Ocean Structures and Materials
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Module - 3
Lecture - 5
Repair Materials for Marine Structures

(( )) Material a virtual classroom and NPTEL, IIT Madras. I am Dr. Srinivasan Chandrasekarn, coordinating this course for you. We have already discussed three modules, - one, two and now we are in the third module. In third module, we will.discuss four lectures. Quickly summarizing what you studied in lecture one, two, three and four, we are looking for the different kinds material that qualify further application in marine environment. Different types of offshore structure we have discussed in module one; and module two, we spoke about different requirements, regulations, construction methodologies, techniques and dredging requirements. In module three, when you talk about materials and their suitability for marine environment; concrete is considered is one of the favorite materials by offshore engineers to use it for construction purposes in ocean and marine structures.

Now, concrete has specific kinds of problem which has got to be addressed with which the applicability and the confidence in concrete as construction materials for ocean structures can be higher. So, this lecture is focusing on one specific methodology by which the durability and strength of concrete can be increased by adding or by treating concrete with some chemical reactants. So, this lecture will talk about crystalline methodology which is one of the interesting and recent advancements in concrete as a construction material, in particular when it is being used for marine environment.

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So, protecting concrete using crystalline technology is the focus of today's lecture. The fundamental question is, do you have to protect concrete, why is it necessary? Because, people think concrete is already impervious, is already having enough strength and durability requirements and the time tested material for construction purposes in any worst environment. So, do we have to test concrete or do we have to really protect concrete, what are the necessity we will talk about that and a recent advancement in the literature talk about crystalline technology which is one of the possible solution for improving the performance of concrete by protecting it from sea environment.

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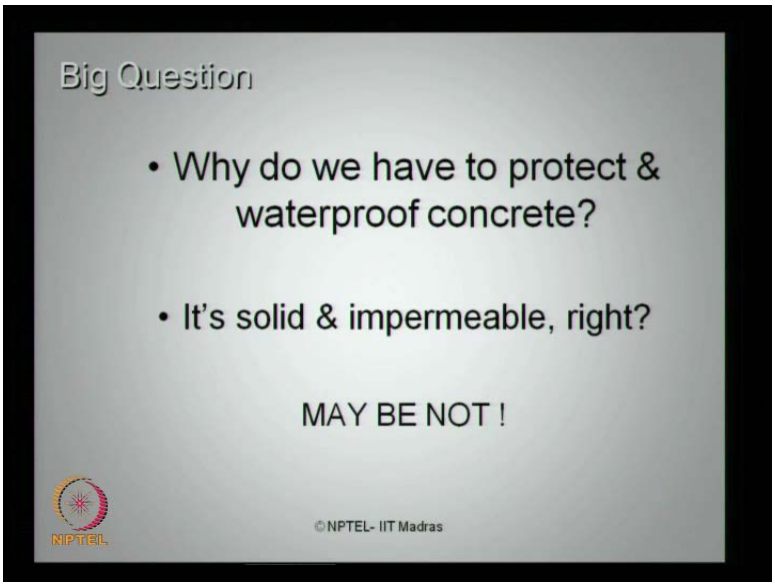

It is a big question that why do we have to protect and waterproof concrete? Because, it is solid and impermeable; if that is a case, if you understand it is impermeable and solid and integrable then there is no need to protect it, but it is not true; it may not be always true. Concrete is porous and permeable.

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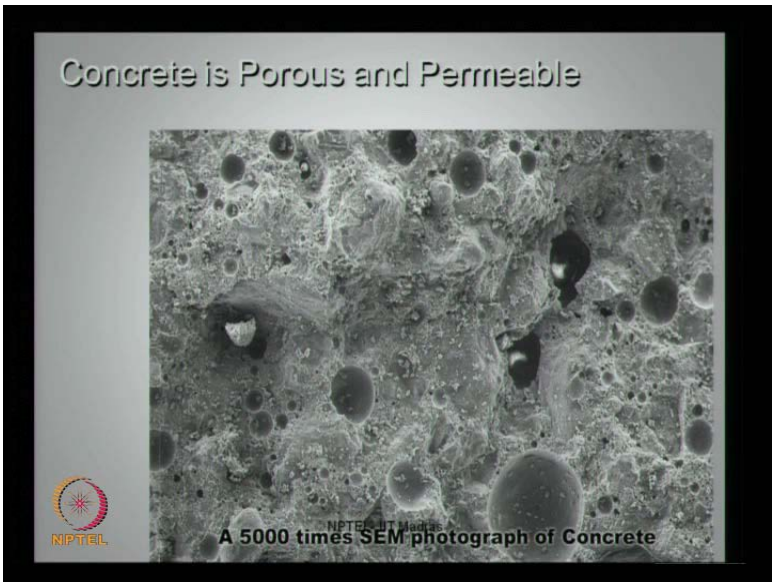

If you look at this photograph which is a 5000 times SEM photograph strand scan electron microscope photograph of concrete. If you look at it closer, further you will see there is a lot of pores and permeability possible in concrete. So, concrete is not a homogeneous impervious material, it has got lot possibilities of poles and permeability through which or through based on which the performance of concrete is challenged under a worst environment, especially in particular the sea environment or offshore environments.

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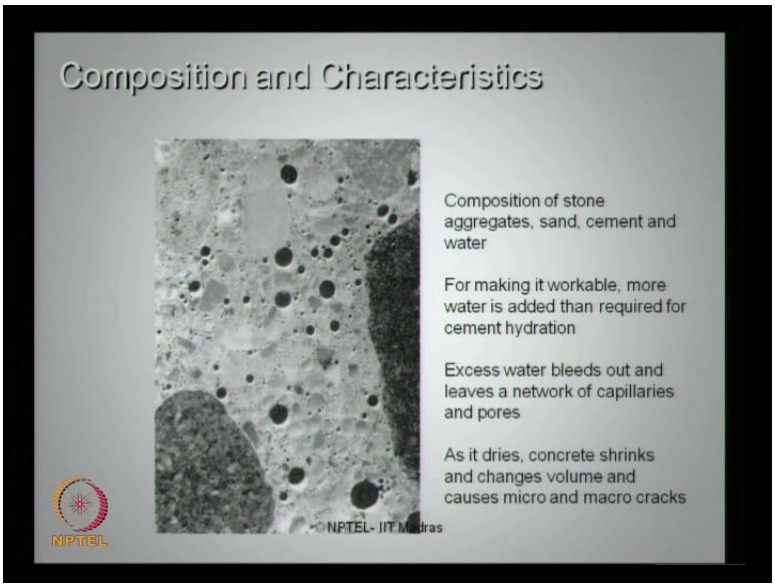

Let us quickly look at the composition and characteristics of concrete. We all understand we are civil and structural engineers, we know the importance and the method by which the concrete is manufactured or made for the construction sites. It is actually a composition of a stone aggregates, sand, cement and water. Now for making it workable, more water is added then required for cement hydration.

Ladies and gentlemen, please listen to this very carefully; that water, cement ratio plays a very important role in attaining the requisition strength of concrete. There is no doubt in this, we have got established design methodologies for doing a design of a bricks of a concrete for various application, for various slump ratios and various strength requirements. There is no doubt on that, but what I am insisting here is that for making it workable, we generally add more water which is more than that required for cement hydration.

So, x is water bleeds out, and leaves a network of capillaries and pores as it dries concrete shrinks and changes its volume, and this causes micro and macro cracks. So, it is very important for us to understand, the composition and because of the composition made what would be those characteristics which contribute to make concrete as non impervious or porous and permeable. These are couple of photographs which shows you evidence that concrete has enough force and capillaries through which the water

entrainment or air entrainment happens which deteriorates the performance of concrete under sea environment.

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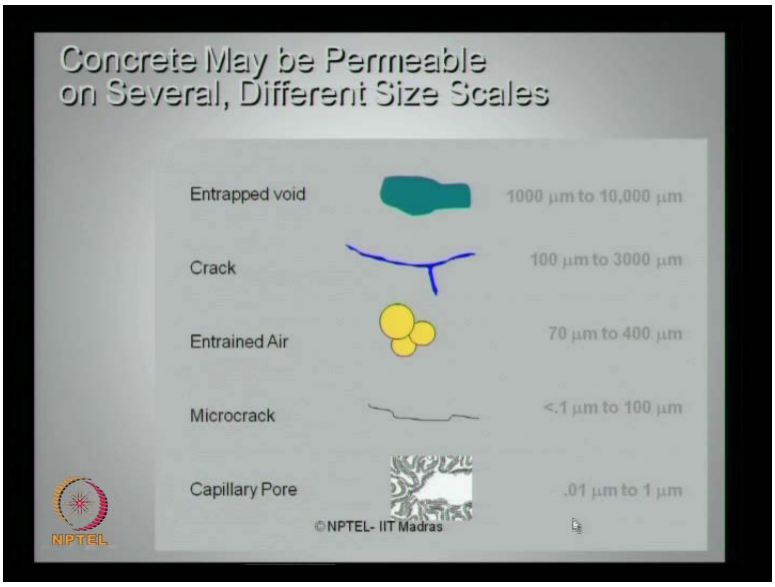

Concrete may be permeable on several different size scales as well. If you look about entrapped voids, the size scales can vary from 1000 mu m to 10,000 mu m. If you look at the cracks, it can have a size varying from 100 to 3000. If you look at the entrained air it can vary from 70 to 400. Whereas, look at the micro cracks which can develop in concrete, because of the effects which we discuss in the last lecture, it may be varying from 0.1 to 100, whereas, look at the capillary pores it can be as minute as 0.01 to 1. So, these are the different varieties of size scales which are responsible for making concrete permeable.

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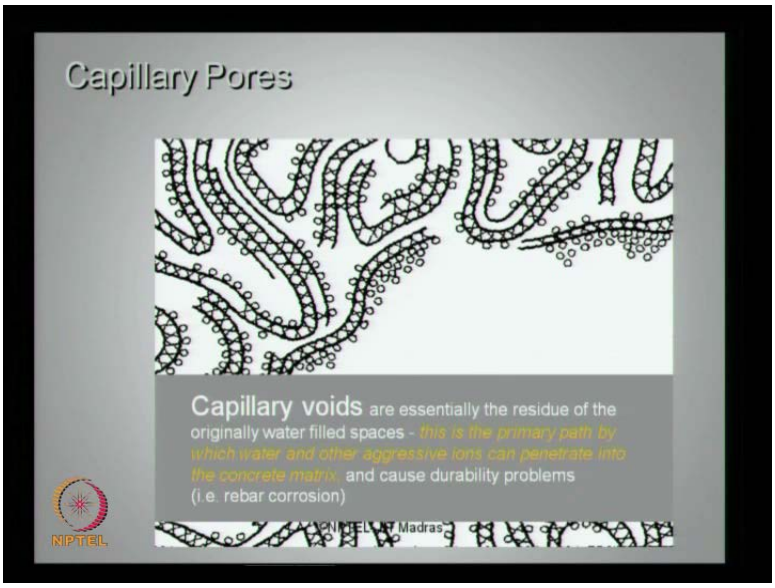

If you look at the capillary pores which are very minute in size, which are inherently present in concrete which makes it porous and permeable. Capillary voids are essentially the residue of the originally water filled spaces. Now this is the primary path by which water and other aggressive ions can penetrate into concrete matrix, and this causes serious durability problems. For example, the reinforced bar gets corroded when water is entrained and this water filled spaces are what we called capillary voids. When this capillary voids are started attracting water from the moisture content or from the sea environment, it enables aggressive ions to penetrate in to this, which are originally filled with void space of water and now this causes very serious durability problems to concrete.

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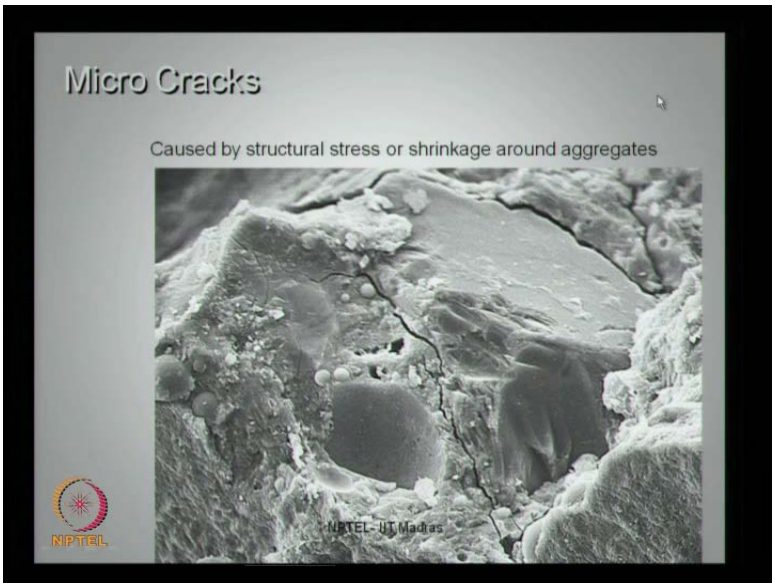

If you look at the micro cracks, which are caused by structural stress or shrinkage around they aggregates, both - one is external, one is an internal process. If you look at the photograph, which shows me the micro crack developed in concrete as you see in this photograph, the micro cracks getting developed in concrete. In the specimen, what we have shot in the photograph here, through a scan electron micro scope. It is very evident that these cracks can also be resulting from the structural stress variation which has been caused in the material or in the member because of variety of combination of loads which are happing in offshore structural members. Alternatively, these can be shrinkage cracks which can result from shrinkage around the aggregates which are used for composing of a fabricating concrete.

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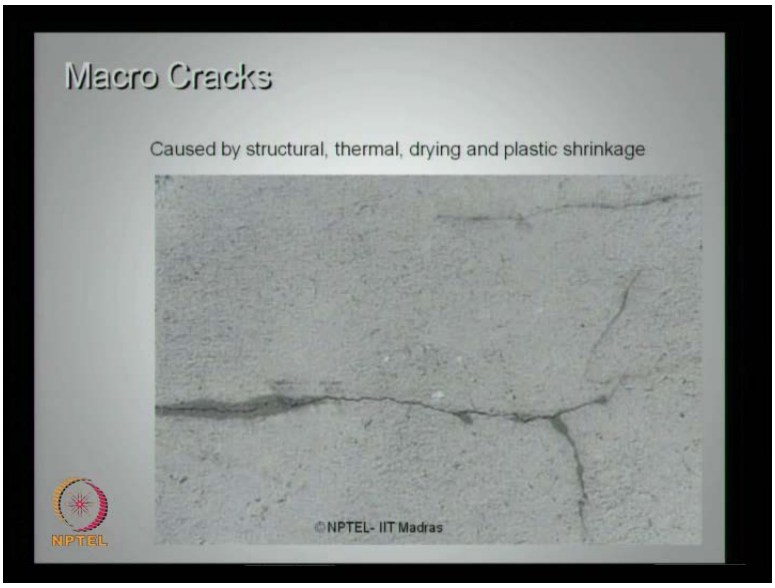

If you look at the macro cracks, this can be resulted from structural, thermal, drying and plastic shrinkage. Ladies and gentlemen, you can now clearly understand these are all possible facets where concrete receives problems, once it is place in position for fabricating a member of an offshore structure or a coastal structure. So, if you look at this photograph which is shot as very close focus, this shows me macro cracks which can arise essentially from a structural behavior, it can be due to thermal behavior or temperature gradient difference, it can due to drying or plastic shrinkage.

As we all understand concrete when put as a structural member in coastal or marine structures, are subjected to different worst environment, which can be resulting from alternate wet and drying which has got enough moisture content by the surface of contact members. So, this is one of the major problems which can cause a thermal variation or alternate drying and wetting process which can also cause a result from what we call a plastic shrinkage.

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Now, what are those reasons that we can quickly focuson deterioration of concrete as a structural material. It is essentially caused by ingress of aggressive chemicals present in the environment. We have shown a photograph here, which is having a chemical reactive pond which is having lot of counter effect on the surface of a member which are essentially caused made of concrete.

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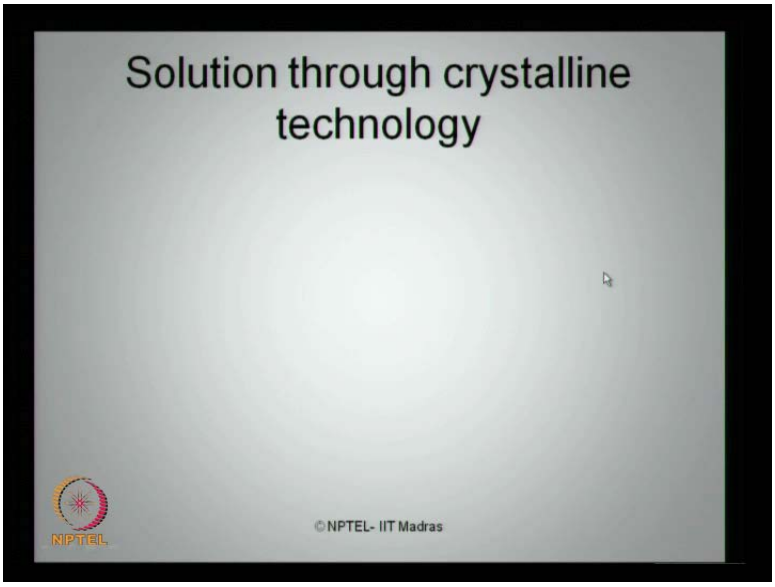

Now, for all these problems, as we thoroughly understand, concrete is a good performing material which is strongly recommended and preferred by offshore engineers for

construction of members may be offshore structural, may be coastal, may be in marine applications. But still, the doubt which is testing in our mind as engineers are that if concrete is not impermeable, if it is porous and permeable; if concrete deteriorates because of different varieties of possibilities of cracks and wide, which can cause deterioration to its performance. Then can be have any recent advancement showing the solution for this problem. Yes, ladies and gentlemen, one interesting recent advancement happened in concrete technology is solute solving this problem through crystalline technology.

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Now, the question comes, what do we understand by crystalline material? The photograph shows you here is a larger view of a crystalline material which is been held in the hands of an engineer. So, the larger view shows the further fineness of this material, which will be used as one of the ingredients to fill up the voids in concrete and making it impervious.

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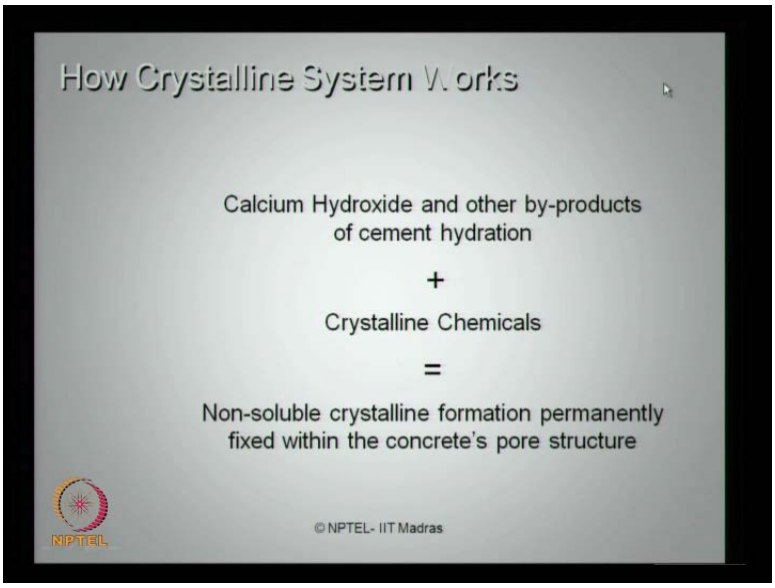

How crystalline system works? Calcium hydroxide and other by-products of cement hydration, when added with the crystalline chemicals results in what we call non-soluble crystalline formation which permanently is fixed within the concrete's pore structure. Remember, it is not a coating or it is not an ingredient or reactant which is added in the chemical admixture of concrete when it is being prepared. It is actually a reactive component which the crystalline chemicals react with the calcium hydroxide and other by-products, during the hydration process of cement which results in a very interesting non-soluble crystalline formation which is permanently fixed in the pore structure of concrete.

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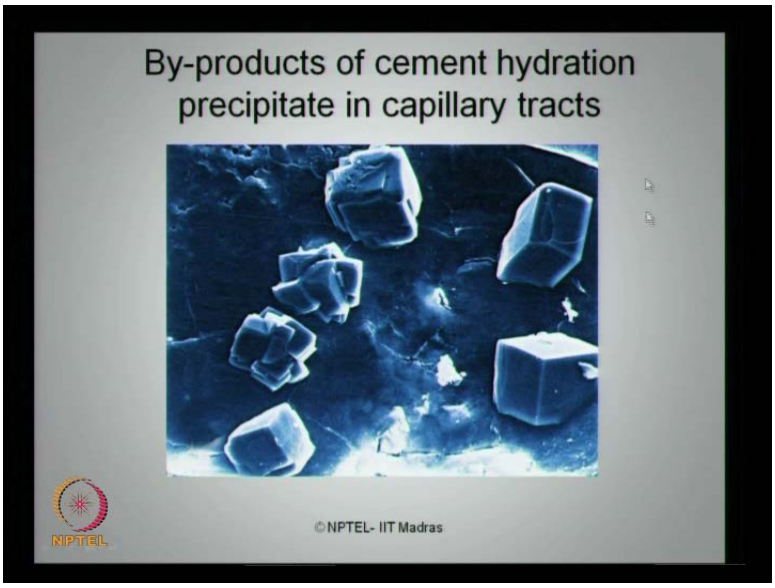

Now, let us look at the by-products of cement hydration, which precipitates in capillary tracts.

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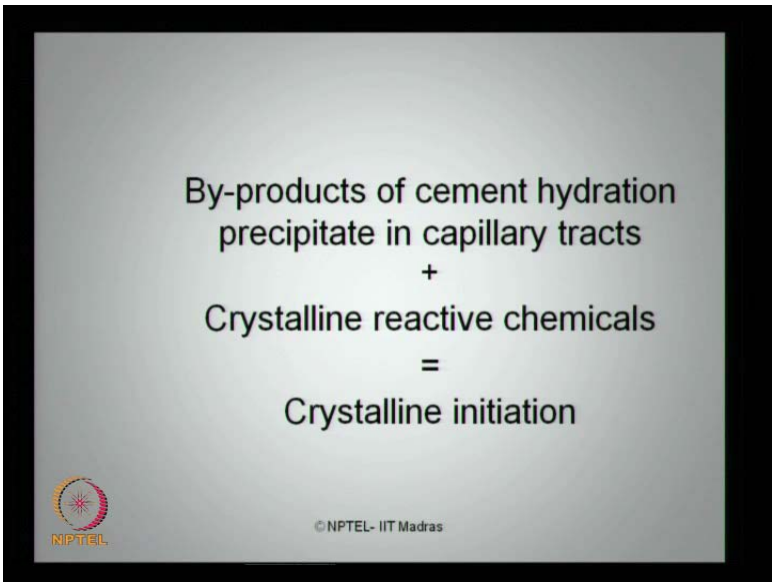

By-products of cement hydration precipitate in capillary tracts when added with the crystalline reactive chemicals results in what we see here as a crystalline initiation.

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So, it is gets initiated which you see a photograph here. So, the crystalline formation have started happening in various locations. Ladies and gentlemen, remember, it is the permanent formulation which sticks on to the pores of the concrete structure.

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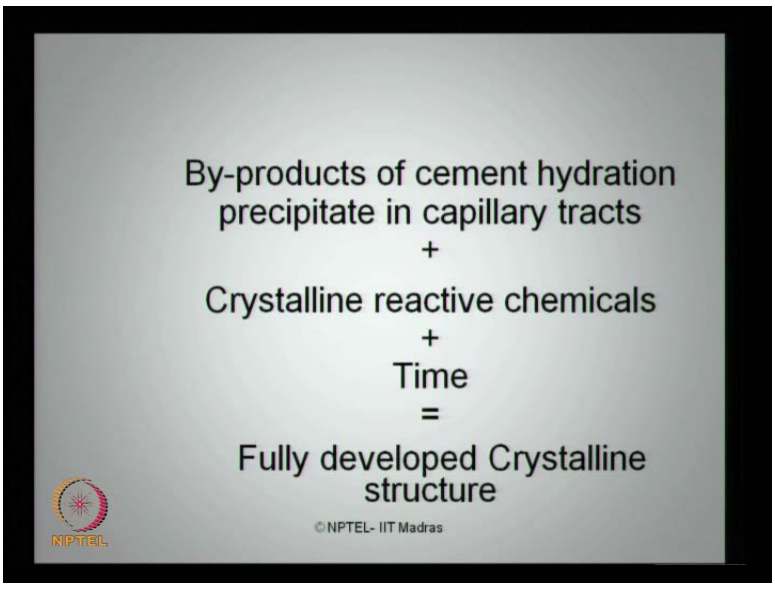

Further, the by-products of cement hydration precipitate in capillary tracts when added to the crystalline reactive chemicals will yield plus the time will yield a product which is seen now here, which is called fully developed crystalline structure.

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Now, you can see here the pores are completely fully occupied and permanently closed, because of the formation of this permanent crystalline structure which is actually a reaction happening with the chemical adhesive presents in the concrete with that of the crystalline material.

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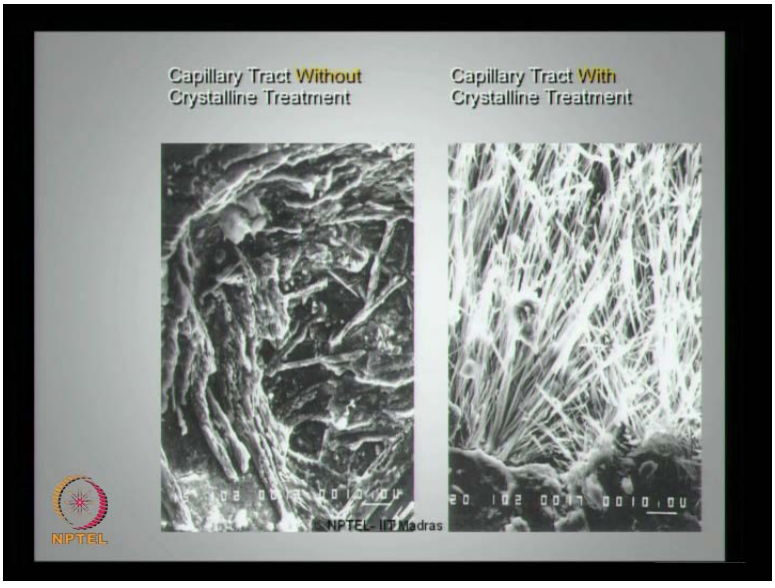

If you look at the photograph of capillary tract without crystalline treatment, and the capillary tract with crystalline treatment, you can see a phenomenal difference which has been shot in a close view of a scan electron micro scope. This shows me that the

crystalline treatment ensures permeability; it makes it impermeable completely, and all the pores and voids possibly present in concrete are gradually filled up with the permanent formation of chemical, which is the most important focus here.

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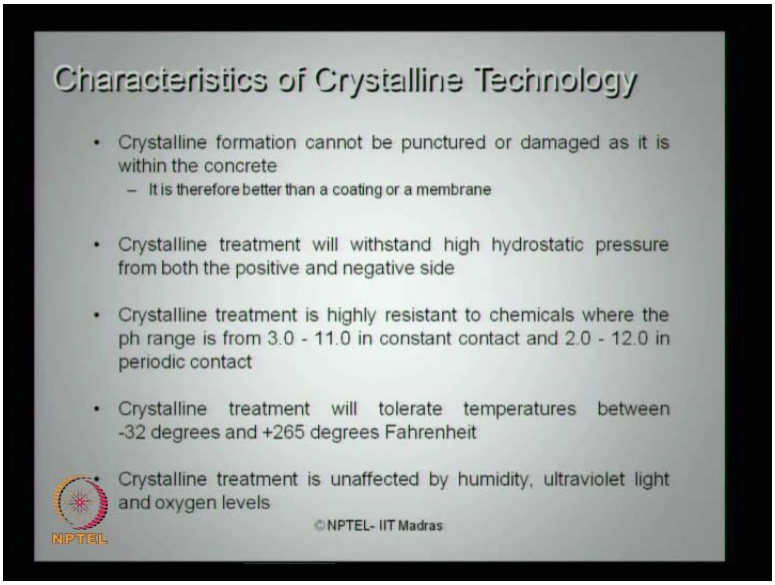

Let us look at the characteristics of a crystalline technology as such, what all the basic requirements we should a crystalline technology fulfill. Crystalline formation cannot be punctured or should not be rather punctured or damage as it is within the concrete. One important advantage what you get by solving the permeable or void formation problem in concrete, because of the presents of micro and macro cracks is that you must look for a permanent product which fills up the pores structure of concrete. This should not be punctured or damaged within the concrete. It is therefore, far superior than applying a coating or putting a membrane over any member for repairing the concrete surface. Second point, which is also very important, is that the crystalline treatment will withstand high hydrostatic pressure from both negative and positive side.

Ladies and gentlemen, it is a very important aspect in marine structures. When we talk about repair of marine structures, for example, walls or (( )) etcetera, there is something called a negative side and positive side of pressure. So, when you have got a wall which is already loaded with sea front on one side, the walls develops the negative pressure and the other side; and if you attempt do any repair for any conventional technology, it may not be successful. You have to indentify a process by which the pores are filled

permanently and much faster in way by which both negative and positive side of the repair structure should be attempted and addressed parallely. So, crystalline technology has been proved to be an added advantage which addresses both the negative and positive side of the repaired element in advance, whereas it can be done parallel.

Crystalline treatment is highly resistant to chemicals; that is another advantage we have, because the ph range is from 3 to 11 in constant contact, and 2 to 12 in periodic contact. As we all understand, they have this wide range of ph which varies from 3 to 11 or rather 2 to 12 gives a great variety of advantage for an offshore engineer to use this technology for one of the repair or one of the problem solution to be addressed to make concrete as a better performance material in ocean environment. Crystalline treatment will tolerate temperatures between the range of minus 32 to plus 265 degree Fahrenheit. So, this wide temperature range is also one of the encouraging factor for an offshore engineer to recommend or to understand or to at least try this kind of treatment for making concrete in better performance, and improve its performance characteristics in terms of its strength and durability in presence of marine environment.

Crystalline treatment has been seen in this literature that it is unaffected by humidity and ultraviolet and oxygen concentration levels, very important because we have shown a photograph or a picture of a pile which has been subjected to different kinds of corrosive environment at different oxygen level concentrations in our previous slides. So, it is very important that in offshore structures or members in offshore structure environment, we have different levels of oxygen concentration, we have got different dissolved oxygen dissolved carbon di-oxide content present in sea water which are equally responsible for deteriorating the strength of concrete as one of the construction material used in marine environment,. whereas, crystalline treatment is unaffected by humidity, ultraviolet rays, and oxygen level concentrations.

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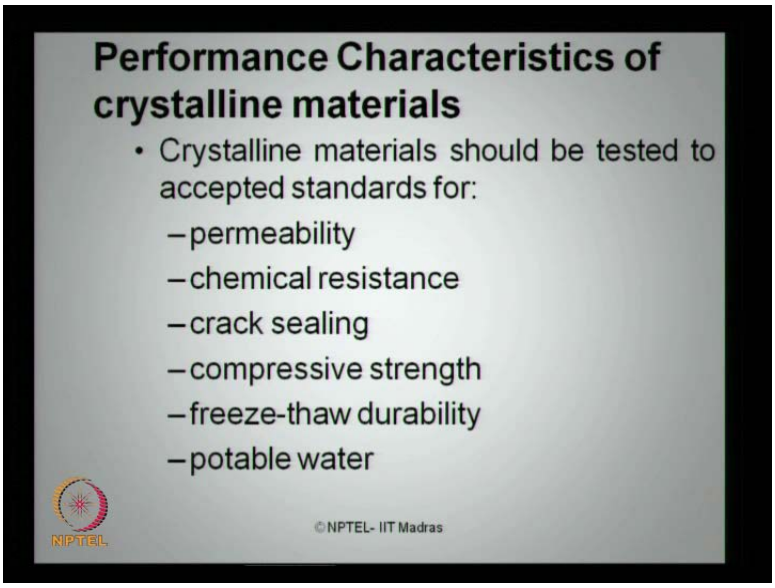

Performance characteristics of crystalline material is a very important issue, because as an offshore engineer when you want to recommend any specific treatment to improve the strength of the material. What are those standard guidelines or what are those standard landmarks based on which I must estimate the performance characteristics of this kind of treatment materials. So, we will look at them. Then, interestingly, crystalline material should be tested to accept the standards for the following. You must check the permeability, the chemical resistance, the crack sealing, the compressive strength, freeze-thaw durability and potable water. So, you have to as look into the performance of the treated surface of concrete with the help of crystalline structural formation for all these following tests based on permeability, chemical resistance, crack sealing etcetera.

Ladies and gentlemen, concrete is thought as one of the very interesting and very advantageous and more economical alternative construction material for marine environment. There is no doubt on that; there are many massive structures which are successfully built in concrete as a construction material for marine environment. But, however, concrete by itself has basic problems related to its permeability and void formulation because of its constituents and the method at which it has been fabricated has been pore inside on members. So, to avoid these problems, or on the other hand,is to improve the strength characteristics, to improve the performance of concrete and durability, we can do crystalline structure treatment as one of the recent advancements happen in offshore literature.

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Now, the question comes, how does it protect against chloride ion diffusion and sulfate attack. The chemical durability is been tested in Iwate university, Tokyo, Japan. And look at this figures, where before soaking and after five weeks and after ten weeks what is been the state of presence of art of the cylindrical specimens which has tested in literature, to check for the chloride ion diffusion and sulfate attack on concrete.

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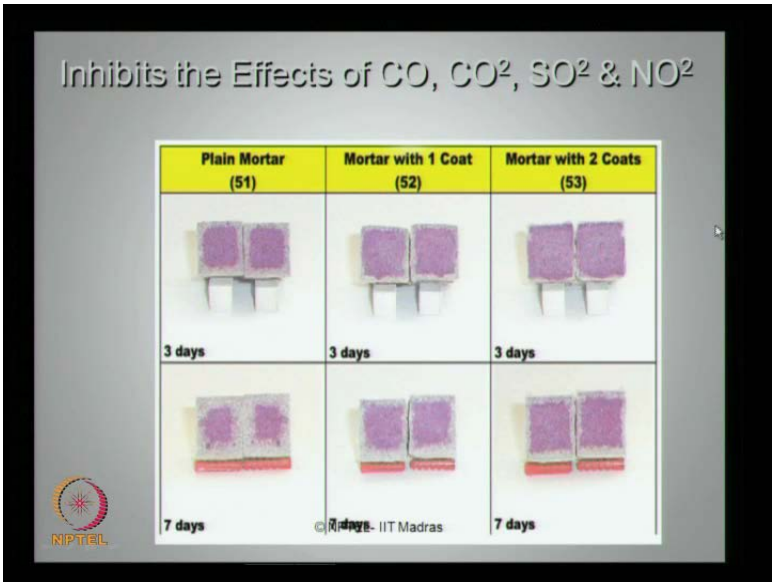

Now, inhibits the effect of carbon mo-oxide, dioxide, SO 2 and NO 2 etcetera. If you look at the plain mortar, thisis what is the state of artist. If you look at the mortar with

one coat in three days, or one coator two coats in three days, in seven days and so on and so forth. You will see that the improvement of coating also does not qualify for a better impermeability or better avoid porosity and concrete in a greater extent.

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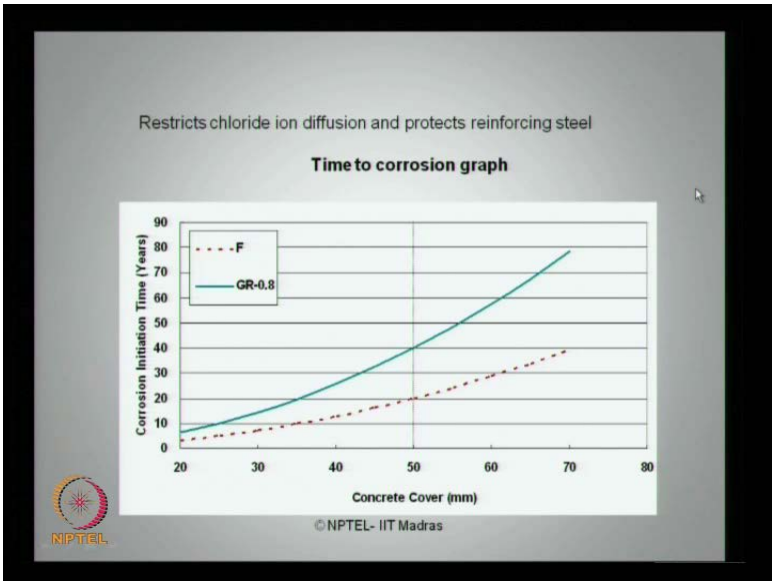

Of course, crystalline structural formulation improves concrete durability. So, this is the curve which shows there has been a delay in the corrosion initiation time in terms of years. So, the dotted line shows that the corrosion initiates approximately forty years of time of construction which is provided for concrete cover of seventy millimeter. Ladies and gentlemen, we all agree that seventy millimeter is substantially a good amount covered to be given for members in structural action for offshore structures. So, under this cover of concrete, if it initiates at 40 years after the construction, now the treatment using crystalline structure may drag it or may delay it to an as height as double of this time. It means crystalline structural formulation as it permanently avoids the voids present in concrete, it delays the probability of corrosion initiation in practically double of its life.

Of course,it does not mean that you should not do a periodic maintenance of a concrete surface for offshore structures. In addition to that if you start using this kind of treatment for concrete as a structural member in marine environment, it is evident from certain literature and review and references that, it delays or retards the corrosion initiation

process practically double of that of an ordinary concrete which is not treated with crystalline formation.

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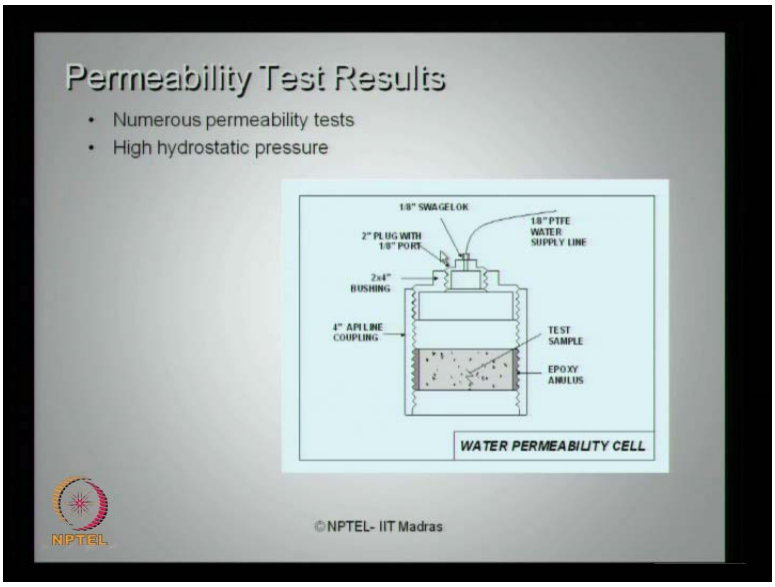

If you look at the permeability test results, numerical numerous permeability tests have been conducted for high hydrostatic pressure. So, there has been a standard test specimen of the methodology by which you can do this test is what we call water permeability cell. So, it is got a specific dimension and test setup as specified by API and standards.

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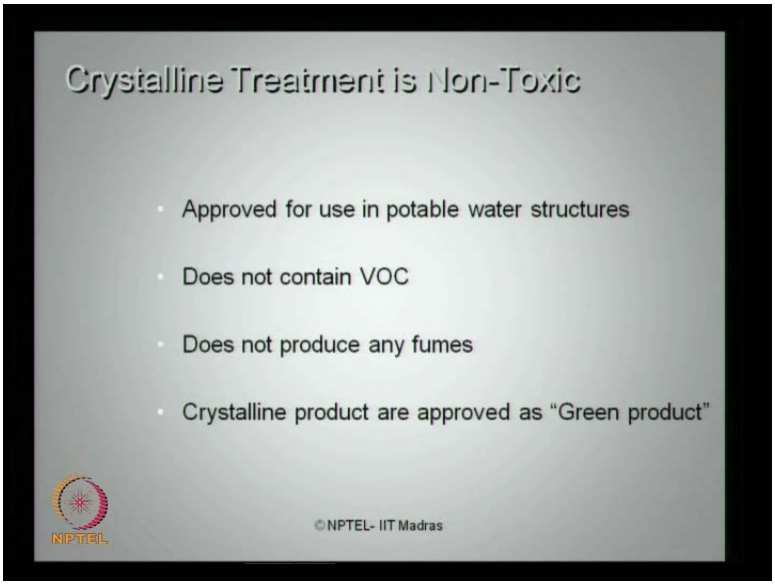

Now interestingly, the crystalline treatment is non-toxic; it is approved for use in portable water structures as well, can even use it for water tanks, but we are not interested in discussing those applications in this present lecture. But it has been tested by the certified agencies that crystalline treatment can also be used for portable water structures. It does not contain what we call VOC, which is a very common problem in any of these chemical treatments given to concrete surfaces. It does not produce any fumes and the crystalline product are approved the literature as green product.

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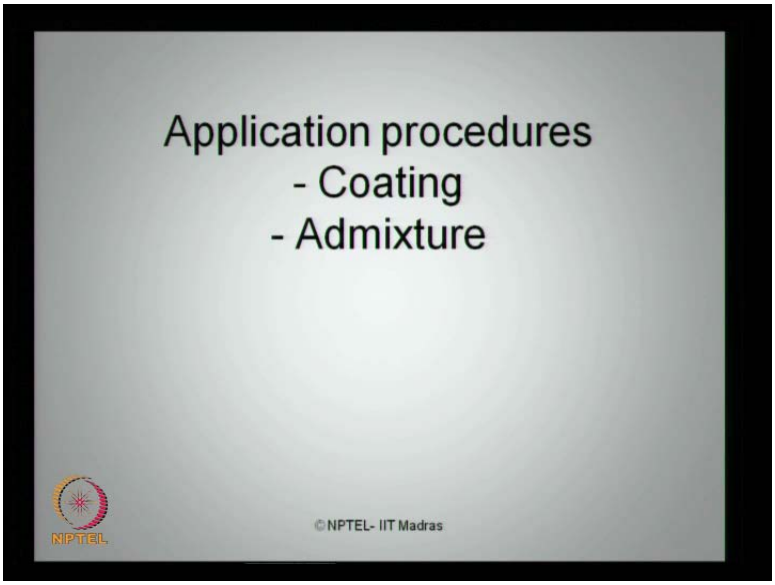

Now, the question comes, yes I am interested to knowing more about the treatment made to concrete surface or concrete as such as a member which improves durability and performance of concrete by crystalline technique or technology. So, how do we apply this on my members which are already constructed. You can also do coating or you can do by an admixture technique, which I will show you now.

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Coating application procedure is showing as follows. Chemicals in highly concentrated solutions will diffuse in the solution of lower density until the two equalize themselves. So, you can apply by coating as well.

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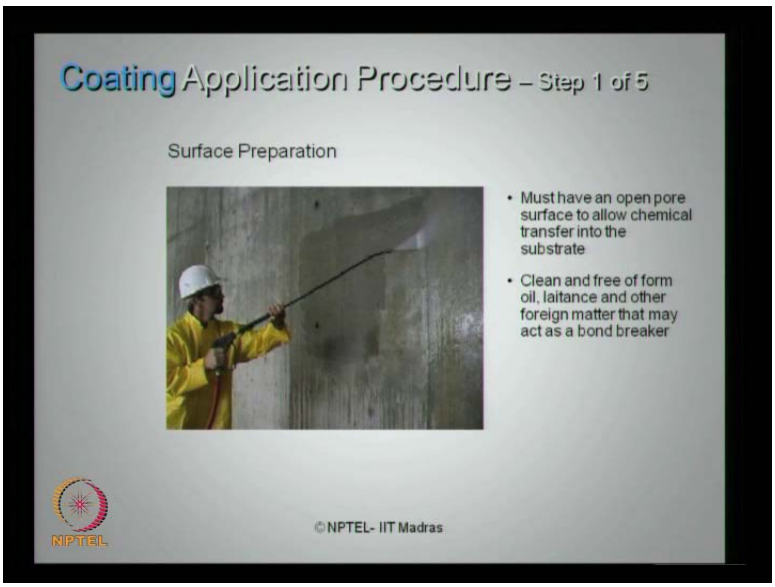

The first step is you must have an open pore surface. So, you should do a surface preparation you must have an open pore surface to allow chemical transfer into the substructure. Clean and free of form of oil, laitance and other foreign matter is essential,

so that you have to do what we call a through surface preparation which will allow or admit the chemical to transfer into the surface.

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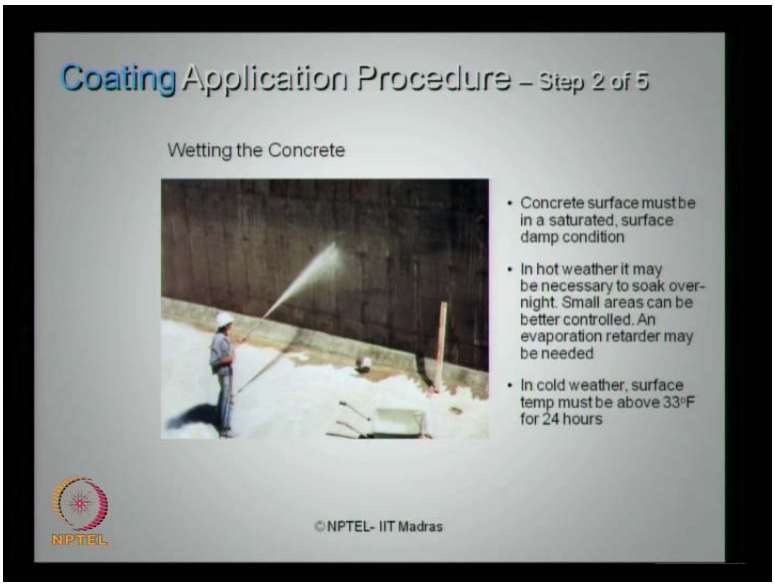

The second step is what we say, wet the concrete or wetting of concrete. Concrete surface must be thoroughly saturated, and the surface should be in a damp condition to apply this treatment what we called crystalline structure technique. In hot weather, it may be absolutely necessary to soak of the structure or the surface over the complete night. Small areas can be better controlled off course and evaporation retarded may be required when you are working this at a high temperature, especially during summer seasons. In cold weather, surface temperature must be above 33 degree Fahrenheit for at least 24 hours of time before you start applying this treatment.

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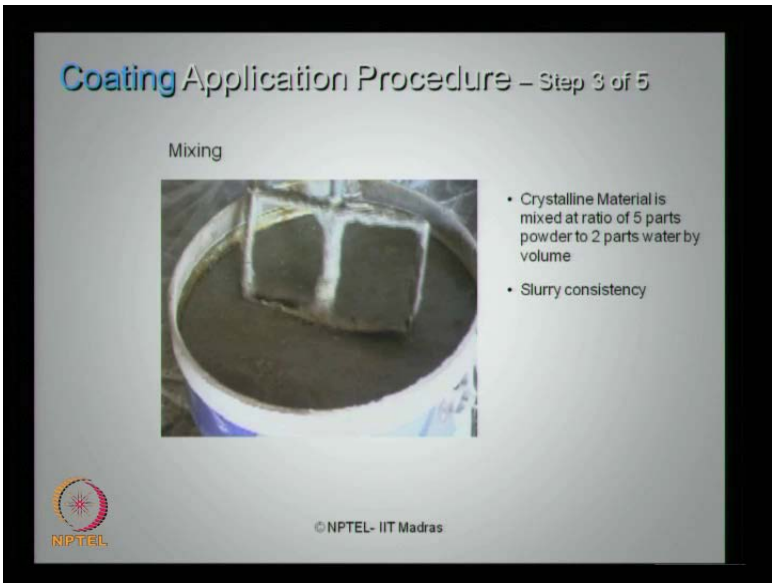

The third step in application of coating is what we called mixing. Crystalline material is mixed at ratio of 5 parts of powder to 2 parts of water by volume. Then you have to also check with the consistency of the slurry, which is formed by this mixture.

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Once the mixture is prepared, and the surface is wetted and surface is prepared and ready for application then applied by a brush, the approximate coverage is hundred square feet an hour. You can also do an hopper gun application which will cover a larger area which is approximately out of 500 square feet an hour.

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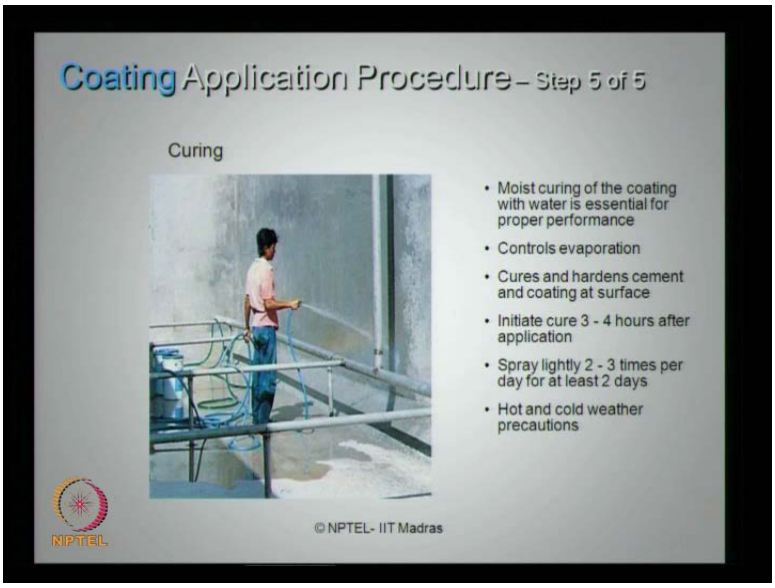

The last step of course is very important every concrete structural construction is curing. So, moist curing of coating with water is absolutely necessary for proper performance of this treatment. It controls evaporation, cures and hardens the cement and coating at the surface, initiates curing for three to four hours after application. Spray lightly two to three times per day for at least two days of period, for hot and cold weather you have to take enough precautions. So that the surface does not get dried up as before the application starts hardening and the crystalline formation happens in the voids of the concrete structure.

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You can also use an admixture application procedure. The admixture also comes in a readymade form.

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The admixture can be used directly in the shattering itself if the concrete is being poured or laid for offshore structural members.

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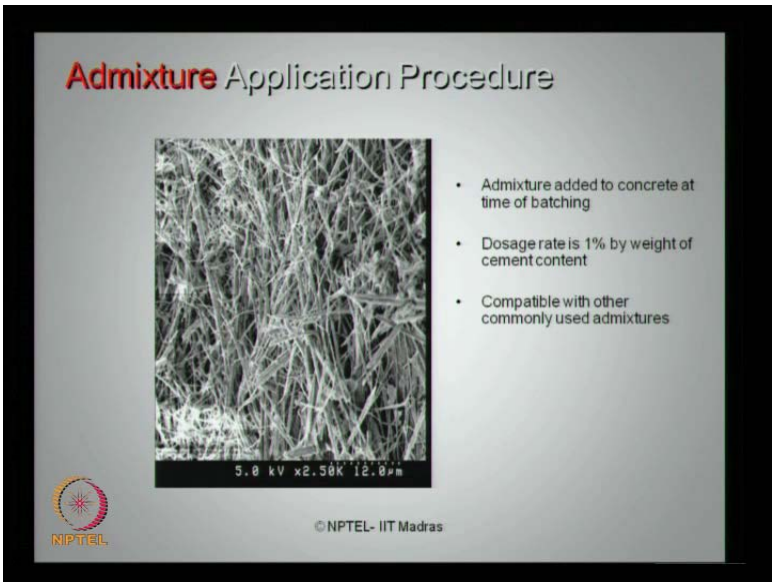

So the crystalline formation basically has admixture added to concrete at the time of batching itself. The dosage rate is about one percent by weight of cement content used in

the design. Compatible with other commonly used admixtures, which we generally use for either slum control or quick drying, quick hardening etcetera.

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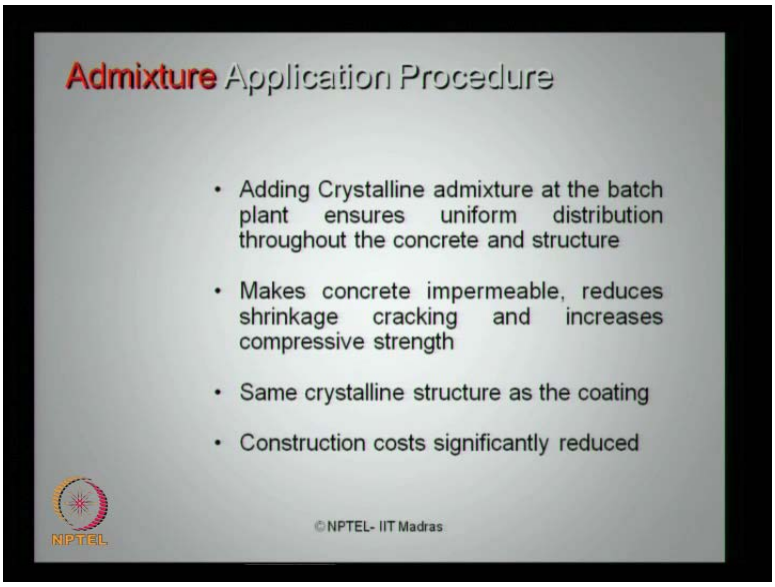

Adding crystalline admixture at the batch plant ensures a uniform distribution throughout the concrete and therefore, throughout the member. It makes concrete completely impermeable, and reduce the shrinkage cracking and increase the compressive strength of concrete as a structural member. Some crystalline structure can also be applied as a coating. The construction cost added to the maintenance as well as initial investment is significantly reduced, because the life of this is greatly increased.

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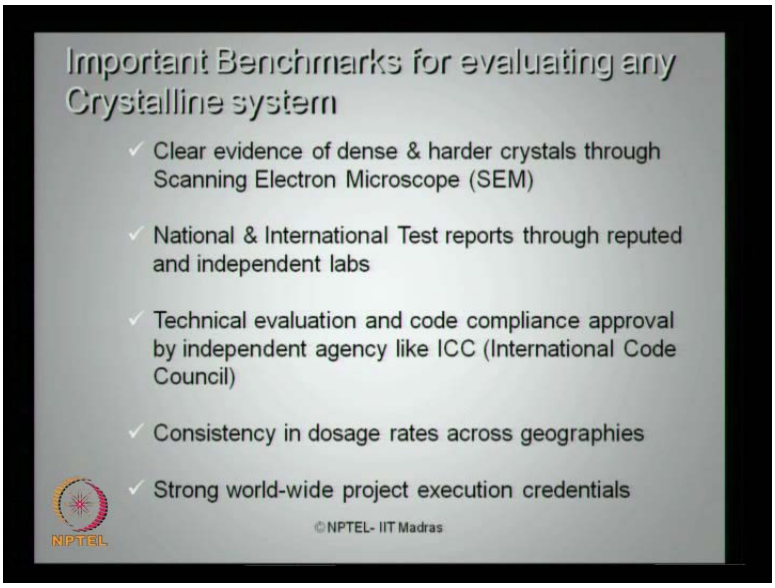

What are the important benchmarks, I must consider for evaluating any crystalline structural system. There should be a clear evidence of dense and harder crystals through scanning electron microscope I must check that. I should also go for national and international test reports through repute and independent laboratories to ensure that I am able to achieve the required performance of concrete by the crystalline technology treatment. The technical evaluation and code compliance approval by independent agency like ICC is also mandatory for international regulations. Consistency in dosage rates across geographies is very important. Strong worldwide project execution credentials of any applicator or any chemical admixture is also equally important.

Ladies and gentlemen, in this lecture, I am sure that we have learnt a recent advancement technique of how to improve the durability and performance of concrete by a crystalline technology method. We will discuss more in detail about the same and parallel methods of treatment in my fourth module, where I will talk about repair and rehabilitation of offshore structure and marine and coastal structure in detail.

So, we have given a brief introduction to you about one of the recent advancements of how to improve the performance of concrete under marine environment. Concrete is a friendly suggestive recommended material where engineers have lot of confidence of using it as a construction material in marine environment. There is nothing against use of concrete in marine environment, concrete has problem because of its constituents

therefore, if one attempts sincerely how to address these issues then performance of concrete is certainly higher can be improved, and the total construction cost especially in terms of marine coastal structures which are have strategic importance can be brought down phenomenally.

Thank you very much.