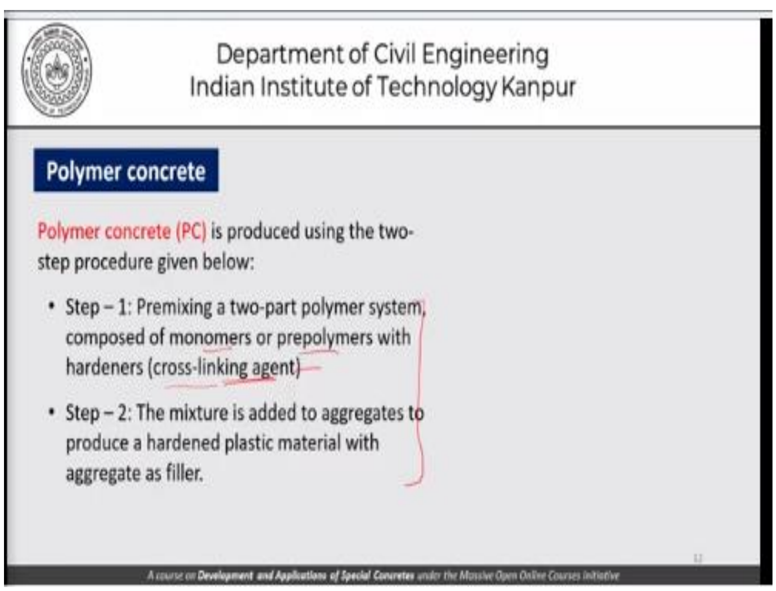

The last few slides just gave you a bird's eye view of what polymerization is and we will go back to something which as engineers we are more interested, that is polymer concrete. A polymer concrete PC is produced using two-step procedure given below. Step 1, is a premixing of a two-part polymer system composed of monomers or prepolymers with hardeners which is the cross-linking agent. And this cross-linking agent facilitates polymerization in a manner that we get the desired mechanical properties.

The step 2, the mixture is added to aggregates to produce a hardened plastic material with aggregates as the filler. So, this is more or less analogous to cement and hydration, except that we do not use cement paste separately and then try to fit it into aggregates. But in the case of polymer concrete, it is a two-step process which is quite different premixing of a two-part polymer system. And then adding that mixture to the aggregate to produce a hardened material with aggregates as fillers, so that is what is the physics of polymer.

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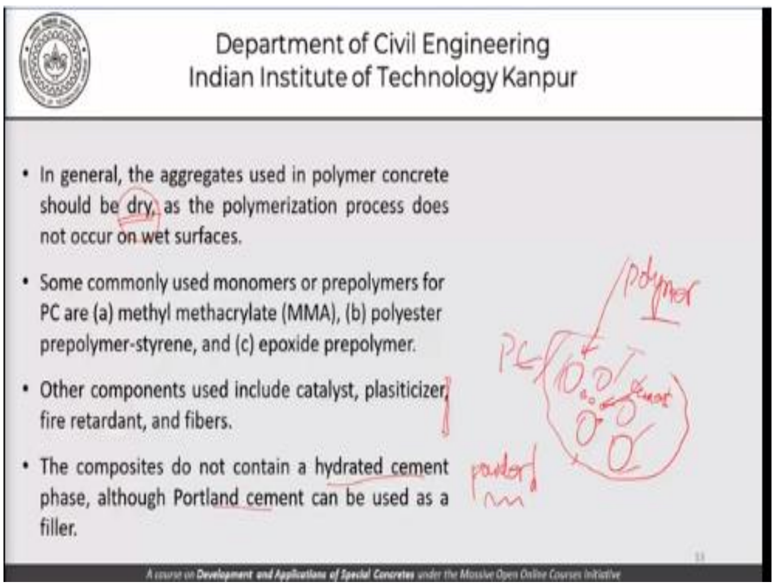

In general, the aggregates used in polymer concrete should be dry. As the polymerization process does not occur on wet surfaces. So, we necessarily have to drive the aggregates in the case of polymer concrete. Some commonly used monomers or prepolymers for the polymer concrete are methyl methacrylate MMA, polyester prepolymer-styrene or epoxide prepolymer. Other components are used include catalysts, plasticizers, fire retardants and fibers.

So, there are a lot of other things that can be added to this matrix of polymers and aggregates to have the desired properties in the polymer concrete. Basically, let us say fire retardation or fibers, plasticizers and so on. This composite that is the polymer concrete does not contain any hydrated cement phase, although Portland cement can be used as filler. So, so long as we do not add water, Portland cement is just a powder, so as a powder there is no reason why we cannot use it.

So, as far as aggregates are concerned, yes, we can have aggregates, we can have smaller particles which could be cement particles. And then in this whole thing we add this premixed polymer or the prepolymers and freeze this whole thing, including the cement particles in it which is acting as fillers, and what we get is polymer concrete.

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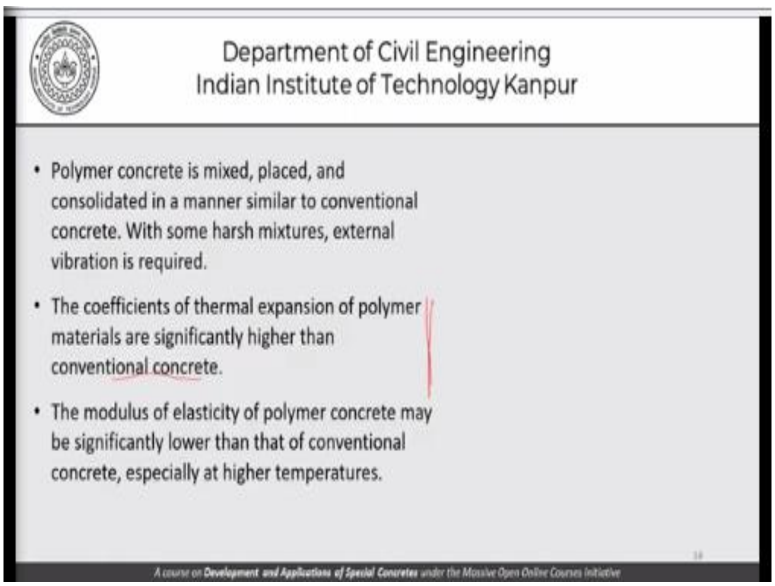

Polymer concrete is mixed, placed and consolidated in a manner similar to conventional concrete, when there are some harsh mixtures, external vibration maybe required. The coefficient of thermal expansion of polymer materials is significantly higher than that of conventional concrete. And these are the kind of properties which we need to bear in mind very carefully as engineers when we try to use polymer concrete, as a structural material or as a material for normal construction works.

The modulus of elasticity of polymer concretes may also be significantly lower than that of conventional concrete, especially at higher temperatures. So, this really tells us that as far as polymer concretes are concerned, the physics is the same. But the properties of the polymer or the hardened polymer or the hardened binder as a matter of fact, that is quite different from the hardened cement paste. And that is what shows when we talk in terms of the properties of polymer concrete, in terms of the coefficient of thermal expansion or the modulus of plasticity or for that matter even the strength.

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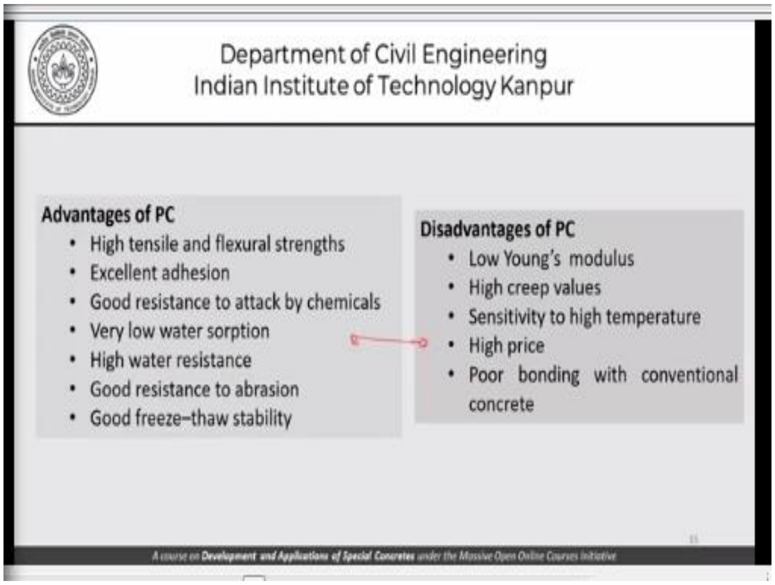

As far as the advantages of using polymer concrete are concerned, it has high tensile and flexural strength, excellent addition, good resistance to attack by chemicals, very low water absorption, high water resistance, good resistance to operation, good freeze-thaw stability. But there are disadvantages like the low Young's modulus, high creep values, sensitivity to high temperatures, high price and poor bonding with conventional concrete.

So, it is a balance between these 2 things, the advantages are listed, the disadvantages are listed and the engineer has to make a considered choice between the 2 when deciding to use polymer concretes in a particular application.

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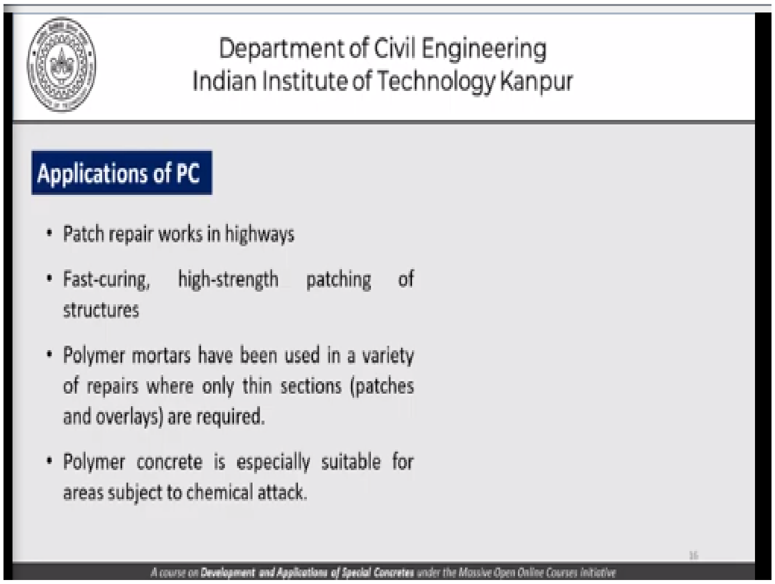

Still, of course, there are applications patch repair works in highways, fast curing, high strength patching of structures, polymer mortars have been used in a variety of repairs where only thin sections are required or are possible. Polymer concrete is especially suitable for areas subjected to chemical attack. So, there are basic applications, there are important applications of polymer concrete and that is why I thought it will be interesting to include at least a brief description or a sensitization towards this material as far as this course is concerned.

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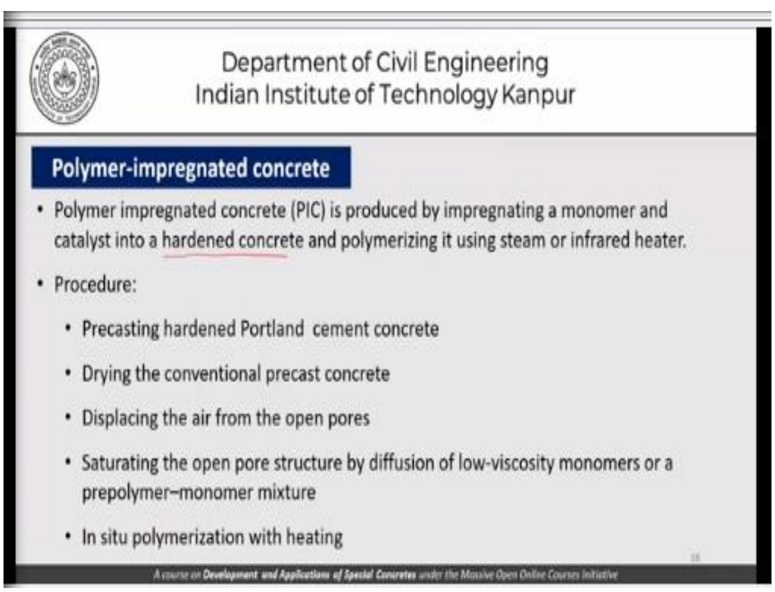

And now we move on to polymer impregnated concrete, that is the PIC. Now, the polymer impregnated concrete is produced by impregnating a monomer and a catalyst into a hardened concrete and polymerizing it using steam or infrared heater. So, what we do is to a normal hardened concrete, we impregnate it with a monomer and catalyst and then induce polymerization by using steam or infrared heating.

The procedure basically is precasting hardened Portland cement concrete, that is have a normal Portland cement concrete which is available to you. Dry that conventional concrete, displace the air from the open pores to facilitate the movement of polymers into those pores. Saturating the open pore structure by diffusing low viscosity monomers or a prepolymer monomer mixture and in-situ polymerization with heating.

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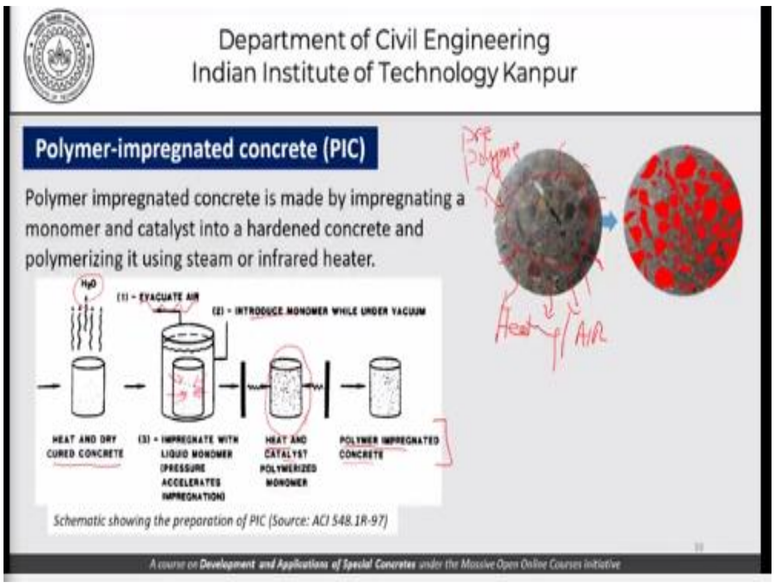

So, basically to make the picture slightly clearer, polymer impregnated concrete is made by impregnating monomer and catalyst into a hardened concrete and polymerizing it using steam or infrared heating and this is a picture which really shows that. So, we heat and dry cured concrete, so this concrete is heated and dried. So, that all the water which can be removed from here is really removed.

After that is done, we try to evacuate the air from this concrete while at the same time introduce monomers under vacuum. And once these monomers have been allowed to enter through the concrete, we apply heat on the surface and that catalyzes the reaction or the polymerization of the monomers which have impregnated into the concrete and we get polymer impregnated concrete. So, if you look at this picture here what you can visualize is that the first step would involve drying and heating this concrete, which means that all the water from here which can be removed is removed.

Then all the air is also removed and we apply a monomer or a pre-polymer which penetrates into the gaps of this concrete and this prepolymer or monomer which may have permeated into the concrete up to different depths is allowed to polymerize by applying heating or steam or whatever it is depending on what kind of product you have used, and then what we will get is polymer impregnated concrete.

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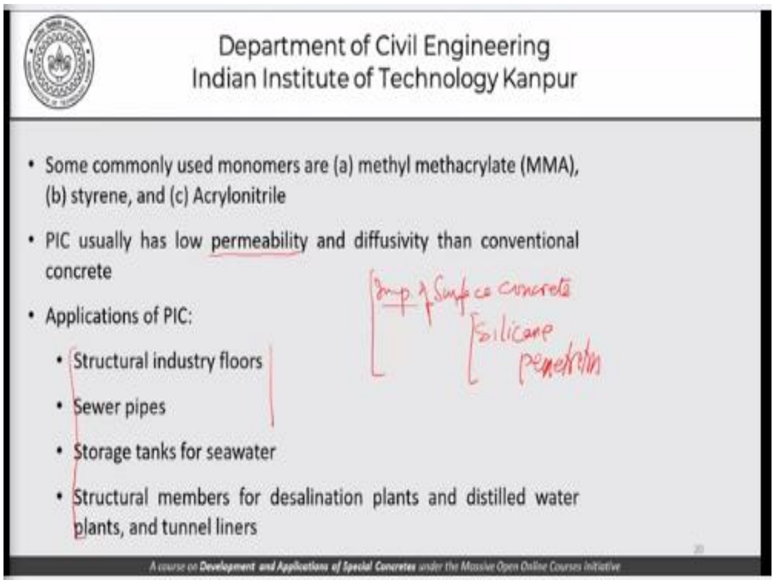

Now, some commonly used monomers in this case is MMA our good old friend from the polymer concrete time is styrene and acrylonitrile. The PIC usually has low permeability and diffusivity than conventional concrete. That is obvious because if you have already filled some of the pores in the concrete, so the permeability and diffusivity will obviously go down. And the application of this concrete that is the PIC is structural industrial floors.

Sewer pipes, storage tanks for seawater and structural members for desalination plants and distilled water plants and tunnel liners. So, these are some of the applications where we will have normal concrete first and then try to impregnate the normal concrete with polymers to achieve or get polymer impregnated concrete. In the next lecture or the lecture after that we will talk about improving the properties of surface concrete by a method called silicane penetration.

And, the silicane is applied on the concrete surface and penetrates into the concrete, seals the gaps. Now this process is something very similar to what we are talking about here. Here we are talking of the application of monomers and catalysts which will go into the pores from the surface and seal those pores leading to a low permeability concrete. So, even though we are talking of a low permeability concrete, one must remember that these monomers do not necessarily penetrate throughout the concrete.

They maybe kind of restricted through the surface and to that extent this process is very similar to what we will talk about in our discussion of improvement of surface properties of concrete.

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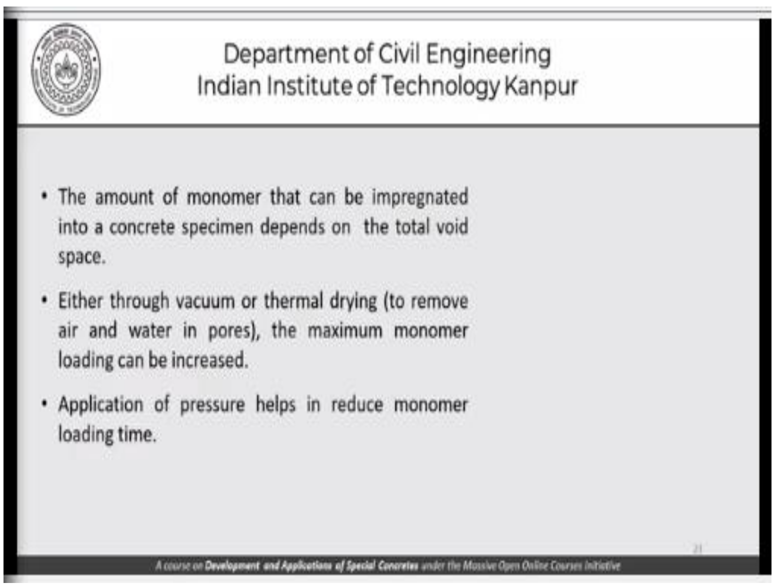

The amount of monomer that can be impregnated into a concrete specimen or a concrete member depends on the total void space in the concrete. Either through vacuum or thermal drying to remove the air and water in pores, the maximum monomer loading can be increased. The application of pressure helps in reducing the monomer loading time. So, instead of letting the monomers load naturally we can apply some pressure and accelerate or facilitate the process of monomer penetration into hardened concrete.

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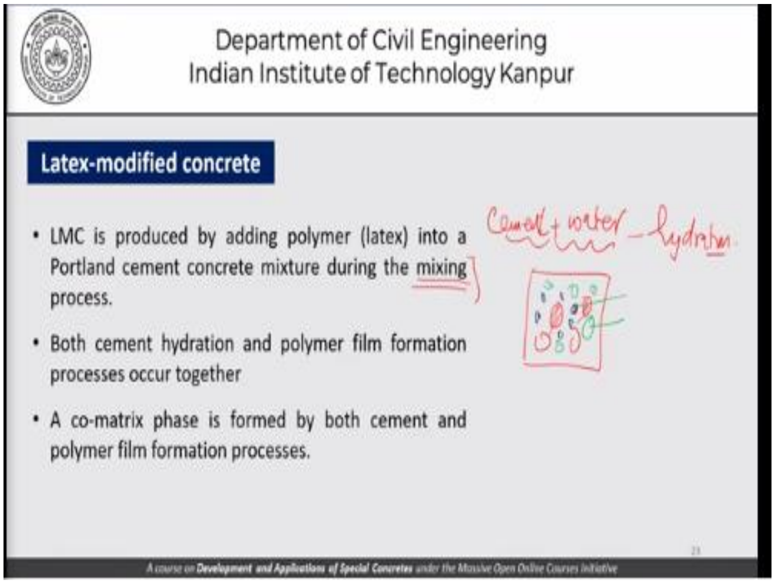

Moving forward to the last discussion that we have promised for today that is the latex modified concrete LMC. Now this LMC is produced by adding polymer which is latex most of the time into a Portland cement concrete mixture during the mixing process. So, in this case the latex or the polymer is added during the mixing itself, not that it takes part in the hydration reaction. Because once we are mixing normal concrete obviously, we have cement and water. So, the cement and water this hydration will continue anyway, this does not wait or this does not get affected at least directly in some form by the presence of polymers.

Both cement hydration and polymer film formation processes occur together. So, as far as the concrete is concerned, we have a matrix where we have aggregates and we have cement particles and water. So, this is my cement particles and water, so hydration products are being formed and at the same time there are polymers also here somewhere, of course this is not to scale. So, we please do not say that these particles the part of polymers are the same size as coarse aggregates.

But we have a system where these polymers or the latex as well as the hydration products are all part of the binder and everything is holding the coarse aggregates together. So, the coarse aggregates here are being held in position or bound with a combination of normal cement hydrates, the hydrated products of cement. And the polymer film formed from the latex or the polymers.

The co-matrix phase is formed by both cement and polymer film formation processes, and that becomes the binder in the case of latex modified concrete.

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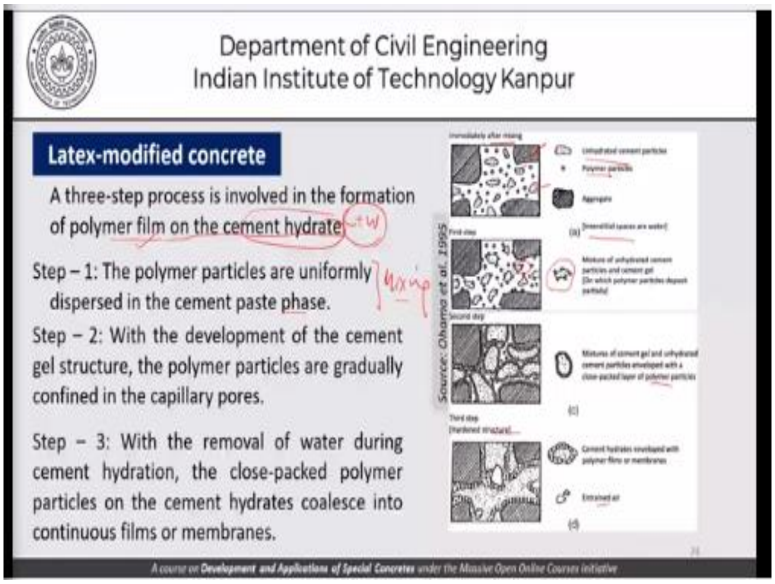

This picture here shows the steps involved or a model there from. A three-step process is involved in the formation of polymer films on the cement hydrates. So, we are talking in terms of our model which says polymer film formed on cement hydrate. So, the cement hydrates are formed with cement and water. And on these hydrates, we have a polymer film as is shown in these steps, so let us see what the steps are.

Step 1, is the polymer particles are uniformly dispersed in the cement paste phase, so this part is part of the mixing. That as we are mixing the cement and the water and all the other ingredients along with this polymer, the polymer particles are uniformly distributed or dispersed in the cement paste phase. The step 2 is the development of the cement gel structure, the polymer particles are gradually confined in the capillary pores.

And, the third step is with the removal of water during cement hydration, the close packed polymer particles in cement hydrates coalesce into a continuous film or membrane. So, this process is diagrammatically shown here that immediately after mixing we have unhydrated cement particles also which are shown here. Along with the aggregates of course we have polymer particles here.

In the first step the interstitial spaces are water, mixture of unhydrated cement particles in the cement gel on which the polymer particles deposit partially, that is what is shown here and is shown here as a matter of fact. In the second step mixtures of cement gel and unhydrated cement particles enveloped with a close packed layer of polymer particles. And finally in the hardened structure that is the third step.

We have cement hydrates enveloped with polymer films of membranes and we have some entrained air as part of the matrix. So, this is a diagrammatic representation or a model that has been proposed for the formation or to explain the behaviour of latex modified (()) (29:51).

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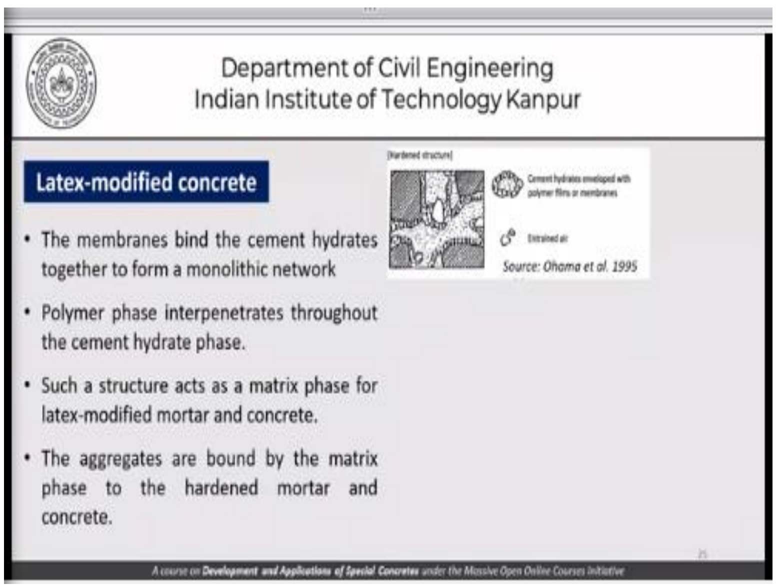

Further the membranes bind the cement hydrates together to form a monolithic network. And the polymer phase interpenetrates throughout the cement hydrate phase. And such a structure acts as a matrix phase for the latex modified mortar or concrete. The aggregates are bound by the matrix phase to the hardened mortar and concrete.

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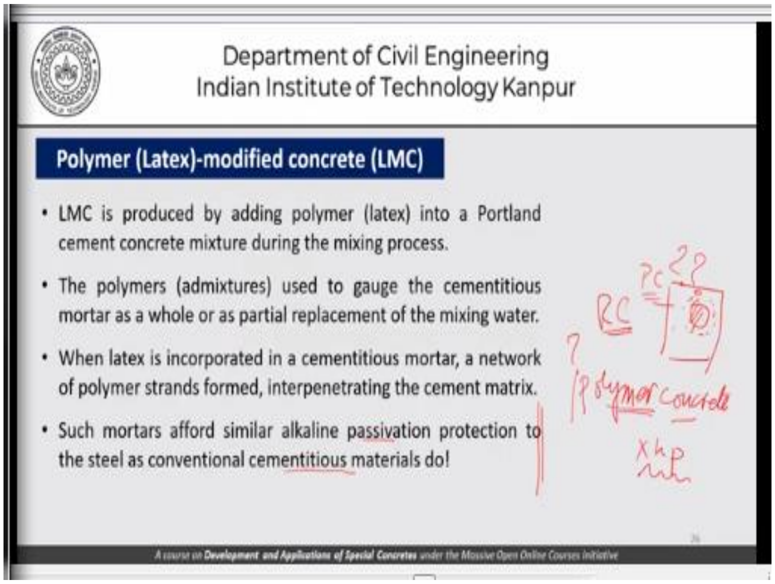

LMC is produced by adding polymer or latex into the Portland cement concrete mixture during the mixing phase to recapitulate. So, the polymers can actually be looked upon as admixtures used to gauge the cementitious mortar as a whole or as partial replacement of the mixing water. And when latex is incorporated in a cementitious mortar, a network of polymer strands are formed into penetrating the cement matrix.

And such mortars afford a similar alkaline passivation protection to the steel as conventional cementitious materials too. I am leaving it to you to think about and look in the literature about this part of alkaline passivation in the case of polymer concrete. In the case of polymer concrete, remember that there are no hydration products, we are not having any hydration products, we have only hardened polymer around the coarse aggregates.

What happens to the neighbourhood of the steel if you are using polymer concrete instead of normal conventional concrete in reinforced concrete structures? Then we will have a reinforcing bar here and it will be surrounded by polymer concrete, what would be the pH of the system around here as well as the reinforcing bar is concerned. That is the question that you can think about, as far as LMC is concerned the answer has been provided here in this slide.

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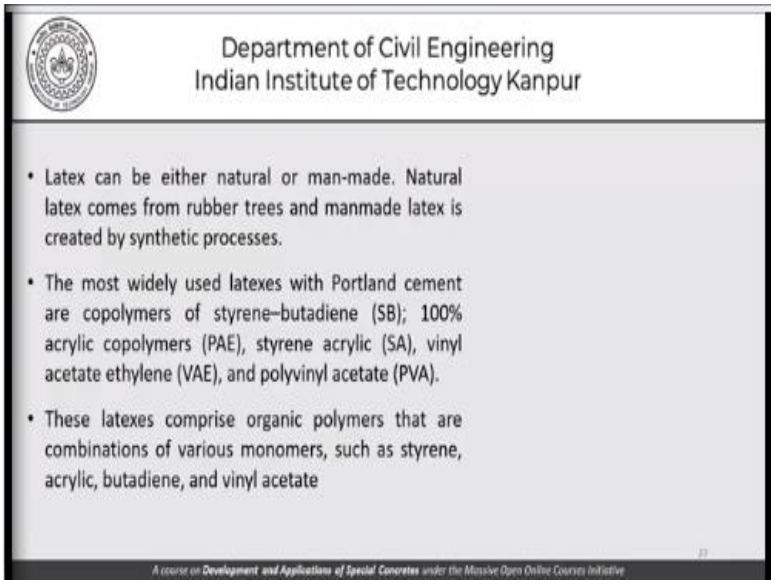

Latex can either be natural or man-made, natural latex comes from rubber trees, and man-made latex is created from synthetic processes. And, the most widely used latexes with Portland cement are copolymers of styrene-butadiene; acrylic group polymers which is PAE, styrene-acrylic which is SA and vinyl acetate ethylene or polyvinyl acetate. So, these are some of the common latexes which are used in combination with Portland cement in making LMC's that is the latex modified concretes.

These latexes comprise organic polymers that are combinations of the various monomers such as styrene, acrylic, butadiene and vinyl acetate.

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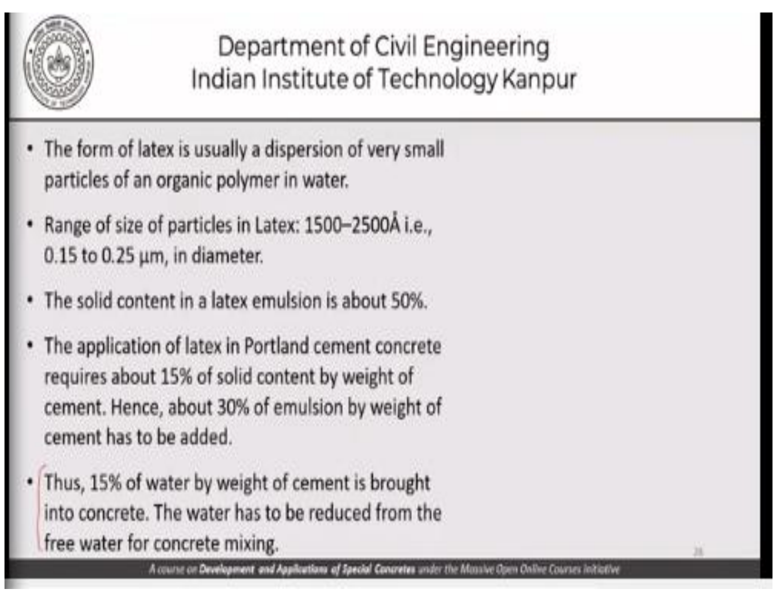

The form of latex is usually a dispersion of very small particles of organic polymers in water and the range of size of particles in latex ranges from 1500 to 2500 Armstrong's, that is about 0.15 to 0.25 micrometers in diameter. The solid content in a latex emulsion is about 50% and the application of latex in Portland cement concrete requires about 15% of solid content by weight of cement.

Hence, about 30% of emulsion by weight of cement has to be added as an admixture when we are mixing concrete. Thus 15 of the water by weight of cement is brought into concrete by this root, and this water needs to be adjusted from the free water that is added to concrete for mixing. So, this is a little complicated looking algebra for taking care of the amount of water which has to be added to the LMC.

Because part of the water now is reaching the concrete or reaching the mixer as the agent which was used to create an emulsion of the latex particles, and the other part has to be added independently as water as usual as far as a cement concrete is concerned.

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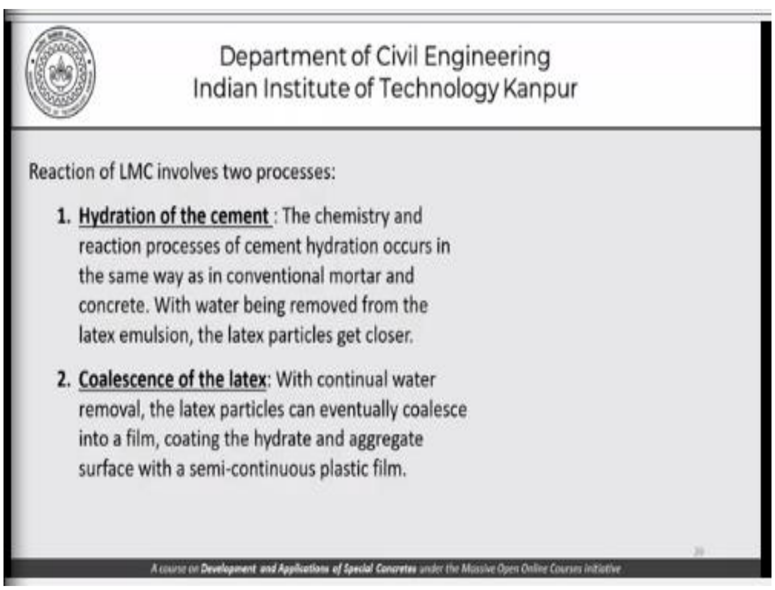

LMC of course now has 2 processes we have already talked about it hydration of the cement, the reaction and the reaction. The chemistry and the reaction processes of cement hydrations occurs in the same way as in conventional mortar and concrete with water being removed from the latex emulsion, the latex particles get together. The water which was a medium to introduce the latex particles into the cement concrete.

Now becomes a part of the water which is reacting with the cement as well as the normal hydration is concerned. And, then we have the coalescence of the latex particles with the continual water removal. The latex particles can eventually coalesce into a film coating the hydrate and the aggregate surface with a semi-continuous plastic film of this latex.

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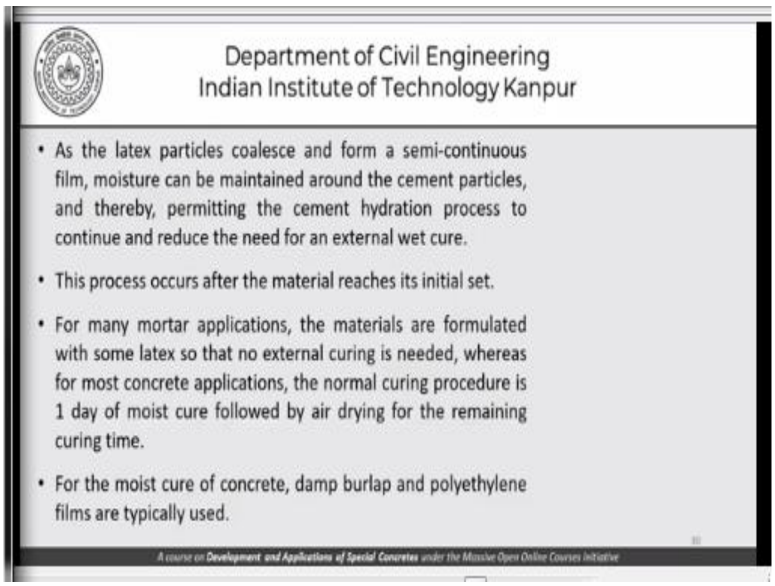

So, as the latex particles coalesce and form a semi-continuous film, moisture can be maintained around the cement particles and thereby permitting the cement hydration process to continue and reduce the need for an external wet cure as far as LMC's is concerned. This process occurs after the material reaches it is initial set. And for many mortar applications the materials are formulated with some latex.

So, that no external curing is needed whereas for most concrete applications the normal curing period is about one day of moist cure followed by air drying for the remaining cure time. For the moist cure of concrete damp burlap and polyethylene films are typically used. So, these are some of the practical tips as far as using LMC in actual construction is concerned.

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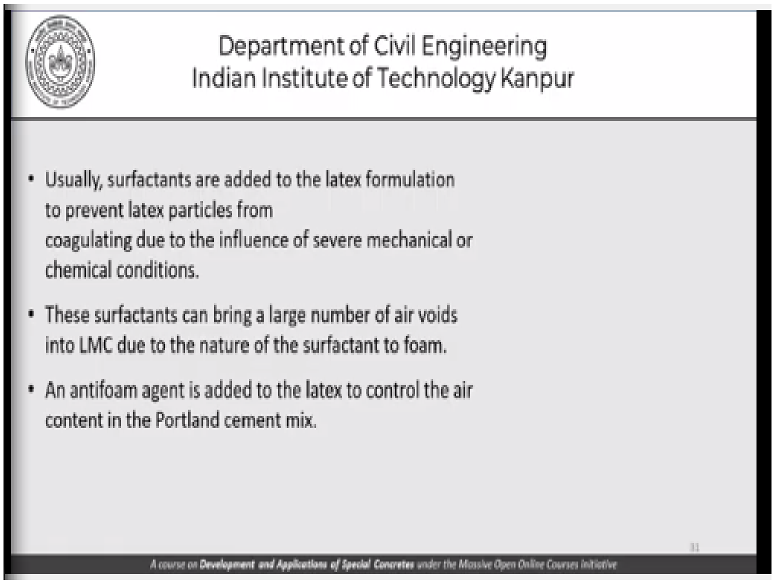

Usually, surfactants are added to the latex formulations to prevent latex particles from coagulating due to the influence of severe mechanical or chemical conditions. And these surfactants can bring a large numbers of air voids into the LMC due to the nature of the surfactants to form and an antifoam agent therefore needs to be added to the latex to control the air content in Portland cement mix.

So, if we are using latex particles and we use surfactants to prevent the latex particles from coagulating, those surfactants will have the side effect of creating a lot of air voids. And therefore, we need to use an antifoaming agent that is what is listed here.

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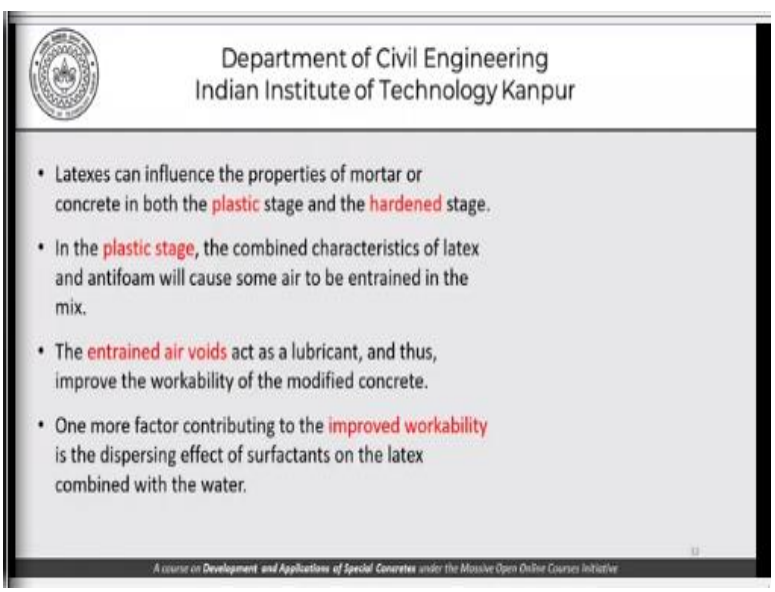

Latexes can influence the properties of the mortar or the concrete in both the plastic stage and the hardened stage. In the plastic stage, the combined characteristics of latex and antifoam will cause some air to be entrained in the mix. And, this entrained air voids act as lubricant, and thus improve the workability of the modified concrete. One more factor contributing to the improved workability is the dispersing effect of the surfactants on the latex combined with water.

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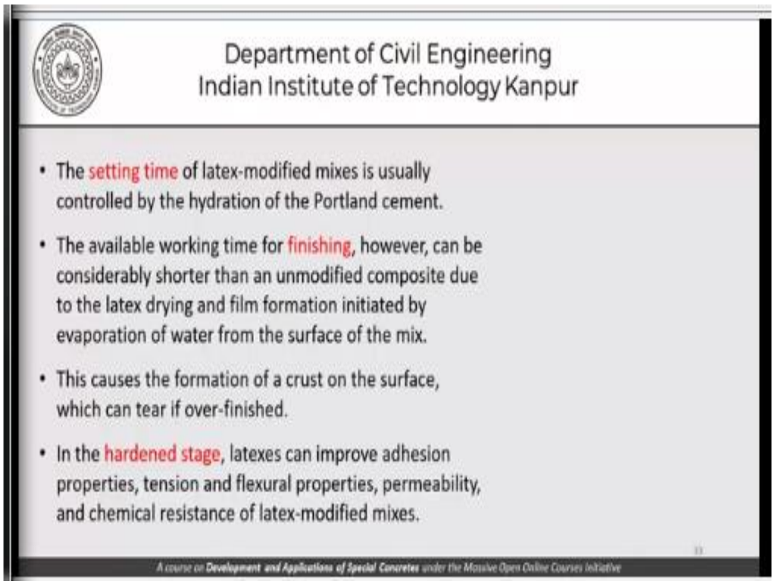

The setting time of LMC mixes is controlled by the hydration of Portland cement. The available working time for finishing however can be considerably shorter than an unmodified composite due to the latex drying and film formation initiated by the evaporation of water from the surface of the mix. This has major implications in terms of the shelf life or the time that is available for us to work the concrete to it is site and the finishing and so on.

This causes the formation of the crust on the surface which can tear if over finished. And in the hardened stage the latexes can improve addition properties, tension and flexural properties, permeability and chemical resistance of the LMC mixes.

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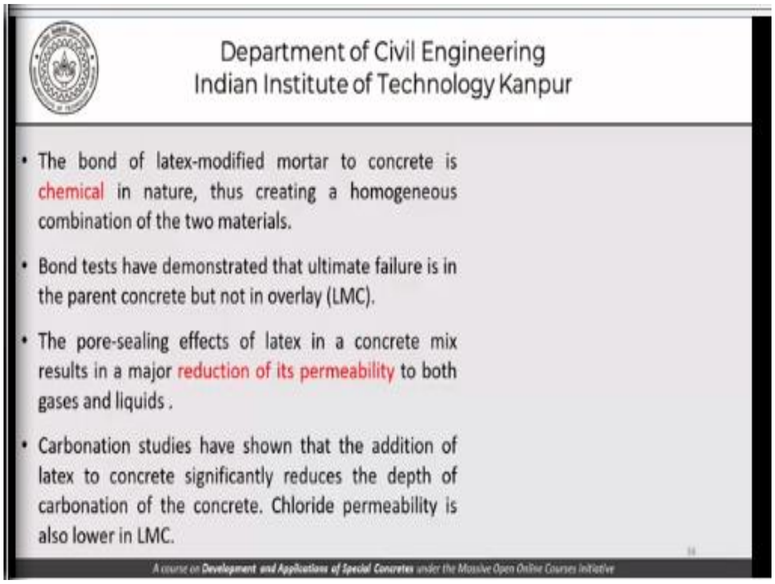

The bond of latex modified mortar to concrete is chemical in nature thus creating a homogeneous combination of the 2 materials. Bond tests have demonstrated that the ultimate failure is in the parent concrete and not in the overlay as far as LMC's is concerned. So, in this case we are talking of latex modified concrete being used as an overlay material on an existing substrate or an existing layer of concrete.

The poor sealing effect of the latex in a concrete mix results in a major reduction of it is permeability to both gases and liquids. Carbonation studies which basically means penetration of carbon dioxide into concrete or similar materials. So, carbonation studies have shown that the addition of latex to concrete significantly reduces the depth of carbonation of the concrete. Chloride permeability too is lower in the case of LMC.

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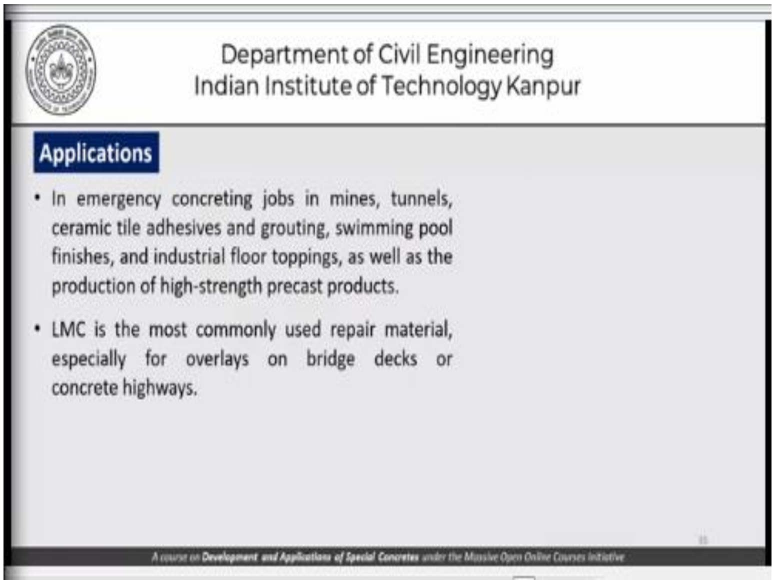

So, as far as applications of the LMC is concerned it is emergency concreting jobs in mines, tunnels, ceramic tile adhesives and grouting, swimming pool finishes, and industrial floor toppings, as well as the production of high strength precast products. LMC is most commonly used in repair material especially for overlays on bridge decks and concrete highways.

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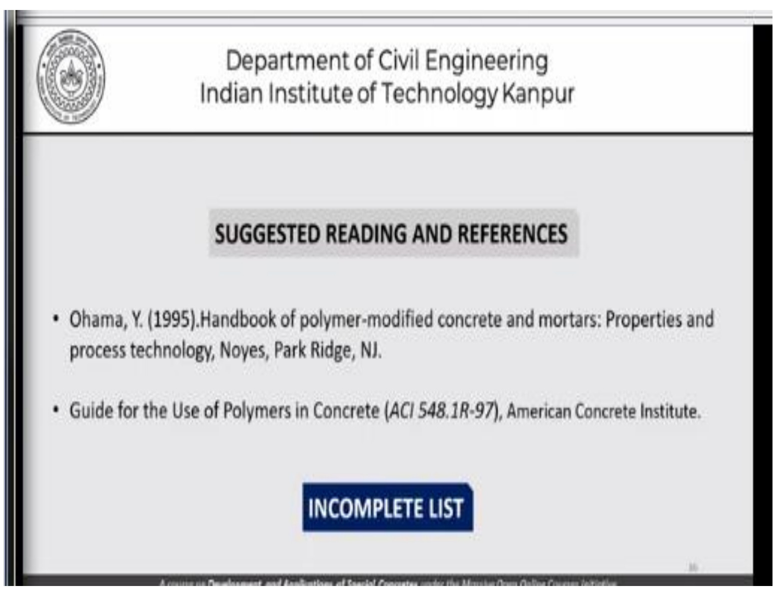

So, with this we come to an end of our brief discussion on the three applications or the three classes of applications of polymers in concrete. The development of polymer concrete, the development of polymer impregnated concrete, and the development of latex modified concrete which have very subtle nuances in terms of applications of polymers. As part of the hydration products, replacement of the hydration products in a certain area.

Or supplementing the hydration products in a certain area is concerned. So, this is an incomplete list as usual of what you could read about polymer modified concretes to enrich yourselves and should you be interested you need to know a lot more about the polymerization process. The different monomers that are used and how they have been used in concrete? The ACI 548.1 that is the ACI committee the American concrete institute committee which talks about the use of polymers in concrete. With this I am giving to you some questions which you can think about and that will probably help you.

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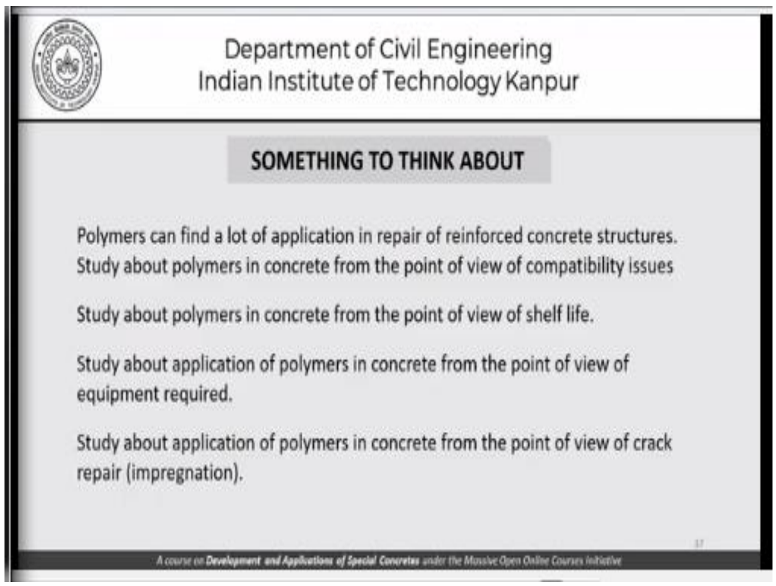

Find material about polymer concretes? The polymers can find a lot of applications and repair of reinforced concrete structures that is true. But study the polymers in concrete from the point of view of compatibility issues, some of it we have already discussed, you can probably take a look at it once again. Study about polymers in concrete from the point of view of shelf life, briefly touched upon that in the context of LMC's.

But what about the polymer concrete itself? What is it is shelf life or how much time do we have to place the polymer concrete in position after we have mixed it? Study about the application of polymers in concrete from the point of equipment required about the application of polymers in concrete from the point of view of crack repair, impregnation and cracks not necessarily the pore spaces within concrete.

So, these are some of the directions in which you could probably do a search and understand the world of polymers in concrete better. Thank you once again and I look forward to talking to you once again in this module which is just mentioned the last week of our course on development and applications of special concretes, thank you.