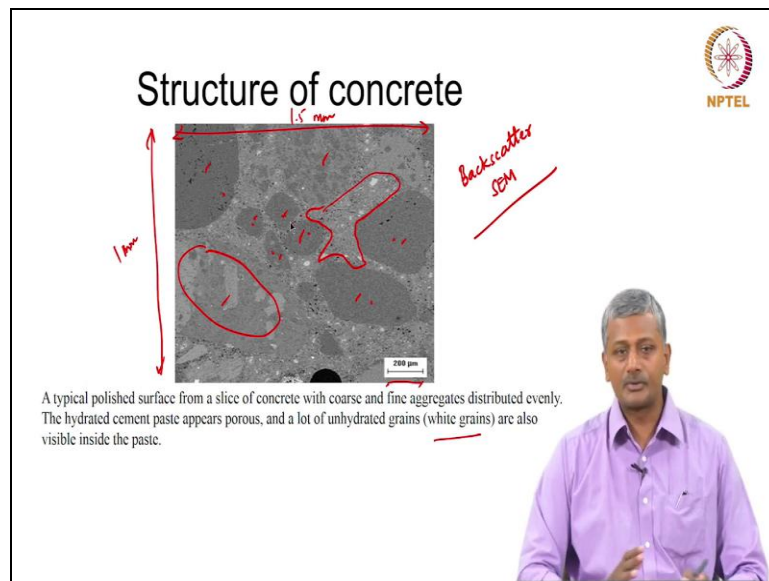


Characterization of Construction Materials
Prof. Manu Santhanam
Department of Civil Engineering
Indian Institute of Technology - Madras

Lecture 4
Structure of Construction Materials an Overview Part2

So, the structure of concrete and here is an example with scanning electron microscopy.

(Refer Slide Time: 00:20)



This is a structure of concrete imaged with the help of Backscatter SEM. We'll talk in detail about this technique later. But this Backscatter SEM technique was used to actually determine this internal structure of the concrete. So you can here see the aggregates which are present. Some are large, some are small, and this size is 200 microns. So the overall field width is about, this is probably about, 1.5 millimetre (X-direction). It is quite small still.

It is not really big and this(Y-direction) is about one millimetre. At that size scale, this is 1.5 by 1 millimetre size that we are looking at. Again, we talked about this in the introduction class that, we are looking at very small portions of this material which is used in meter scales. And we are trying to convert that to a few millimetres or even sub-millimetre scale to take a look at what is actually inside.

So, you can now understand the challenge that we want to go from this scale to explain the properties of the concrete compressive strength that you measure in the lab or the performance of concrete in a structure where it is actually a very large beam, for instance, or a very large

column. So, the idea here is to look at, how the different phases are getting distributed. So, you can see a typical polished surface from a slice of concrete.


It shows the coarse and fine aggregate. Of course, this could be a piece of the coarse aggregate, but most of the others which have almost a uniform colour; those are pieces of fine aggregate that are present in your system. So, coarse aggregate could have some chunks from, which are small enough to be viewed here. Otherwise, the size of coarse aggregates is quite large you will not be able to actually see it in this field.

What you also see is the paste. You see this region, inside the aggregates, that is basically your paste region. And the cement paste region is composed of several different levels of grains as you can see from this picture. The whitest particles are the unhydrated cement grains, that have not reacted with water. The grey, different shades of gray are from the cementitious compounds, the hydrated products that are forming out of the reaction of cement with water.


And, you can also see the black spots within the paste. Those black spots are basically the porosity that exists within the paste. And this porosity is ultimately responsible for most of the properties of your concrete. If you have more porosity, you have lesser strength. If you have more porosity, that is interconnected, you have low durability of the concrete. So, strength and durability are dependent on porosity of the concrete.

(Refer Slide Time: 03:13)

2-phase system



- Cement paste + Aggregate
- Aggregates are inert, while the structure of the hydrated cement paste keeps evolving over time
- Hydrated cement paste is composed of capillary pores and the hydration product. The pores within the structure of the hydration product are termed 'gel' pores.
- Hydration product includes $C-S-H$, CH , AF_t , AF_m , etc.
- Gel pores are included within the structure of hydrated cement.
- According to Powers, $1/3$ of the pore space is comprised of gel pores, and the rest are capillary pores.



We have classified concrete as a two-phase system composed of cement paste and aggregate. We assume that most of the time the aggregates are inert, whereas the structure of the paste,

keeps evolving with time. The structure of cement paste keeps evolving with time. And, hydrated cement paste is composed of porosity which can be classified as capillary porosity and the hydration product.


The structure of the hydration product, C-S-H and other gel-like constituents within this hydration product may also have internal porosity in it which is otherwise known as gel porosity. C-S-H is also known as C-S-H gel, and the porosity within this gel is also called gel porosity. And the hydration product is not just C-S-H, it also includes other forms of hydrates like Calcium hydroxide, Calcium aluminosulphates and so on.

So, according to Powers, (Powers was one of the foremost scientists who worked in cement chemistry in the 1940s and 50s), one-third of the pore space is composed of gel porosity and the rest is capillary porosity. So, one obvious question that arises from here is that how do I understand what is gel porosity, what is capillary porosity, are there size scales which define these porosity, and that is what we'll look at when we deal with characterization techniques for porosity.


We will see how this porosity can be classified, how it can be measured and what is the relevance of the measurement of this porosity with actual properties of the concrete? And that is something you will come across later when we deal with porosity, with pore size analysis.

(Refer Slide Time: 04:51)

Interfacial transition zone



- Zone of bonding between cement paste and aggregates
- According to researchers, the porosity of the paste as well as the proportion of calcium hydroxide in this zone is considerably higher than in the bulk paste.
- Thus, this zone forms the weak link in the concrete, and is usually the site of first occurrence of cracking.
- Indeed, failure cracks in normal strength concrete tend to travel along the transition zone rather than through the aggregates, as in high strength concrete.



One of the important characteristics of concrete is the presence of the zone called Interfacial transition zone. So, we are talking about two dissimilar phases that are combined together to

form concrete. You have the cement paste and the aggregate phase. The issue is, when you bring these together, the differences of the zone, just around the aggregate with the bulk cement paste, sometimes can lead to very interesting characteristics in the concrete.

So generally, researchers agree that porosity of the paste, as well as the proportion of calcium hydroxide in the zone just around the aggregate (the bonding zone between paste and aggregate, which is otherwise also known as Interfacial transition zone), is much higher than away from this zone. So, very often, we attribute this zone to be the weak link in concrete.

And generally, this is where the first cracks start appearing, when the concrete is subjected to any load. And these failure cracks in normal strength concrete tend to travel along this interfacial transition zone because, when you break a cube and observe the fractured surface in laboratory, you will see that the zone around the aggregate is where the failure is developed and not really through the aggregate.

So, when we strengthen the ITZ or Interfacial transition zone by strengthening your paste and lowering your water-cement ratio, cracking will more progressively go right through the aggregate rather than around the aggregate. So, for higher strength concrete the cracking is more brittle. It goes right through the aggregate.

(Refer Slide Time: 06:30)

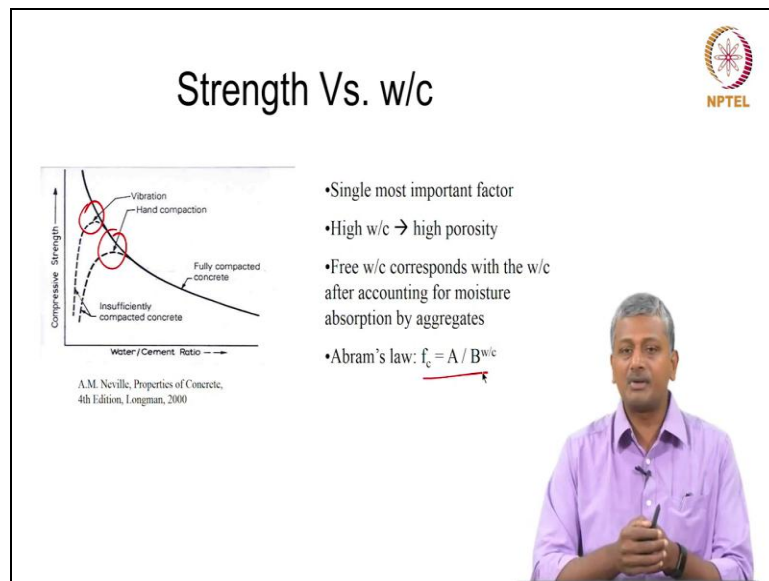


So again this is a schematic depiction of the interfacial transition zone. You have the aggregate here. You have the bulk cement paste here and that is your transition zone close to the aggregate. Generally, it is agreed that it is around 50 microns from the surface of the aggregate.

About 50 microns from the surface of the aggregate is where you have this interfacial transition zone, which is composed of large porosity and many more calcium hydroxide crystals as opposed to your bulk paste.

And this is actually a picture taken from close to the aggregate in microscopy, which shows a deposit of calcium hydroxide, right at the interfacial transition zone.

(Refer Slide Time: 07:09)




Now we know that, as the water-cement ratio increases, the strength decreases. There are obviously limits to where you can actually increase your strength because of compaction. When you reduce water-cement ratio, strength will increase up to the point where you can't compact your concrete well enough. And, we also have a rule that is usually used to actually represent the relationship between strength and water to cement ratio, it is called Abram's rule or Abram's law.


And of course, this law does not have to follow the same pattern all the time, the same power relationship all the time, you could have other relationships also describing this characteristic. But the important point to understand is, as the water-cement ratio increases, the strength decreases.

(Refer Slide Time: 07:57)

Common durability problems in concrete



1. Corrosion of steel in reinforced concrete
2. Sulphate and other chemical attack of concrete
3. Alkali-aggregate reaction → reactive agg.
4. Freezing and thawing damage



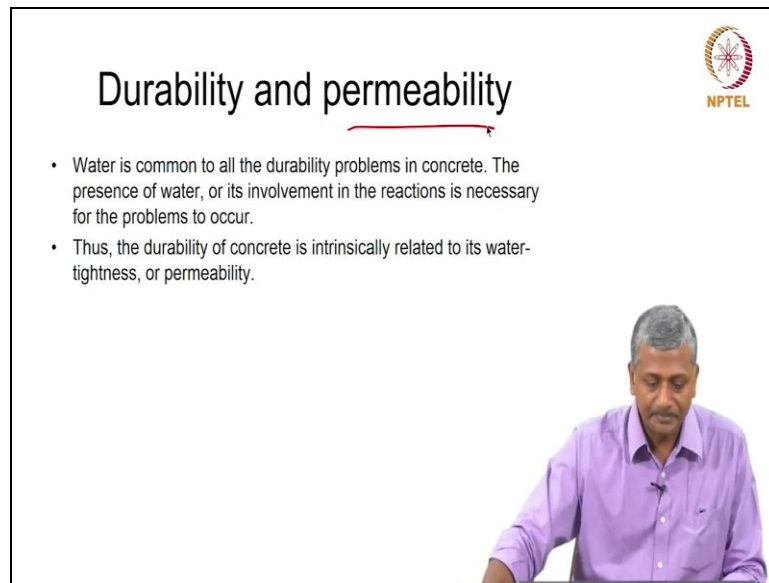
Concrete is subjected to a host of durability problems in service. And many of these are associated with the presence of water, because any aggressive chemical is brought to the concrete only by water. If concrete is dry, you will really not have a problem. But most of these techniques or most of the problems that are associated with concrete durability involve the presence of water.

So, corrosion of steel in reinforced concrete is probably the biggest durability problem, followed by other smaller problems which are affecting concrete and not actually the steel. So we have sulphate and other chemical attack like acid or chloride attack, for instance.

Alkali-aggregate reaction is actually because of a reactive aggregate. Other problems are happening because of reactions with the paste, but the alkali aggregate reaction happens because of reactive aggregate. And this is when the aggregates themselves are of a glassy nature. That means they exhibit some degree of amorphousness. And that can happen with some of the volcanic rocks that are commonly used in several countries. For example, if you go to New Zealand, you will hardly find an aggregate that is not alkali reactive.

In several other Northern European countries also, we have to deal only with alkali reactive aggregates, because many of their rocks are of volcanic origin. And then, there are problems associated primarily with cold climates of freezing and thawing damage. And that happens when water inside the concrete transforms to ice, on freezing, and converts back to water on thawing. This is associated with the volume change and that volume change leads to cracking in concrete.


(Refer Slide Time: 09:40)



Durability and permeability

- Water is common to all the durability problems in concrete. The presence of water, or its involvement in the reactions is necessary for the problems to occur.
- Thus, the durability of concrete is intrinsically related to its water-tightness, or permeability.

NPTEL




As said before, without water, none of these durability problems would happen. That is why the intrinsic characteristic of the concrete that determines its durability is just the permeability of the concrete. So, permeability is the most important characteristic with respect to durability. Although of course permeability will not really govern the reactivity of the aggregate, it governs everything that leads to transport of aggressive species from the external environment into the concrete.

But if you read about alkali-aggregate reaction, you will see that one of the major reasons why expansion actually happens is because of the imbibing of water. And where is this water coming from? From the external surface to the interior of the concrete and again there if you have concrete that is impermeable, it will prevent this water from getting to the reactive aggregate and causing this expansion to happen.


So in all cases, presence of water is absolutely important for the durability problem to happen.

(Refer Slide Time: 10:48)

Creep of concrete



- Creep → deformations due to sustained loading
- Creep of concrete varies with age; at early ages, lot of creep occurs in concrete
- Aggregates in concrete are not susceptible to creep.
Only the paste undergoes deformations upon sustained loading, due to its high porosity and the water held within it that slowly gets driven out under a sustained load.




Concrete is subjected to sustained loading during its life cycle and this sustained loading can actually start internally rearranging the structure of the cement paste. Now you know that, cement paste has a structure that evolves with time, and there is a lot of porosity inside. And because of the sustained loading, there is a continuous rearrangement of the structure. First of all, some extra water that is inside the system may start getting driven out.

Just like in soils, you have consolidation over some time, because of a sustained loading, water drains out of the soil. That is called consolidation. Just like that in concrete also, the excess water can start migrating out of the cement paste regions and migrate to other regions. Or associated with drying, you can actually have the drying out of this water also, while the water is migrating out the paste.


So in other words, internal rearrangement will lead to a volumetric change in the concrete. And that is basically called 'creep'. We assume that aggregates are not susceptible to creep because they are much stiffer than the paste phase. So in general, the higher the volume of aggregates in concrete, more resistant the concrete would be to creep deformations.

(Refer Slide Time: 12:03)

Shrinkage of concrete



- Shrinkage → reduction of volume of concrete.
- Types of shrinkage in concrete: Plastic shrinkage, chemical shrinkage, autogenous shrinkage, drying shrinkage, and carbonation shrinkage.
- When a restraint to the volumetric contraction is present, cracking occurs in the concrete.
- Shrinkage cracks - not a structural concern, but can affect the long-term durability by providing easy access to water and aggressive species into the interior of concrete.



Similarly, you have another long term deformation which is called shrinkage. And shrinkage just happens because concrete has moisture, and this moisture will dry out eventually in a drying environment. Once again it is the paste that is susceptible to shrinkage and not the aggregate. And hence, the higher the aggregate content, the lesser will be the shrinkage of concrete.

So again, creep and shrinkage will happen inevitably in any concrete member. But once again, the primary defining factor for both of these is the moisture content in the concrete. So, water plays a very important role not just in durability, but also in dimensional stability of your concrete.

Now, of course, shrinkage, if it is allowed to happen without any restraint, is not really a problem. Only when a restraint happens, cracking occurs in the concrete. And that leads to other problems such as ingress of chemicals and water into the concrete quite easily. If there is cracking, obviously, the water can enter much easier and that leads to long term durability issues. So, if shrinkage is allowed to happen there is no problem. But there is going to be restraints which will cause cracking in the concrete.

Now shrinkage itself is composed of several different types like plastic shrinkage, chemical shrinkage, autogenous shrinkage, drying shrinkage and carbonation shrinkage. But we'll look at some of the techniques that are applied to studying shrinkage and we will try and characterize some of the different types in that lecture.

(Refer Slide Time: 13:41)



Asphalt Concrete



With that, the overview on cement concrete is done. We will see a lot of examples from cement concrete, when we discuss characterization techniques. So let us now start discussing about asphalt concrete. So again, asphalt concrete is different from cement concrete in just one regard.

Again, asphalt concrete is a two-phase system. You have the continuous phase which is, asphalt or asphalt cement it's called. The discontinuous phase is the aggregate. Again you have coarse and fine aggregate which is used in asphalt concrete. So instead of cement paste, which is cement and water as the binder, in asphalt concrete you have asphalt as the binder. But that is not the only difference. The difference also lies in the means with which the loads are taken by cement concrete and asphalt concrete.

(Refer Slide Time: 14:34)



Bituminous materials

- Bituminous materials: a class of black or dark-colored (solid, semi-solid or viscous) cementitious substances, natural or manufactured, composed principally of high molecular weight hydrocarbons, of which asphalts, tars, pitches, and asphaltites are typical.

ASTM Definition (ASTM D 8-97 (2000))

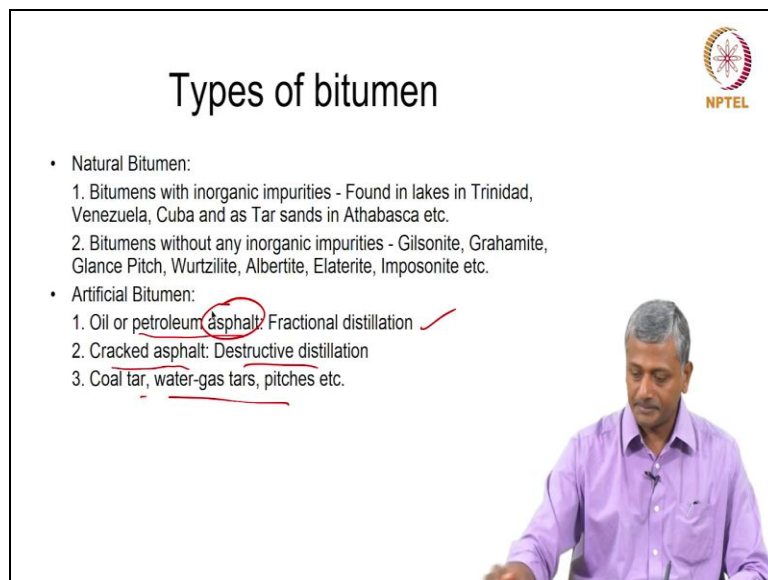


Now, asphalt concrete belongs to a class of materials called Bituminous materials. So ASTM definition says that bituminous materials are a class of black or dark-coloured cementitious substances which are natural or manufactured and which are composed principally of high molecular weight hydrocarbons. So amongst bituminous materials, the most common ones are asphalt, tar, pitch and asphaltites. So, all these are part of this larger family of bituminous materials.

Of course, the colloquial usage when you go to speak to any person on the street they will think that everything is made with tar, like the roads are made with tar. But civil engineers know that it is not tar which makes the pavement it is asphalt or bitumen that actually goes into making of the pavement. But, tar has other interesting characteristics. For example, it can be used to prolong the life cycle of asphalt pavement because tar does not dissolve in gasoline and other organic solvents, whereas asphalt does dissolve it, because asphalt is obtained from the same process as gasoline.

So if you have a petrol spill on your road, if there is asphalt on the surface, it will start getting dissolved. But if you have a surface treatment done with Tar, it will be protecting the road surface and prolonging the life cycle of your road.

(Refer Slide Time: 16:00)



The slide is titled "Types of bitumen" and features the NPTEL logo in the top right corner. It lists two main categories of bitumen: Natural Bitumen and Artificial Bitumen. Under Natural Bitumen, there are two sub-points: 1. Bitumens with inorganic impurities (found in lakes in Trinidad, Venezuela, Cuba, and as Tar sands in Athabasca etc.) and 2. Bitumens without any inorganic impurities (Gilsonite, Grahamite, Glance Pitch, Wurtzilite, Albertite, Elaterite, Imposonite etc.). Under Artificial Bitumen, there are three sub-points: 1. Oil or petroleum asphalt: Fractional distillation (with a red checkmark), 2. Cracked asphalt: Destructive distillation, and 3. Coal tar, water-gas tars, pitches etc. (with a red underline). A presenter in a purple shirt is visible in the bottom right corner of the slide frame.

Types of bitumen

- Natural Bitumen:
 1. Bitumens with inorganic impurities - Found in lakes in Trinidad, Venezuela, Cuba and as Tar sands in Athabasca etc.
 2. Bitumens without any inorganic impurities - Gilsonite, Grahamite, Glance Pitch, Wurtzilite, Albertite, Elaterite, Imposonite etc.
- Artificial Bitumen:
 1. Oil or petroleum asphalt: Fractional distillation ✓
 2. Cracked asphalt: Destructive distillation
 3. Coal tar, water-gas tars, pitches etc.

So of course, natural bitumen can also be found across the world. Primarily, you have bitumens with inorganic impurities like lakes in Trinidad, Venezuela, Cuba and so on. And bitumens without any inorganic impurities are also found in pure forms. And these are given the mineral

names as Gilsonite, Grahamite, Wurtzilite, Albertite, Elaterite and so on. So these are all found in different locations, geographical regions across the world.

And if you really look at the history of building materials, a lot of the past construction where they wanted binders to fix large masonry blocks, one of the common binders that people actually used was asphalt. Before lime and cement came into being, asphalt was one of the natural binders available for actually binding masonry materials. Artificial bitumen which we are more commonly prone to using these days is formed from different processes.

So, the most common one is the petroleum asphalt - Oil or petroleum asphalt which is obtained from fractional distillation. This is the process that we commonly see in our refineries. You also have the production of tar from destructive distillation of coal and you can also get other forms of artificial bitumen like coal tar, water gas tars and pitches. But for the most part we deal with asphalt, from the petroleum processing industry which is obtained from fractional distillation.

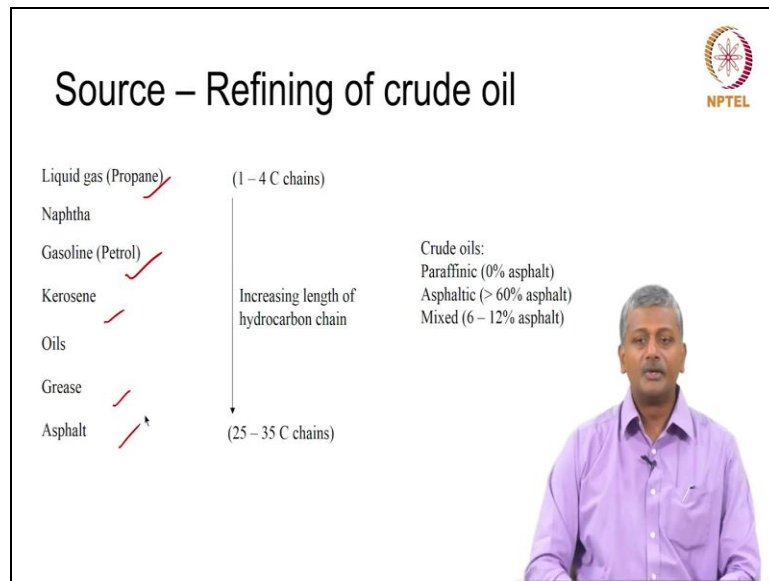
(Refer Slide Time: 17:32)

Asphalt	Tar
<ul style="list-style-type: none">•Obtained as residue in the refining of petroleum•Also found in natural pools•Used as binder in pavement construction•Long chain hydrocarbon	<ul style="list-style-type: none">•Obtained by destructive distillation of bituminous coal•Not used in paving•Used for waterproofing and pavement treatments•Cyclic (aromatic) hydrocarbon

So just to distinguish asphalt and tar, asphalt is obtained as residue in the refinement of petroleum. It may also be found in natural pools. And this is what we use as a binder in pavement construction. And it is a long chain hydrocarbon. High molecular weight, but it is a long chain hydrocarbon. On the other hand, Tar is obtained from destructive distillation of bituminous coal. It is not used in paving, but it is used in waterproofing and pavement treatments. And major difference is it is a cyclic or aromatic hydrocarbon.

So, long-chain is also called aliphatic. Cyclic is also called aromatic hydrocarbon. So, that is the primary distinction between these two classes of materials.

(Refer Slide Time: 18:18)



So again, when you do the distillation of crude oil, there are various processes that go from the formation of propane gas, to petrol, to kerosene, to grease and finally you get asphalt as the residue in this process. So, if you look at a refinery, the least profitable material for them or actually a waste for them is asphalt. But, that is gold for civil engineers, because we have to use asphalt for the construction of pavements.

More than 90 percent, 95 percent of the pavements across the world are done with asphalt. So because the owners of these refineries realize that even this residue or a waste, can be a very large profit-making material, as far as its application and construction is concerned, so, these days, obviously you do not get pure asphalt anymore, there are a lot of modifications done to the asphalt to make modified binders which have superior characteristics to that of the pure asphalt.

So, a lot of research is going on in trying to understand the characteristics of the asphalt and how to actually modify or improve the characteristics by using other types of additives into the asphalt also.

(Refer Slide Time: 19:43)

Asphalt properties



- Highly viscous at room temperature (~250000 Poise)
- Techniques to lower viscosity:
 - heating the asphalt
 - making an emulsion
 - dissolving in organic solvent
- The technique used defines the type of asphalt



So, one of the major characteristics of asphalt, is its dependence on temperature. Like any other polymer, asphalt properties are highly dependent on temperature. At room temperature, around 20 to 25°C, asphalt is highly viscous. The viscosity of the asphalt is, about 250,000 Poise, at room temperature. But when you want to actually use this as a pavement material, if you work with that viscosity, obviously it is not going to mix with the aggregate and get compacted to a roadway pavement.

So you have to lower this viscosity, to make it suitable for application. And this lowering of viscosity is typically done by, heating the asphalt. In most applications, we heat the asphalt, but there are other ways to do it also. You can make an emulsion. What is an emulsion? Essentially an emulsion is suspending droplets of asphalt in water with an emulsifying agent, just like in paint.

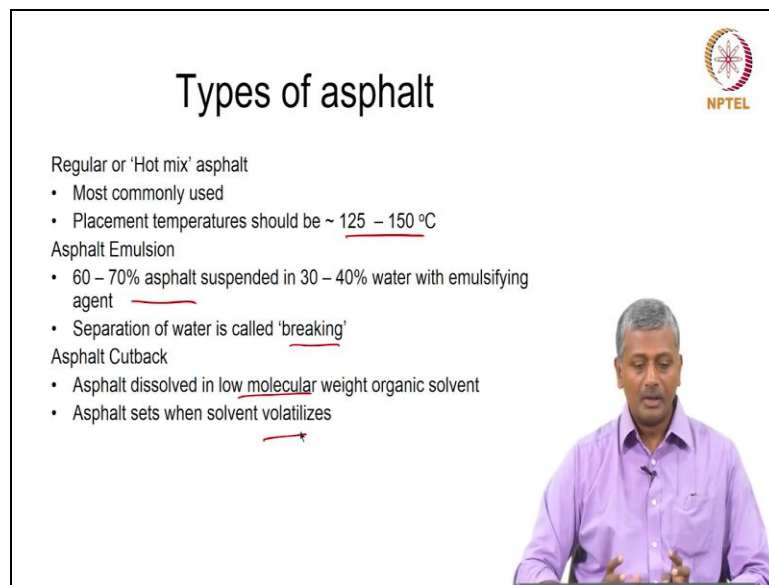
There are also emulsion... emulsion paints and those are basically based on suspending your globules of paint in water using an emulsifying agent, because paint and water won't mix together. So what happens is, when you use this material, when you mix with the aggregate and compact it in the roadway pavement, the water will simply evaporate leaving the asphalt behind. And this asphalt will bind the aggregate.

The other way to do it is to dissolve the asphalt in an organic solvent. Now all these organic solvents that were shown here gasoline, kerosene, and so on, will be able to dissolve the asphalt, because asphalt is obtained from the same process. So when you dissolve it into this organic solvent, mix it with aggregate and compact it, what will happen to the organic solvent?

It will simply volatilize, it will go away, leaving behind the asphalt which can then bind the aggregates.

So in all these techniques, all you are doing is simply, lowering the viscosity. So the technique used obviously defines the type of asphalt.

(Refer Slide Time: 21:40)



Types of asphalt

Regular or 'Hot mix' asphalt

- Most commonly used
- Placement temperatures should be ~ 125 – 150 °C

Asphalt Emulsion

- 60 – 70% asphalt suspended in 30 – 40% water with emulsifying agent
- Separation of water is called 'breaking'

Asphalt Cutback

- Asphalt dissolved in low molecular weight organic solvent
- Asphalt sets when solvent volatilizes

So, the hot mix asphalt is when the asphalt is heated. And the heating temperature typically is 125 to 150 °C, because at that temperature, the viscosity is lowered almost to the extent that asphalt is like a liquid at that temperature, and it mixes very well with the aggregate, it coats the aggregate well, and because of that we get a homogeneous asphalt concrete composite. Now in emulsion, 60-70 % asphalt is suspended in 30-40% water with an emulsifying agent. When water evaporates, the process is called as 'breaking'.

Cutback is nothing but, the dissolved asphalt in a low molecular weight organic solvent. When the solvent volatilizes, asphalt remains behind and binds the aggregate. So, we have seen now different types of asphalt. In the next lecture, we will continue with assessment of how this structure of asphalt concrete evolves with time. And how does that lead to modifications or rather complications in analysis of asphalt properties. We will also then look at steel as a material and polymers and plastics to wind up this segment on structure of construction materials, ok? Thank you all.