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

**Lecture 5**
**Structure of Construction Materials an Overview Part3**

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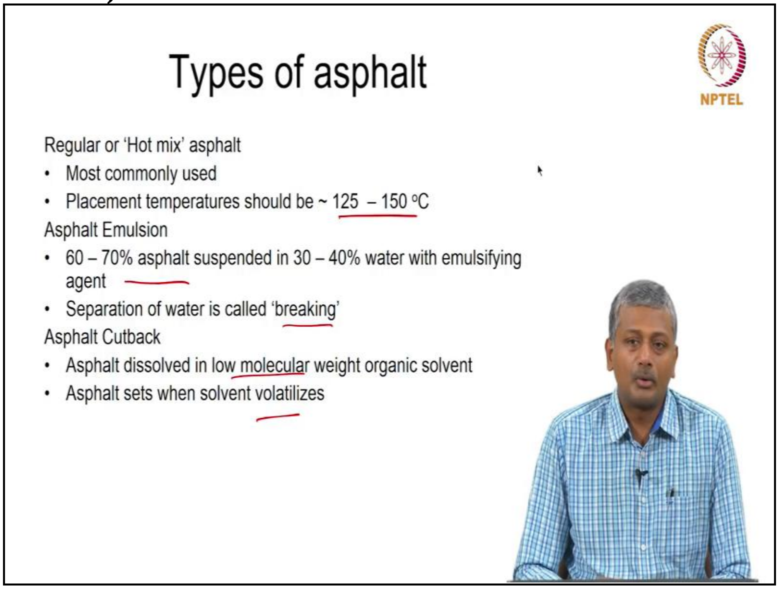


In last class, we were talking about the structure and properties of certain construction materials, we started of with cement concrete and we were engaged in the discussion on the structure of Asphalt concrete which is basically a mixture of bitumen plus the aggregate. We were looking at how and what are the different techniques with which you can lower the viscosity of the Asphalt to enable its mixing with the aggregates followed by placement and consolidation.

The three common techniques to heat the Asphalt in order to prepare an emulsion or to prepare cutback, which is basically the solution of the Asphalt in organic solvent. Now, as I was talking about earlier Asphalt has a major tendency to be affected greatly by temperature just like any other polymer the properties of Asphalt concrete affected tremendously by temperature.

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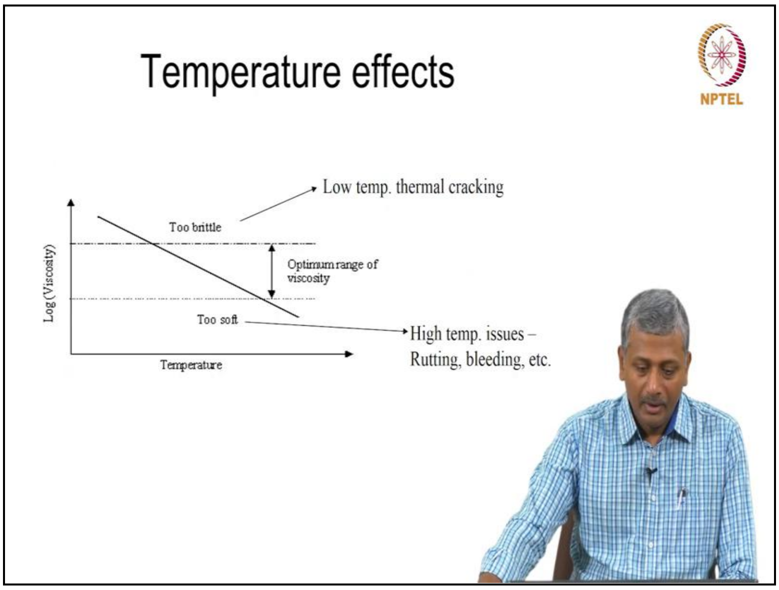


So as a result we need to look at safe working temperatures or ideal working temperature with this material. We know that when we design a pavement for service in a particular location. There are specific ranges of the temperature to which this location will be subjected to and we need to ensure that the kind of material that we select or the asphalt that we select is suitable for that specific environment because if we look at the viscosity verses temperature plot, we see the region which is below (too soft line) indicates that the Asphalt is too soft.

That means the temperature is extremely high and viscosity is very low asphalt is too soft in this condition. This leads to high temperature issues like rutting and bleeding which is quite commonly seen in India. It is because of temperature being quiet high, leading to the flowability of asphalt. If you go to very cold climates; the temperature becomes extremely low and asphalt get extremely brittle just like any other polymer and because of that you get the problems of low temperature thermal cracking. For every type of the asphalt binder there is an optimum range of viscosity that defines the range of temperatures in which asphalt will be giving the desired performance. So, we need to ensure that you build your pavement with the right idea about the material. This means that we need to have some basic understanding of characterization of the raw material itself to try and understand about the working temperature in which asphalt can actually give the right kind of properties.

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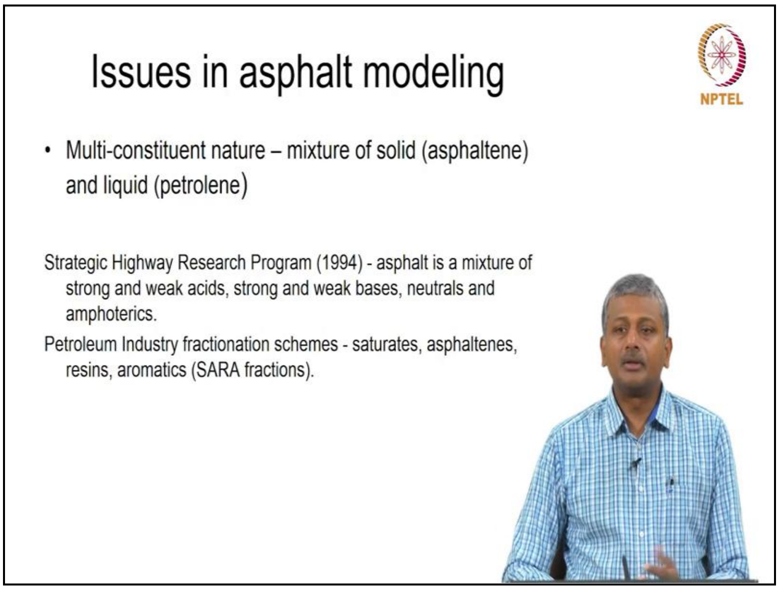


The other major challenge with Asphalt apart from temperature is that is not just homogenous material as it appears to us as a black gooey substance which looks quite homogenous.

In reality it is quite heterogeneous but not as heterogeneous as concrete perhaps we have some heterogeneity for asphalt as it is a multi-constituent material. Asphalt has the solid phase asphaltene and liquid phase petrolene which are intermingled.

If you look at the definition given by the strategic highway research program, asphalt is a mixture of strong and weak acids, strong and weak bases, neutrals and amphoterics. We have several different kinds of chemical species present inside the asphalt. Petroleum industry gives different schemes of fractionation of the constituents of Asphalt.

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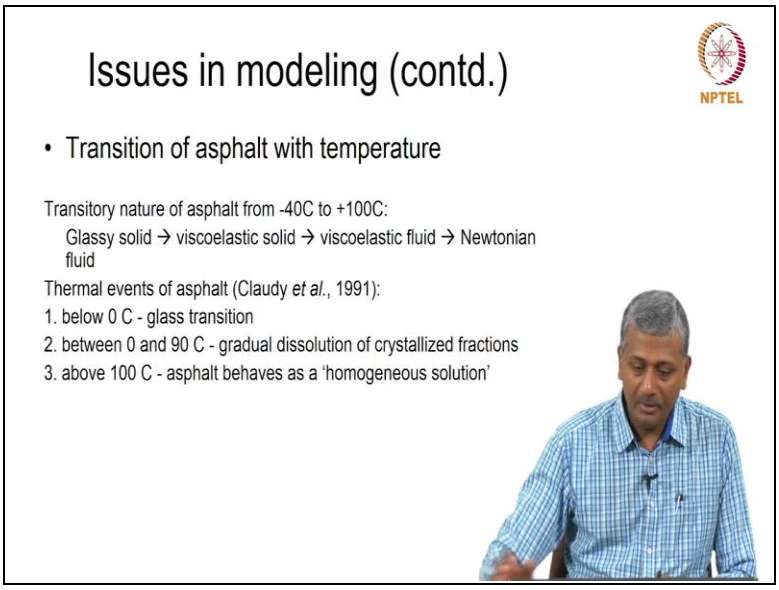

For asphalt the two key points are its multi constituent nature and temperature which we have discussed in the same lecture. So looking at specific characteristics of asphalt; we know that asphalt behaves in a very transitory manner between – 40 and 100 degree Celsius and much of this is in the range of working temperatures in most parts of the world. There are parts of the world that go down to -40 and go up to 55 degree Celsius (ambient temperature).

Since asphalt is black in colour it will absorb a lot of heat and actual temperature may actually rise up to 100 degree Celsius. Asphalts with in this temperature range have different transformations occurring. At very low temperatures; asphalt is brittle or a glassy solid and with increase in the temperature it becomes highly viscoelastic, but remains as a solid and that is what we see in the actual pavement that are functioning outside.

But when it is taken to slightly high temperature it transforms to viscoelastic fluid and starts moving .When temperature reaches about 100 degree Celsius, asphalt becomes a Newtonian fluid which has no inbuilt shear resistance and can flow continuously. According to Claudy the thermal events of asphalt includes phenomenon such as, below 0 degree Celsius there is glass transition.

Glass transition is the transition from the glassy solid to the viscoelastic solid which happens at temperatures below 0 degree Celsius. In between 0 and 90 there is a gradual dissolution of crystallized fractions and when crystallized fractions start dissolving the material becomes highly fluid and starts flowing.

Above 100-degree Celsius asphalt behaves like a homogeneous solution which is similar to the Newtonian fluid. So, we need to understand that the temperature of testing will be very critical as for as for Asphalt concrete is concerned.

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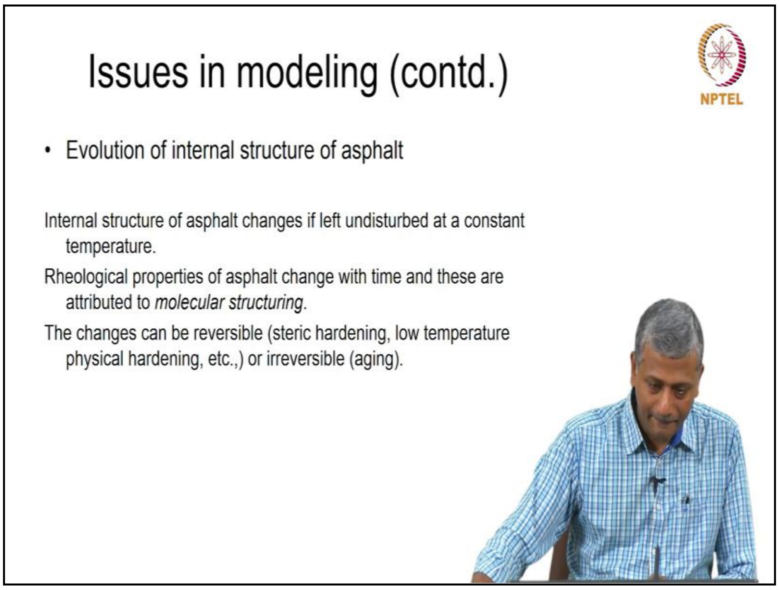


The internal structure of the asphalt also keeps evolving with time. So there is some molecular structuring that can take place inside and lead to internal structure evolving with time. We think that it is only cement which hydrates with water and continues to react until we cure the concrete and the structure of paste keeps on evolving, but the structural changes can also happen in Polymers and Asphalt and can also be sometimes irreversible. The structure keeps changing because of which characteristics also keep changing. This is the reason why characterization of asphalt is extremely important.

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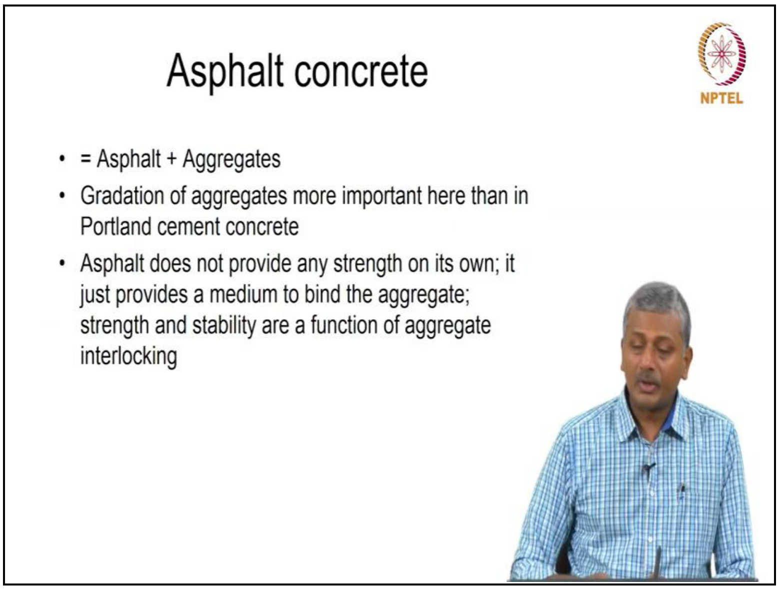


Asphalt concrete is just the level of sophistication that we get from Portland cement concrete. Here instead of Portland cement and water as the binding medium, we have asphalt as the binding medium. Unlike concrete which mainly gets its strength from the bond between the paste and the aggregate, asphalt concrete derives its strength primarily by aggregate interlock which also makes it stable. Due to that aggregate gradation is very important and you need to ensure that the aggregate gradation is chosen carefully so that you get the best stability of pavement.

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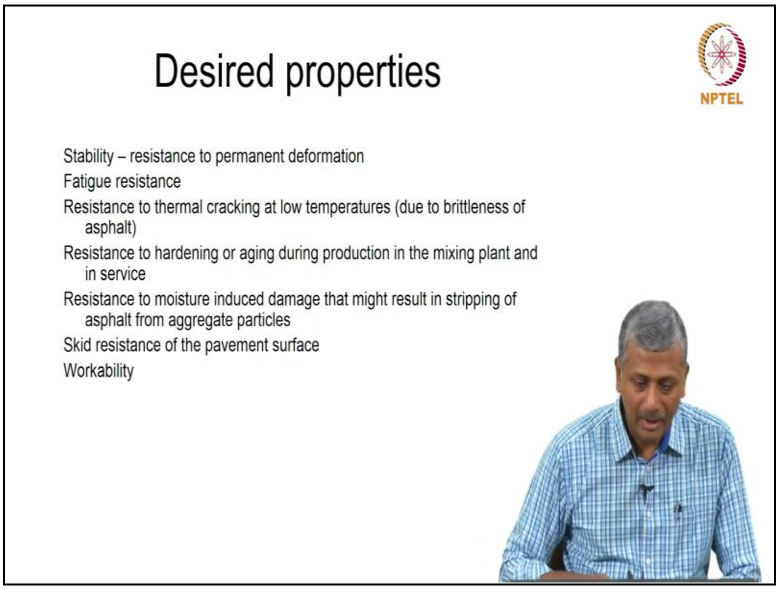


Now there are certain characteristics that you desire from Asphalt concrete pavements obviously stability is the most important characteristic which is the resistance to permanent deformation. As we have vehicular load which is continuously moving on the structure and because there is a continuous type of movement hence there is fatigue that comes into place. Fatigue resistance is also very important characteristic of Asphalt pavement.

Thermal cracking at low temperatures it is observed that when Asphalt becomes too brittle it results in thermal cracking. Hence asphalt should be resistant to thermal cracking. There is resistance to hardening or aging during production in the mixing plant and in service. Like for any other polymer when it is exposed to external environment i.e. moisture and ultraviolet radiation from the sun; the polymer properties starts and keeps on changing. This is basically called aging and with aging asphalt starts losing its flexibility which can cause some problems during service.

Asphalt concrete should resist moisture induced damage such as the loss of bond between aggregates in asphalt. This could be a very important problem to deal with especially during the rainy seasons. There are other rideability parameters like skid resistance and so on and the workability of the material itself at the time of placing asphalt concrete. So, these are the characteristics that need to be designed for when you design asphalt concrete mixture.

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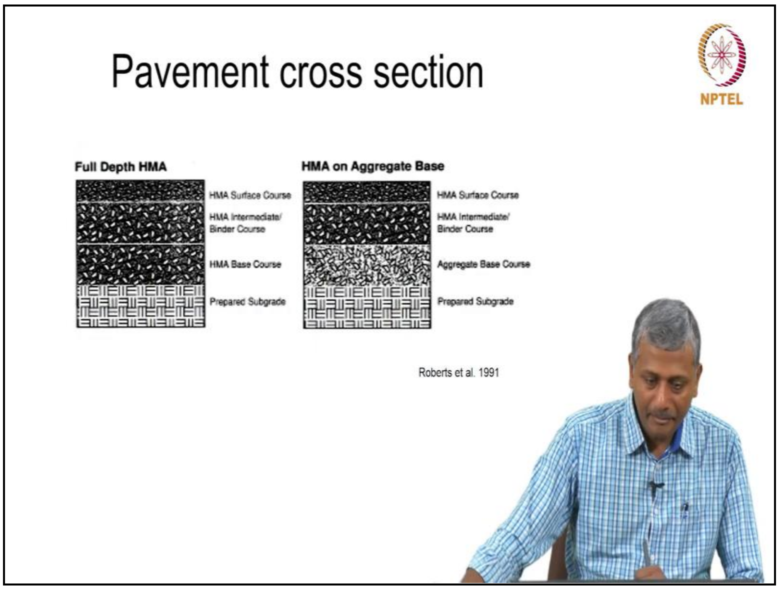


Of course you all know that asphalt concrete forms generally the top two layers of flexible pavement. The bottom layers are essentially composed first of a granular course which is basically the base course and then the sub base followed by compacted soil layer. This just for rekindling your memory on pavements you all know very well about flexible pavements and the design of flexible pavement but probably you may not have paid that much attention to the structure of the Asphalt concrete itself which needs to be different for the two layers that are there.

First is the surface layer and then we have the binder layer so you need to choose your aggregate sizes sufficiently well, so the surface layer give your dense impermeable and smooth characteristic. Whereas the binder layer has maximum part of the Asphalt concrete that is responsible for strength and stability of pavement. The binder layer keeps the pavements stable whereas surface layer primarily is responsible for the rideability characteristics as well as the resistance to moisture penetration and so on.

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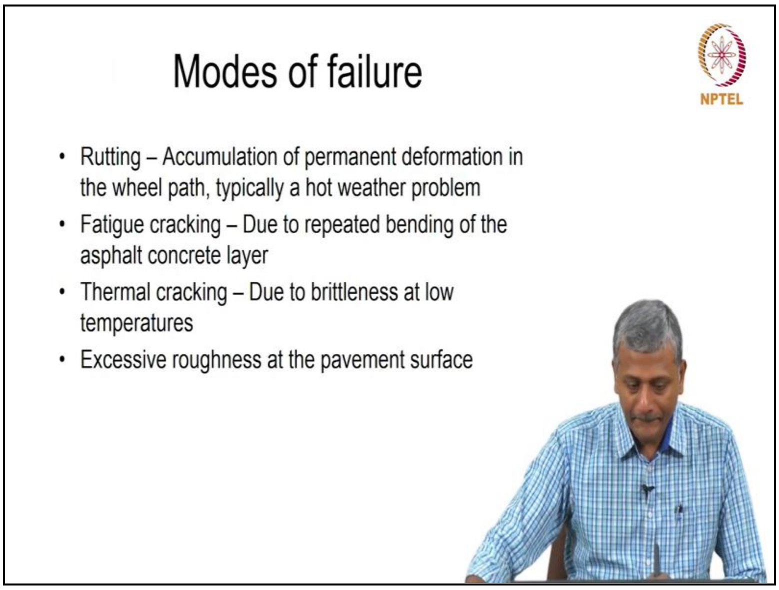


There are several modes with which Asphalt pavement can fail like rutting which happens when there is high temperature and because of which there is permanent accumulation of deformation right under the path of the wheel you would have seen this in many pavements. Fatigue cracking happens because of repeated bending of the asphalt layer and then we have thermal cracking because of brittleness at low temperatures. You could also get excessive roughness on the pavement surface that causes the loss of probability conditions.

Then you also have bleeding or flushing when the asphalt becomes extremely fluid it starts coming out and settles on the top surface as pools. So that basically is called bleeding in high temperatures. Ravelling associates with loss of flexibility in the asphalt because of ageing and oxidation which renders the pavement not as flexible is it used to be before or material not as flexible because of which it starts cracking. Then we have stripping which is loss of bond between aggregate and asphalt that happens because of the moisture intruding in the pavement.

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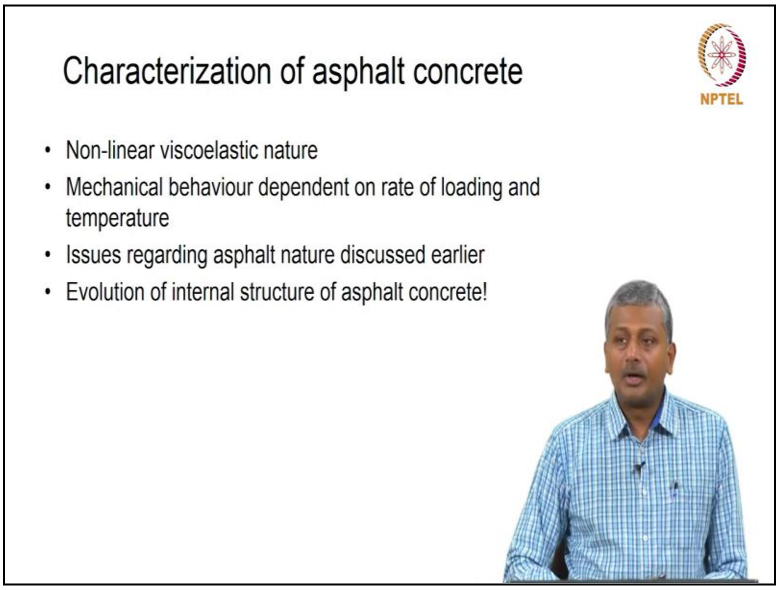


Now again because of all these difficulties that we discussed earlier you can add to those difficulties, the nonlinear viscoelastic nature of Asphalt concrete. Nonlinear itself means a lot of issues to deal with when you actually start modelling the material and characterizing the properties to do that modelling can be quite a bit of challenge with nonlinear material.. Something like glass or chalk has got the linear brittle sort of a relationship.

But in case of asphalt you have a nonlinear viscoelastic nature. So, with loading you not only have the elastic response you also have a viscous response just like other polymers. So, because of this viscoelasticity exhibited by asphalt apart from temperature, the other characteristic that determines the response of asphalt concrete is the rate of loading. Of course, in cement concrete we choose certain specific rate of loading and we do our characterization test like compressive and flexural strength.

But in case of concrete the rate of loading does not have as big of influence as it does with polymeric materials, especially with asphalt concrete. So for asphalt concrete, the rate of loading has been specifically maintained to ensure that we get consistent results each time .The internal structure of the asphalt concrete can also change entirely.

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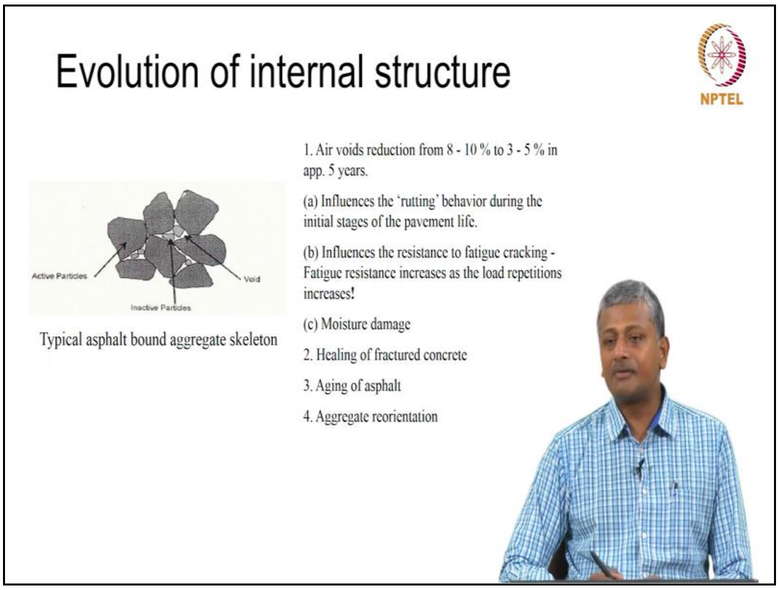


Asphalt concrete is a mixture of asphalt and aggregates and obviously we cannot have a system that is free from voids, so we will be having voids inside this system. For example, here we have these active aggregate particles and we have the spaces in between that are voids. So, these voids can keep changing with time. Air voids basically reduced from 8 to10% in the beginning to about 3 to 5% in approximately 5 years.

When your air void system is evolving inside the composite material, obviously the properties will also change. The asphalt concrete structure evolves with time and hence it is important to characterise the air voids which influences the rutting behaviour and the resistance to fatigue cracking. Fatigue resistance increases as the load repetition increases that seems to be contradictory, but that happens because now we have lesser voids present in the system.

As you have more voids in the system the structure gets more compacted. Then of course there are other issues also with internal structure like rearrangement of the positions of the aggregate if the gradation is not proper and so on and then you have a complete volumetric change that can lead to different types of properties exhibited by the asphalt concrete unlike what you started of it in the initial stages.

So, with cement concrete and asphalt concrete, the primary things that we were concerned with were the time-dependent deformations. With metals like Steel time-dependent deformations are not such a great concern. Creep for example with metals is almost minimal as compared to something like concrete or asphalt concrete. So, with metals the elastic characteristics or load responses, temperature responses are lot more crucial than long-term loading or sustained loading performance.

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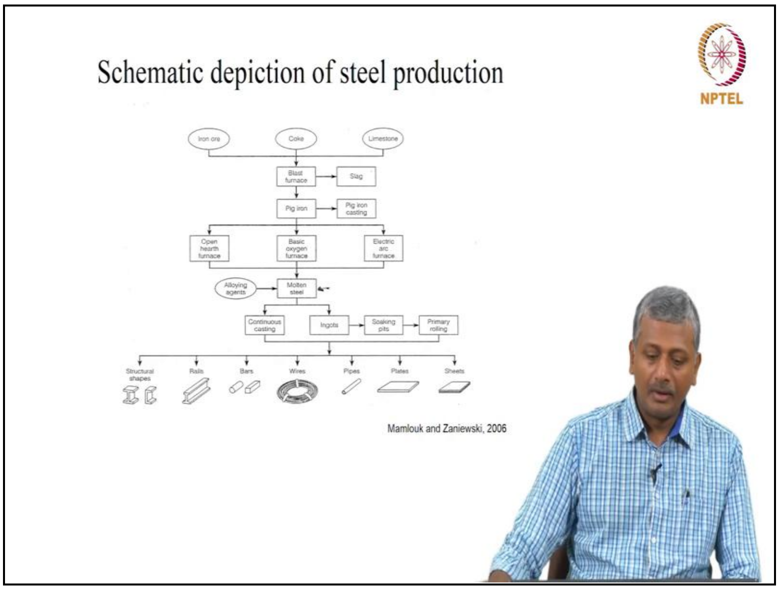


We know very well that steel is obtained from a well-controlled process where first where we have the blast furnace where the pig iron is produced. It is followed by further purification or removal of the carbon content from the pig iron to obtain the molten steel and molten steel is then casted into various shapes and types of steel rolls. Civil engineers are primarily concerned with structural shapes, rails and bars.

Most of the times we are dealing with structural sections with steel which are used directly for steel construction. Rails are obviously important for transportation network and bars or rounded bars of Steel are used as reinforcement in concrete.

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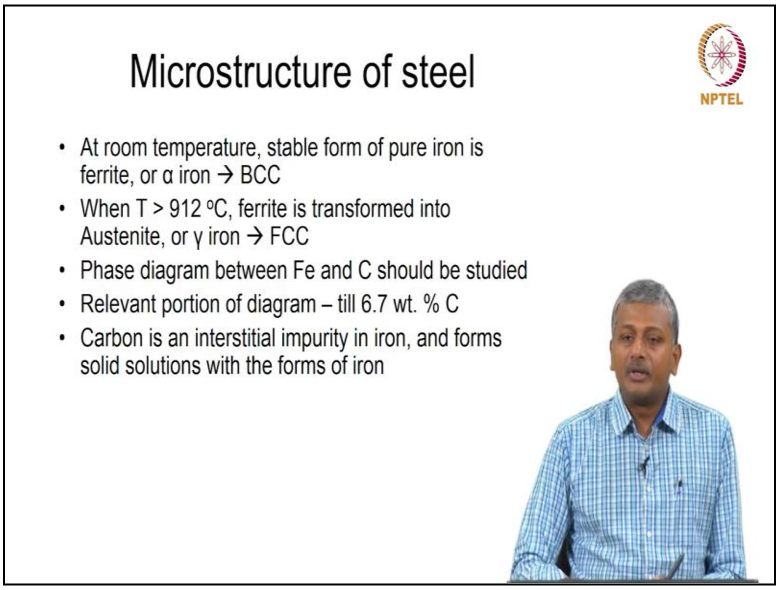


Steel may appear to be homogeneous at macro level but at the micro level, it has different type of microstructure exhibited at different temperatures. At room temperature the stable form of pure iron (without any carbon) is α iron or ferrite which is called body centred cubic structure. We will learn a little bit more about crystal structures later when we actually undergo the chapter of X-ray diffraction. Body centred cubic specifically means that you have atoms at cubical corners and one atom right in the centre of the cube if you consider a single cubic unit cell.

When you increase the temperature more than 912 degree Celsius the ferrite which is pure α-iron is transformed into austenite or γ-iron. While processing steel, we actually mix iron and carbon because in case of having pure iron, it is too ductile and soft in nature. These characteristics are undesirable because structural steel should impart high strength and limited hardness with some ductility.

The required hardness is introduced in steel by the incorporation of carbon. But if you incorporate too much carbon, the steel becomes too hard and too brittle which is not suitable for structural applications hence we actually have very limited amount of intrusions of carbon into steel. So, when you start mixing two solid phases and do a time temperature transformation you result in obtaining phase diagram.

It is essentially needed to study the phase diagram between iron and carbon which are the two constituents or components in the iron carbon mixture commonly called as steel. The relevant portion of the iron-carbon phase diagram which corresponds to most types of steel used in practice shows about 6.7% weight percentage of carbon present.

We need to know that there are atomic percentages and weight percentages. Atomic percentage means if we have formula let us say of NaCl the atomic percentage of sodium and chlorine is 50% each but the weight percent of one mole of NaCl will depend on the relative molecular weight of Sodium and chlorine. So, the weight percent has be calculated that way but the atomic percentage is calculated directly from the chemical formula. So, this is 6.7 weight percent of carbon which actually transforms to the chemical formula $Fe_3C$ and this material is called cementite.

At 0% or at very low percentage of carbon you have ferrite phase and when you go towards 6.7% carbon you have cementite phase. All the relevant iron carbon phase diagram that you see in textbooks will be between 0 and 6.7 percent of carbon or between the ferrite phase and the cementite phase. If you look at the macro level steel looks homogenous and at the micro level is heterogeneous. This heterogeneity is introduced by carbon which is an interstitial impurity iron and forms solid solutions with the forms of iron. When a solid is dissolved into a solid we call it as solid solution. In metals many phases form because of solids dissolving into other solids.

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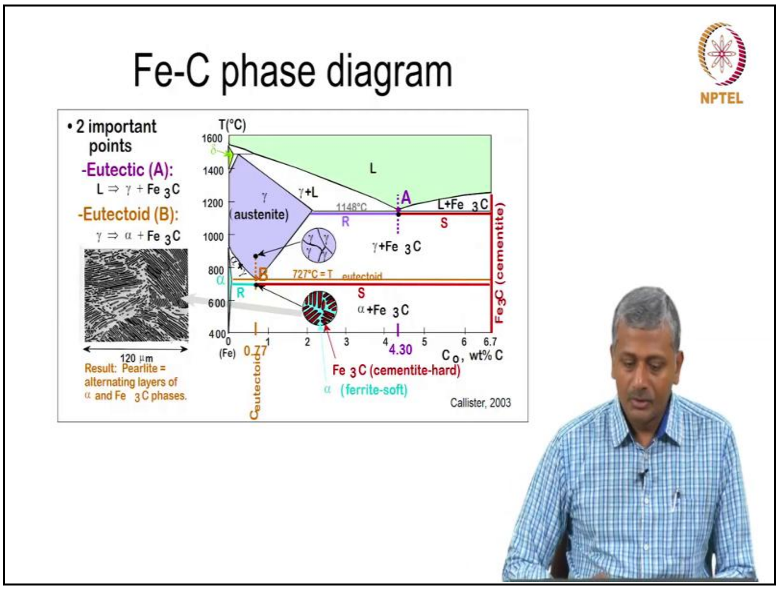


On looking at the iron carbon phase diagram there are very specific point of interest that at 0 percent of carbon, you have α phase called ferrite and at 6.7 % carbon you have cementite or $Fe_3C$ phase. If you look at the diagram in between these two phases you have different types of structures exhibited or different types of phases exhibited with different carbon contents. So, as discussed earlier, we are interested primarily in very low carbon contents to ensure that we have sufficient blend of strength and ductility introduced into the steel.

In most cases as far as structural steel is concerned; we deal with carbon content which are extremely low. Now for tools used in the workshops and the machine shops need extremely high hardness because they have to wear out the other metals which are to be ground. These tools will have a higher carbon content. As there is no need of ductility from the tools, you need greater amount of strength and hardness.

As the carbon content increases, the strength increases but the ductility decreases. So in general for most materials, that is one compromise we need to make whenever we increase the strength, the ductility of the material reduces. This happens with most of the materials like cement concrete, asphalt concrete, steel, polymer, etc. The higher the strength, the lower is the ductility.

Here, we are talking about the region of phase diagram that is corresponds to extremely low percentage of carbon marked as the eutectoid transformation. Eutectoid transformation happens at 0.77%, carbon content.

If you take an iron carbon mixture with 0.77% carbon content and heat it to a temperature that is above this eutectoid temperature or 727 degree Celsius, it becomes entirely the $\gamma$ phase or austenite phase which has face centred cubic structure (FCC). When you start reducing the temperature and it reaches below 727 degree Celsius this $\gamma$ phase gets completely transformed into a mixture of ferrite phase and cementite phase.

We see that one solid phase gets transformed into mixture of two other solid phases which are ferrite phase and cementite phase. So, we started with components i.e. iron and carbon, which are intermingled and mixed together because of which we get phases. The phases that we get are $\alpha$ phase and cementite phase. If you look at the microstructure of the phase under the microscope, you will see that looks like something which is known as the mother of Pearl that is why it is given the name pearlite and its structure is called pearlite structure.

At 0.77% we have eutectoid transformation i.e. one solid into two other solids and at that temperature austenite converts completely in to the mixture of $\alpha$ phase and $Fe_3C$. There is one more transformation which is eutectic transformation. Eutectic transformation involves the conversion of one liquid phase into a mixture of two solid phases. So, the difference between eutectoid and eutectic is clear that the former is one solid to two solids and latter is liquid to two solid phases. But we are not really worried about this portion of the diagram because we never go to this iron-carbon content as far as structural steel is concerned. We are primarily dealing with the low carbon contents. Typically the mild steel has carbon content of less than 0.2 %.