Mechanical Characterization of Bituminous Materials
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Lecture No 37
Mixing and Compaction Temperature - Part 1

So, hello everyone as part of this NPTEL course on mechanical characterization of bituminous materials, we are actually going to talk something very interesting this is about the mixing and compaction temperature for binders, and in fact.

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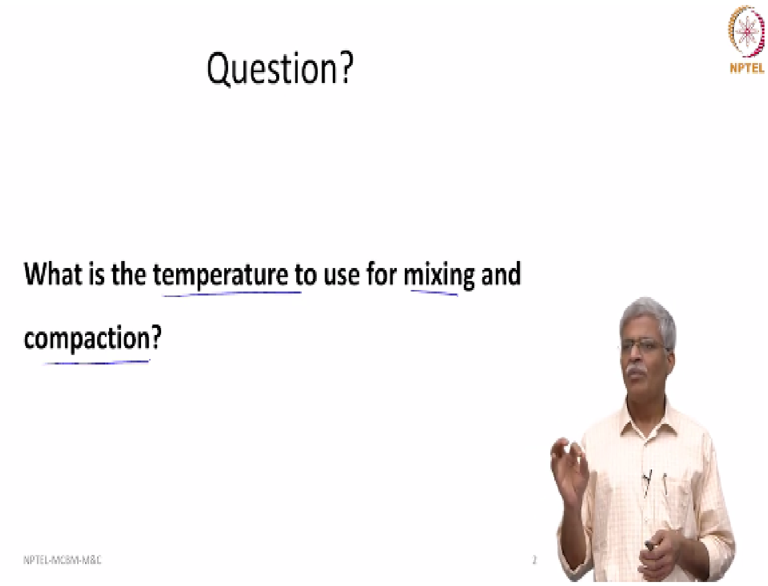

We are going to ask a very simple question. The simple question that we want to ask and for which we also want to find out the answer is, what is the temperature to use for mixing and compaction of bituminous mixtures? So, you must be wondering as to, what is there in this that one should even have a separate lecture on the mixing and compaction temperature because we see roads are being constructed, binder is being heated aggregate is being heated.

And they are mixed together, and they are laid in the field there should not really be any big issue associated with that. To some extent the answer to that is yes, there is not really a big issue as long as you are using unmodified binders. When we start using modified binders what really happens is the behavior of the material changes completely, at the mixing as well as the compaction temperature.

The material starts showing what is really called as a non-Newtonian response. So, the moment it behaves like a non-Newtonian material the shear rate dependency kicks in and it is not easy for us to find out a precise mixing and compaction temperature. The issue is serious enough in the sense that in NCHRP they spent quite a bit of money on trying to find out a correct protocol that could be prescribed as an ASTM or AASHTO standard.

But till now one cannot say with confidence that we have a rigorous method that is available. So, most of the time the practicing engineers use their wisdom and try and adjust the mixing as well as the compaction temperature of the binder so that they get a workable mix in the field. But the understanding of the physics as well as the mechanics of the problem associated with it is far from being resolved.

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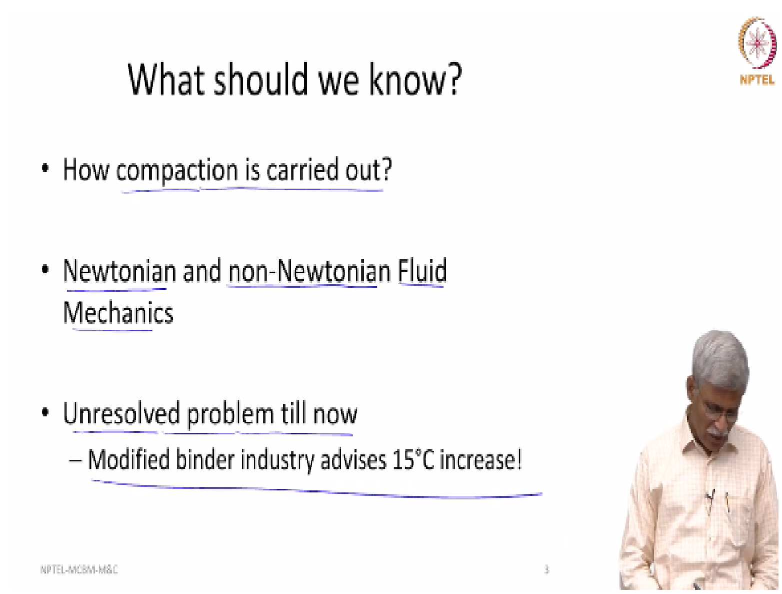

What and if you really want to understand the issues related to mixing and compaction temperature, we should first know how compaction is carried out; No.1. And we should also know little bit, not exactly everything but at least little bit about Newtonian or non-Newtonian fluid mechanics and these are all courses that you can, you have to take at least 3 or 4 courses to even understand a little bit about non-Newtonian fluid mechanics.

The measurement geometries, the problems, the velocity fields that one should understand the governing equations to be used under the wide variety of models that are available. So, and as of now this is an unresolved problem and the modified binder industry typically will increase the temperature, will suggest that you increase the temperature by 15 degree centigrade, why so? We will look at it as we go along.

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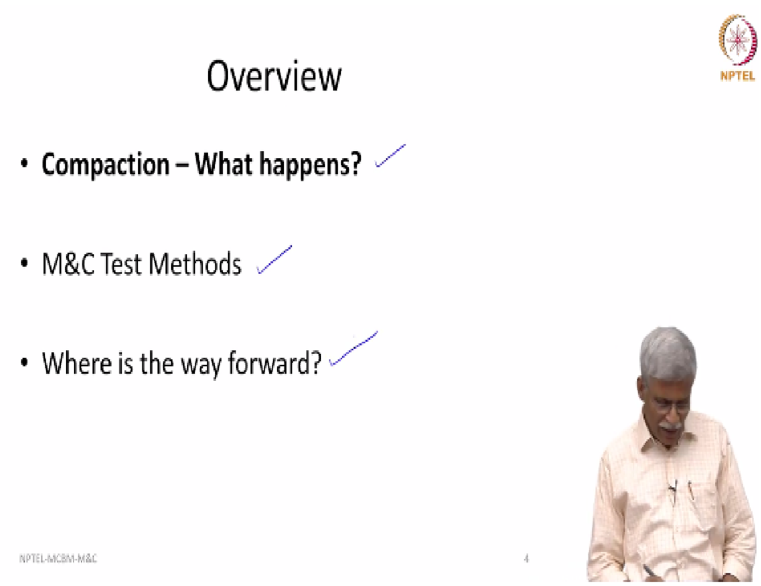

So, the overview is first we need to understand compaction, what really happens? What are the mixing and compaction test methods that are currently available? And is there any way forward, what should we really do about it?

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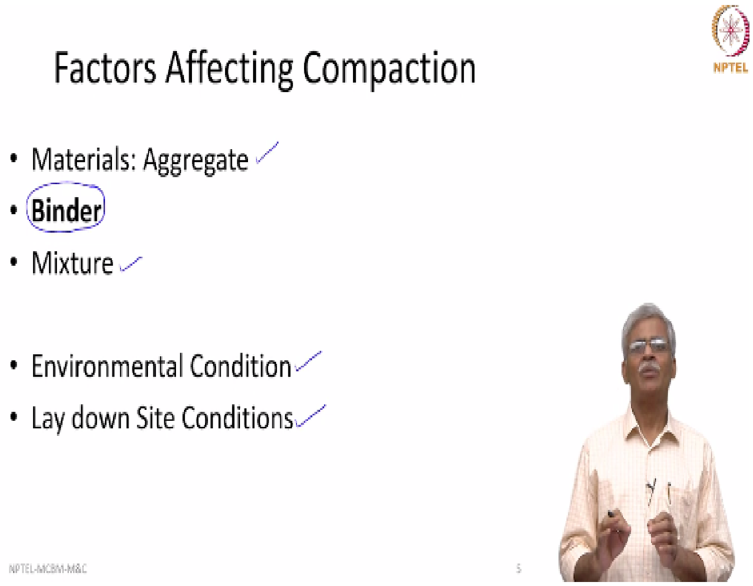

What really are the factors that are affecting compaction? Of course, the aggregate but most importantly binder and that is why I have given it in bold face and finally the mixture. The conditions; environmental conditions, the lay down site conditions also plays a critical role. This course is more about the mechanical characterization of bituminous mixtures; this course is not about pavement construction.

So, I would not get into the details associated with how the mix is produced? How it is transported? And what really happens during the rolling operations? Because there are different types of rolling but we will be talking only about the change in the rheological behavior of the binder as it goes from 180 degrees centigrade all the way to 90 degrees centigrade.

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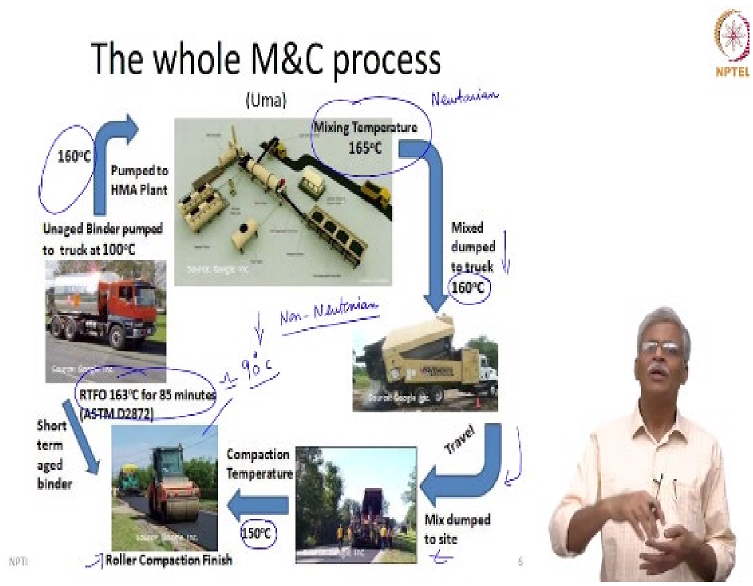

So, this whole mixing and compaction process, in fact one of my PhD students, she kind of put together this clean chart, so what you can actually see here is, this is the hot mix plant here. This is at around 165 degrees centigrade is the mixing temperature, roughly these temperatures are should not be taken as precise numbers depends on the mix depends on the kind of equipment that you have got here.

But these are the bal part numbers the mixer is dumped in the track most likely around 160 degree centigrade. And it goes to the construction site and it is dumped there and the compaction temperature may be roughly around 150 degrees centigrade and finally what will really happen you finish the roller compaction here and in fact if you start come from this. Look at only the binder behavior you are going to see that you take a binder at 160 degree centigrade.

And when it goes through this whole process there is a short-term aging that happens. And it is at 163 degrees centigrade for 85 minutes and we have already discussed about it in the aging on bituminous binders. Now what will really happen as far as unmodified binder is concerned? The response of the material here will be Newtonian. I am talking about the behavior of the binder and by the time the roller compaction is finished.

Which we expect around roughly 90 degree centigrade the response of the material becomes non-Newtonian. I have not mentioned anything about whether the material will shear thin or shears thicken. I am only going to say that it is just non-Newtonian. So, as the binder starts at 100 degrees centigrade comes at 160 degree centigrade, becomes a mixture at 165 comes to the truck at 160 goes to the site at 150 and gets rolled and compacted and reaches 90 degrees centigrade.

It goes through a complete change in its rheological behavior. So if it is an unmodified binder the variation of the viscosity or the apparent viscosity can be easily captured by some unique testing procedure, but if it is going to be a modified binder and again, we have discussed there are different types of modified binders that you can have. An elastomer, a Plastomer, a reactive terpolymer rubber modified binder, not one unique protocol can capture the essence of the behavior of this material in this whole temperature regime.

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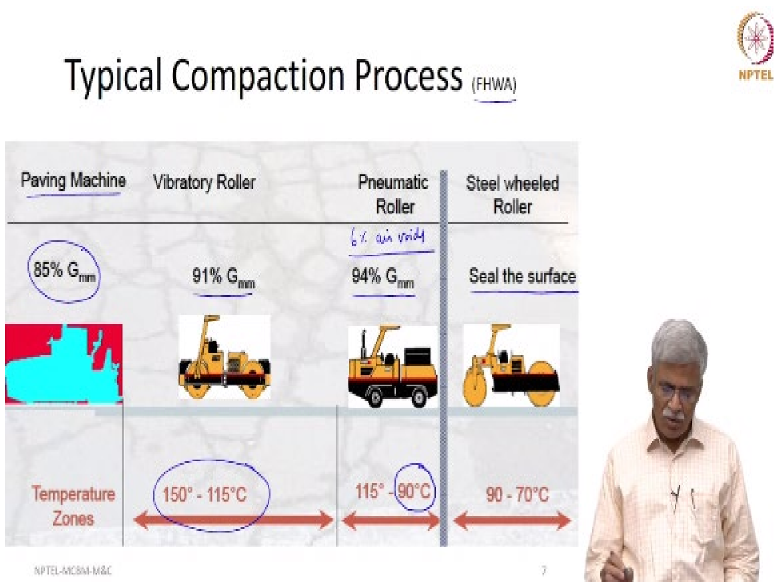

So let us look at this typical compaction process, in fact this particular information is available for free download from the Federal Highways Administration website US and I have taken it from there, thanks to them, So you can actually see that there is a temperature zone this is your paving machine that you see here and 85% of Gmm. Gmm is your theoretical maximum specific gravity.

And as the roller starts, rolling roughly the theoretical maximum specific gravity goes to 91% and we are somewhere in the 150 to 115 degree centigrade and by the time we finish and reach this 94% Gmm which corresponds to let us say 6% air voids some specifications say that we should leave 8% air voids in the field 6 to 8% air voids. So, we will stick to 6% air voids.

So, this is what will happen and after this compaction is over typically sealing the surface and ensuring that it becomes impervious is done here. And, so almost all the compaction operation is finished by 90 degree centigrade. So, this is the compaction process that you notice here.

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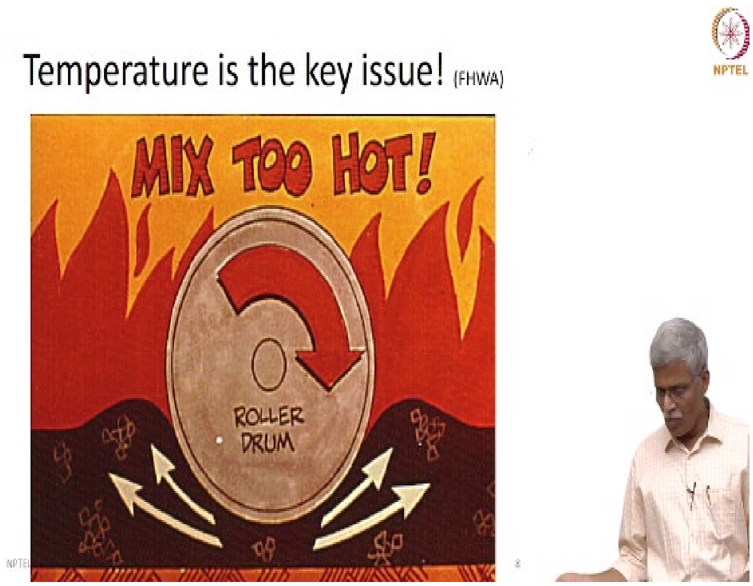

Now the main critical thing is the, temperature is the key issue. Now if the mix is very hot what you see here, what will really happen? The binder will, the mixture will kind of move away from the, below the roller, that is one thing.

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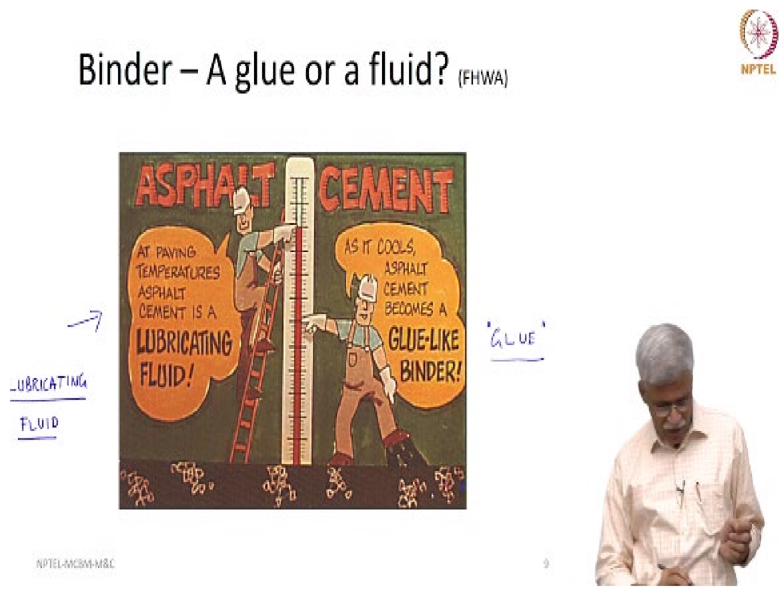

Now, the interesting part that we want to know is at paving temperatures, you can actually see from this picture very nicely captured here, you want it to be behaving like a lubricating fluid. It is necessary that we write this word and emphasize it. So, what it means is you have aggregates of different shapes and sizes all coated on their surface by the bituminous binder and this bituminous binder should play the role of a lubricant.

So that when the roller is rolling on top of it, this should allow the aggregate particles to get compacted to reach the optimum position. As the mat cools, now we want the same binder to behave like a glue so that means we do not want aggregate to start moving here and there and the binder should hold them together. We need to really understand that we have a heavy-duty roller that is rolling this whole thing.

And if the binder becomes very cold or if the glue becomes very stiff, the possibility of the aggregates getting crushed during the rolling operation also exists. So, from one end of the extreme, which is the lubricating fluid to the other end we want to behave like a glue.

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So, temperature is the key issue, so if the mix is going to be very cold then there will be a possibility of the aggregate particles are going to be prevented from compacting.

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So, if you really look at the close-up picture of the compacted hot mix Asphalt, you are going to see the aggregate here, as you can see, and binder here and air voids here. So, when you use stones, of with fractured or crushed faces. They, you are going to get this completely better interlock.

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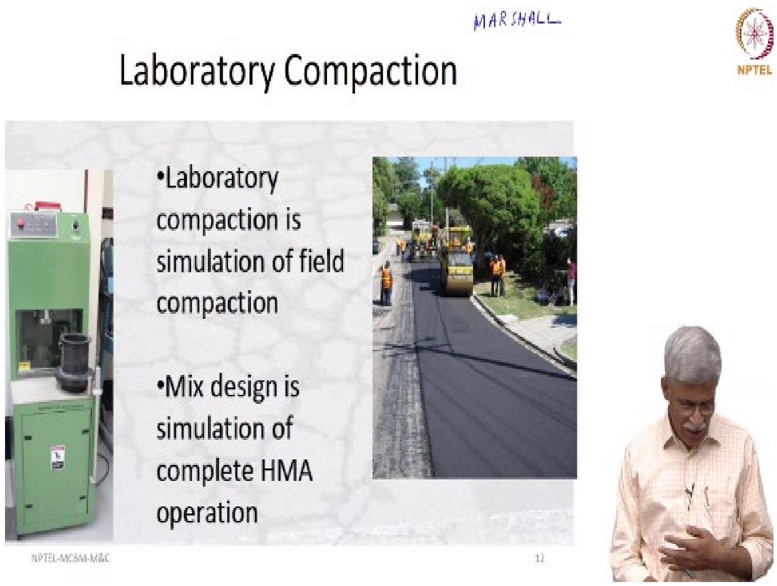

So, this is as far as the field compaction is concerned. But how do we really simulate this compaction in the laboratory? We have a family of compaction devices that have been developed for many, many years. We started with the MARSHALL, which is nothing but an impact hammer and we all know that it may not really do the correct job of simulating the field compaction. It has its own advantages and disadvantages.

Advantage is the, ease of use; you can take the MARSHALL compactor wherever you want. So now more or less many decades of development have led to the gyratory compactor. And this gyratory compactor in a sense tries to do the simulation of the field compaction and in fact we can even say the whole thing. Whatever the mix design that we do in our laboratory of heating the aggregate particles, heating the binder, mixing them together, keeping it under aging conditions and then compacting it, is more or less a simulation of the HMA operation that we see in the field.

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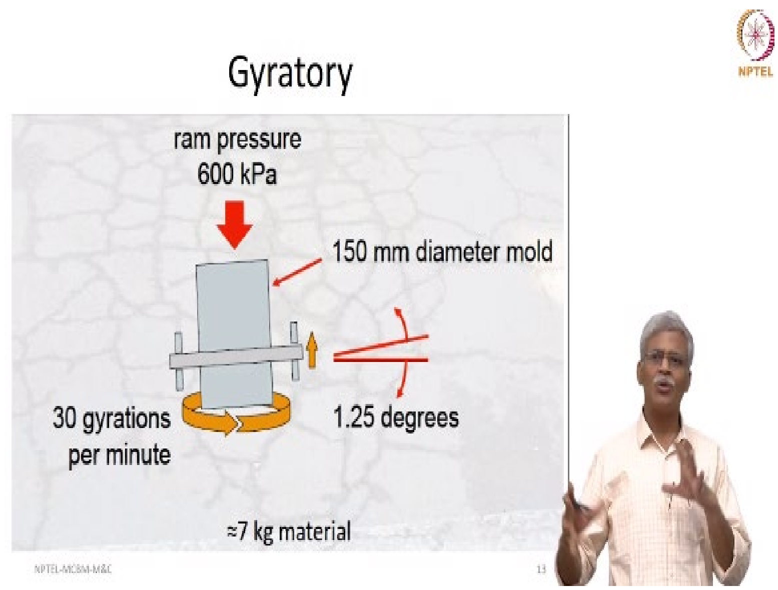

Now, how does the gyratory compactor work? It is fairly straight forward around 7 kg of material is dumped in and axial pressure of 600 kilopascal is applied and this is a 150-diameter mold and it is subjected to gyratory motion. So, during this gyratory motion there is an axial force that is applied, there is also the shear force that is applied which in a sense allows the particles to get completely compacted inside. The gyratory angle that is applied is 1.25 degrees and this is the gyrations per minute that is allowed here.

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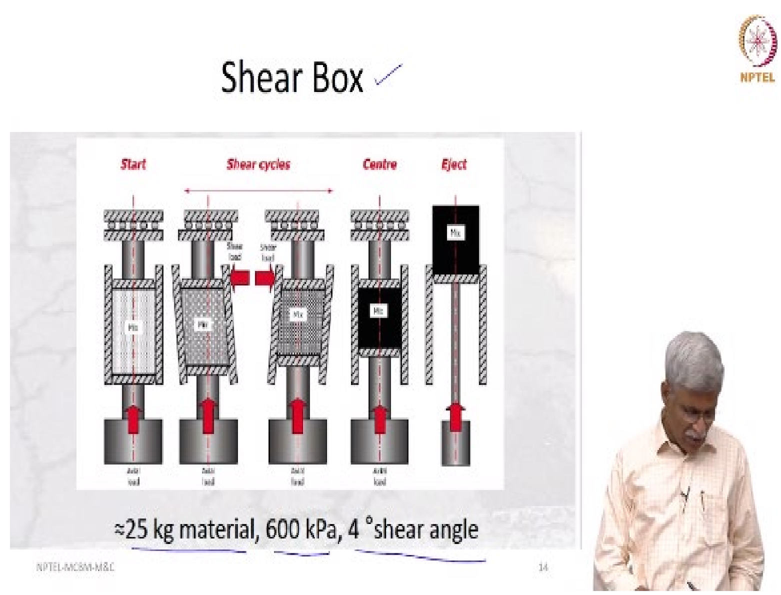

The recent one that has come which is doing a much better job of compaction is the Shear Box compactor in which the principle is the same except that instead of a cylinder, we have a big rectangular shaped, prismoidal shaped beam specimen that is used and the amount of material that is used also is very high it is 25 kg material. The axial pressure is the same 600 kilo Pascal, but the shearing angle is slightly higher which is 4 degree that is given here.

So, you apply this particular 600 kilo Pascal and then there is a shear force that is applied on either side through the movement of the angle. So the bottom is kept fixed and then it just keeps moving one side of the other and then we finally eject it and we get it, and based on the work that we have carried out at IIT Madras we have found out that the density variation is considerably less in shear box compactor.

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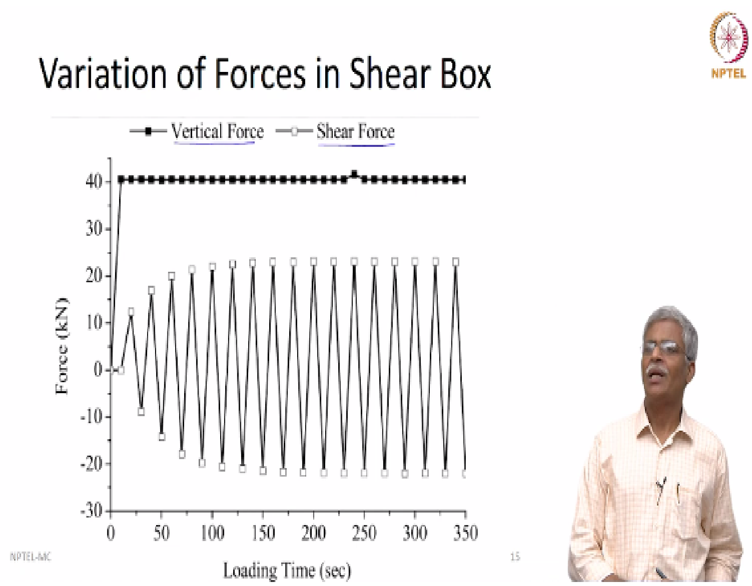

And interesting thing is you also get not only the vertical force data, which is given here you also get the shear force data. In fact, in gyratory compactor also if you use an optional accessory for every gyration, what is the shear force that is necessary to introduce that 1.25-degree angle? You can also get the same thing.

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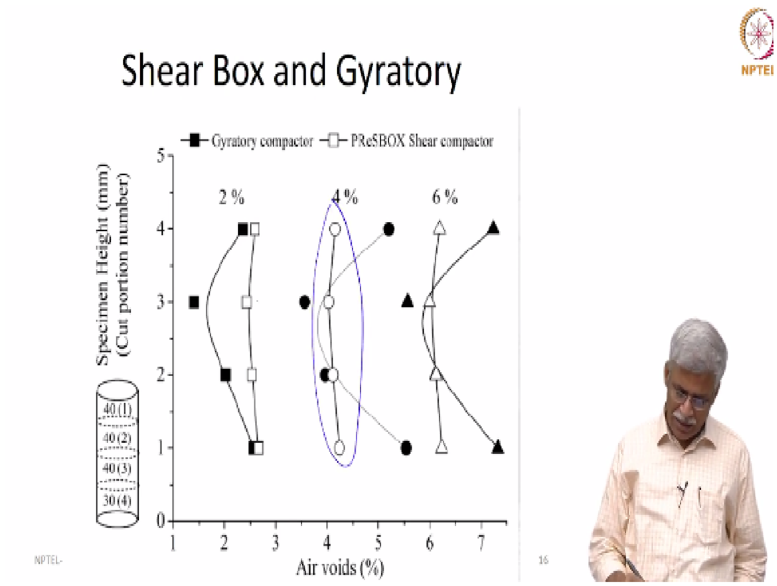

And one common complaint about the Gyratory compactor is that, the air voids variation is substantially different in the sense that, from the top as well as the bottom and the middle portion when you slice the sample and take a look at it, there seems to be a density gradient and actually you can see that in the Shear Box compactor that we have seen here there are going to be the variations of considerably less whether we are compacting it for 2%, or whether we are compacting it for 6%.

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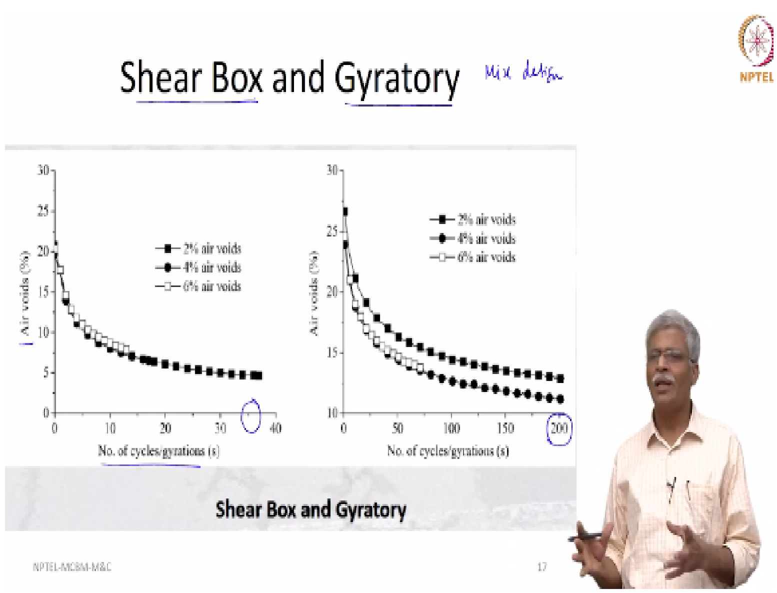

And one interesting thing in which we can actually take a look at it here is, in fact we can actually see the density versus the number of cycles or Gyrations. So, this is one is for the Shear Box compactor and another is for the Gyratory compactor, you can actually see the number of cycles associated with this here. One needs to caution here this Gyratory compactor has some meaning related to the mix design.

So that means there are different levels of compaction that we need to give that will not only give the laboratory compaction or the rural compaction, but also the field compaction whereas, a Shear Box compactor is not yet ready as to be used as a mixed design tool. I just wanted to show you that in the laboratory when we do the compaction which is basically a simulation of the field compaction you can have different types of compactors and each of them can give you material that are completely different with respect to the others.

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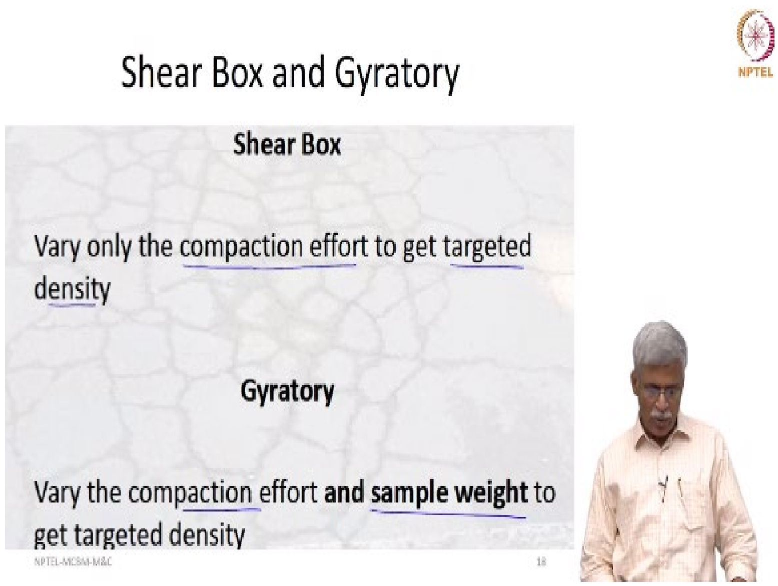

So in the Shear Box compactor what we do is we vary only the compaction effort, to get targeted density, whereas in the Gyratory what we can do is, we not only vary the compaction effort we also need to play around with the sample weight to get the targeted density. So, this is more or less the very general discussion that I really wanted to have.

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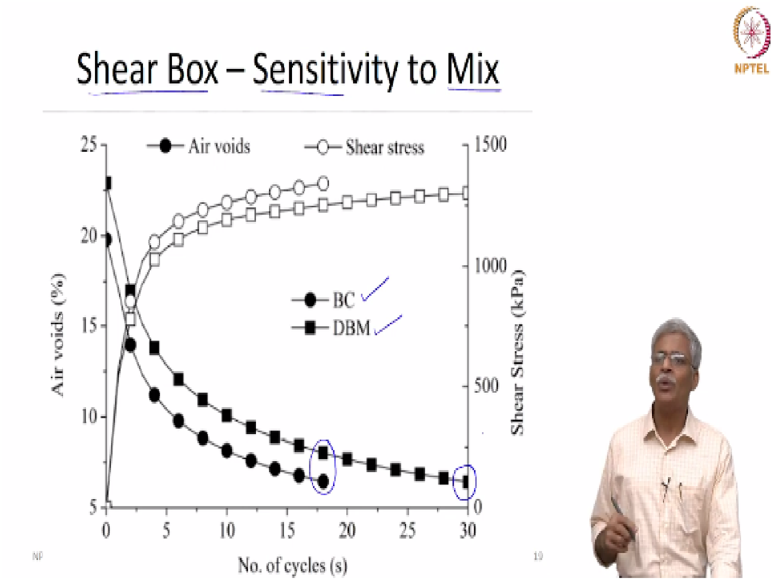

And it is also known that the Shear Box compactor is extremely sensitive to the mix, that you are using for instance, what you see here is a bituminous concrete, a typical bituminous concrete mix and dense bituminous macadam. The dense bituminous macadam has slightly lesser binder content, more coarser aggregate compared to the bituminous concrete. And you can actually see that the number of cycles that are needed to reach a target density is sensitive here and we have not been able to capture that kind of a sensitivity as far as the Gyratory compactor is concerned.

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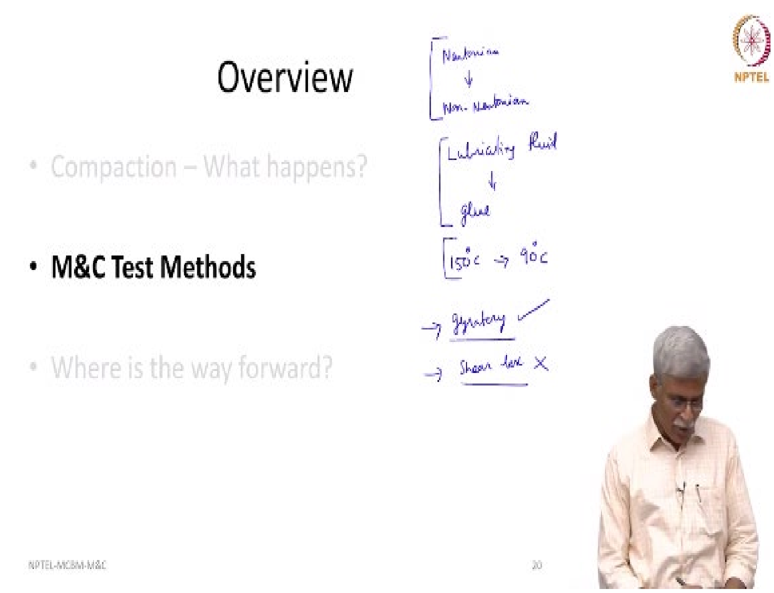

So, this is what I really wanted to say something about field compaction as well as the laboratory compaction. So, to summarize in the field the response of the binder varies from Newtonian to non-Newtonian, number 1 and then this is the first set of terminology that we used, and we also said we wanted to behave like a lubricating fluid to a glue and we started talking about the compaction process that goes from 150 degree centigrade to 90 degree centigrade. So, this is about field.

In the laboratory there are many types of compactors that are available the default standard for super pave is Gyratory, we also have a Shear Box compactor and there are some issues related to Gyratory as far as the non-uniform density distribution is concerned, which is not seen in the Shear Box, of course, this is a mixed design tool. But this is not really a mixed design tool. So, we need to understand all these things. Now, what do we really do to use this information to find out the mixing and compaction methods?

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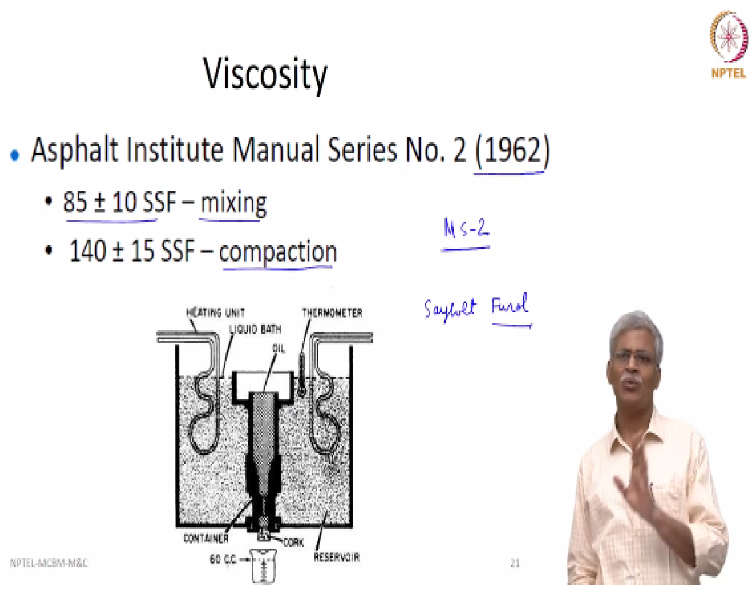

So, let us start looking at it. In the olden days in the asphalt institute manual series 2, MS 2 in 1962, they used a Saybolt Furol viscometer. And this was the value that was given for mixing, and this was the value that was given for compaction. So, what you need to do is to use Saybolt Furol viscometer, find out the temperature at which the viscosity will be given in this specific unit and use it for mixing and the viscosity that is given in this unit.

And then use it for your compaction and in fact what we really do this is nothing but a volumetric flow kind of a device you allow the bitumen to flow through a calibrated vessel and collect the fluid for 60 cc. Find out how much is the time and that is given as an indication of the viscosity of the material. All these will work as long as the response of the material is Newtonian.

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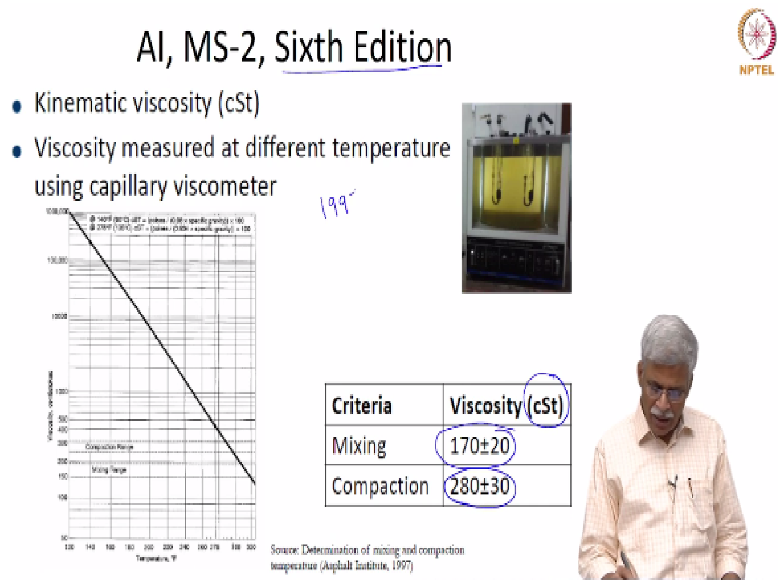

Later asphalt institute in their 6th edition, they changed and they now give units in terms of kinematic viscosity, previously it was given in empirical measures, so that means if you used different volumetric flow rate viscometers the values will be different but these time they standardized into kinematic viscosity and then they wanted you to measure the kinematic viscosity as a function of temperature.

And they mentioned that the mixing is 170 plus or minus 20 and compaction is 280 plus or minus 30 centistokes. This is 1997 and this is where Super Pave started slowly picking up.

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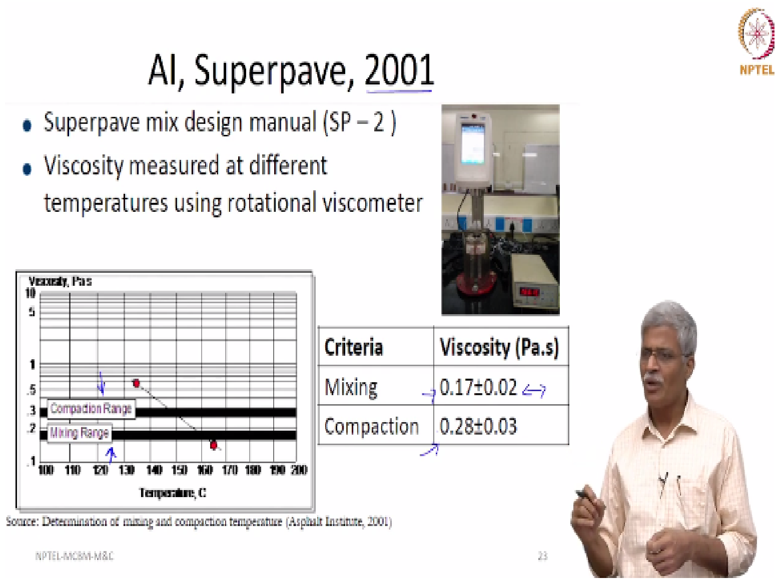

And as the superpave came they asked you to go away from the kinematic viscometer and use rotational viscometer of something like that is given and in fact what they really did was they just did they straight forward conversion of this kinematic viscosity to dynamic viscosity or viscosity assuming that the density of bitumen specific gravity of bitumen is 1 and they gave this in Pascal second 0.17+ or -0.02, 0.28+ or – 0.03.

In fact, there is also an ASTM standard that is available that tells you how to find out draw the viscosity versus temperature graph and you can actually see that there is it is given clearly this chart says what is the mixing range and what is the compaction range? So far so good so we know what to do and you can even in fact you can even ask so what is the sanctity of this 0.17 and 0.28.

Based on different field practices they wanted to see how much will be the viscosity of the binder, so that one can get around a 10-micron film thickness on the aggregate. So this 10 micron film thickness on the aggregate, so this is some sacred number that highway engineers believed in, because based on various field and laboratory studies this seemed to have really worked and to get this 10 micron film thickness they did determined using and studied what should be the viscosity?

And it started with the Saybolt Furol, came to kinematic viscosity and then came to rotational viscometer.

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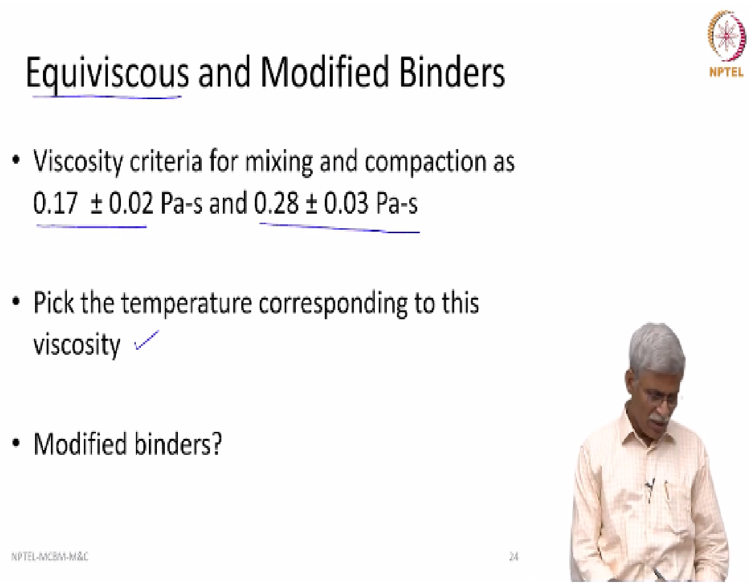

So, they called this as the Equiviscous temperature. So, viscosity criteria for mixing and compaction, is given in the following way and we need to basically pick the temperature corresponding to this viscosity, but what about the modified binders?

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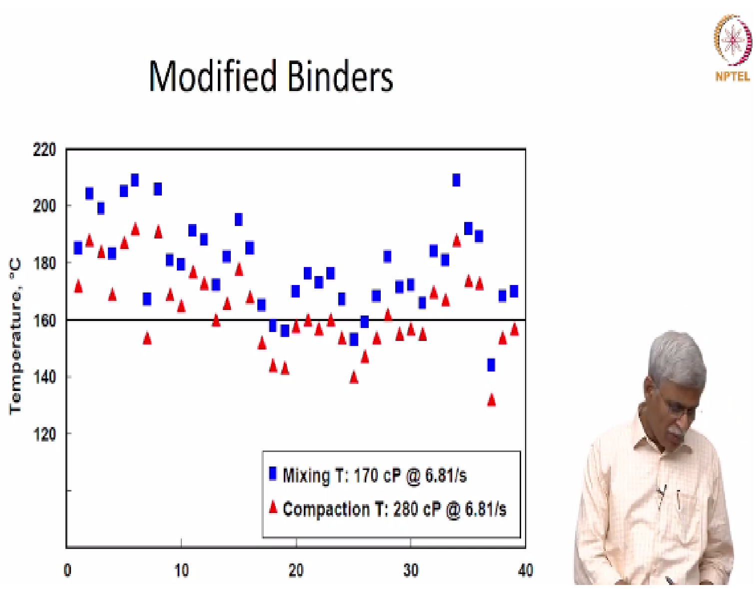

We have an issue here. So, this is a data that was available as part of an NCHRP project on finding out the mixing and compaction temperature because once originally when people started using.

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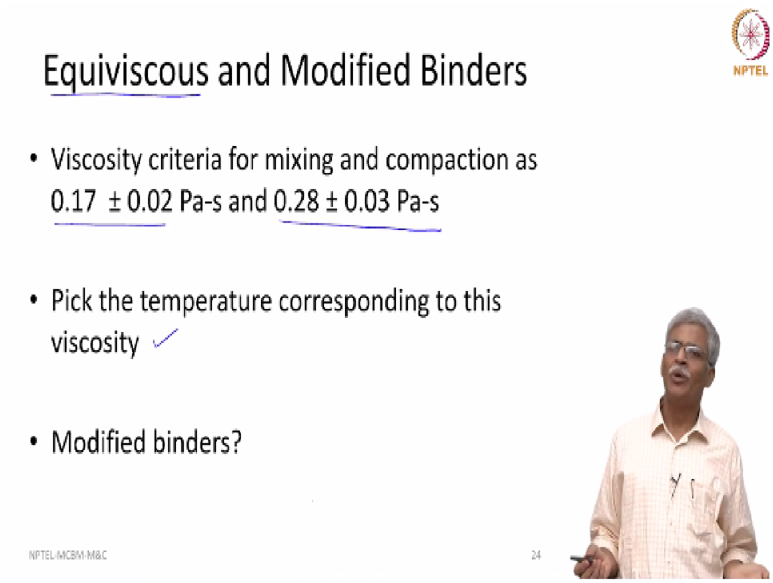

This particular viscosity was not very clear, what will be the shear rate to be used? What will be the temperature at which one can get?

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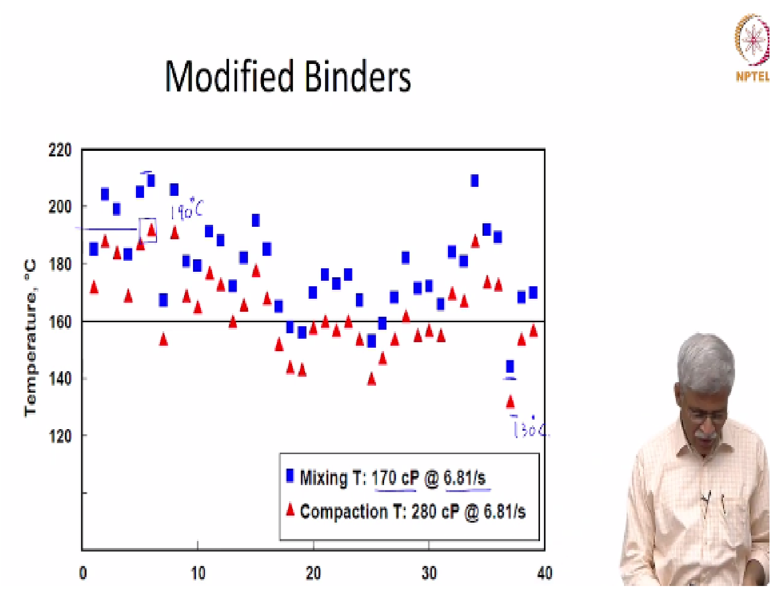

So, what you see here is a different sample, the x axis is how many number of samples, so you can actually see that temperature in the y axis. Whatever you see in the blue is the values corresponding to mixing temperature. Whatever you see in the red is the viscosity corresponding to compaction temperature. So, you can actually see that if you are looking at 170 at shear rate of 6.81.

You are having a range of binders; you can actually see the maximum is somewhere here, around 210 degree centigrade and it goes to even around close to 140 or 145 degrees centigrade. So you can have modified binders which will show the same mixing viscosity at this particular temperature in this wide range. If you are talking about the compaction temperature, again you can have around if it is the maximum value.

If you take it as around 190 degree centigrade, you can have the minimum value coming here almost close to 130 degree centigrade. So, this is the range that you are now getting here, why is this happening? Because, this particular viscosity that is prescribed is nothing but Newtonian viscosity. when for instance, a simple recipe for an elastomer will be let us say you take a VG 30 kind of a binder add 3.2 % or 3 % of SBS.

Maybe and most of the manufacturers also add some kind of a cross linker, maybe Sulphur 0.5% or 0.25%. So, you are going to see that till 160 or 170 degree centigrade the response of the material is going to be non-Newtonian. So that means depending on the shear rate the viscosity is going to change, so there is not going to be one unique viscosity that you can prescribe for any given temperature as you keep varying in the shear rate.

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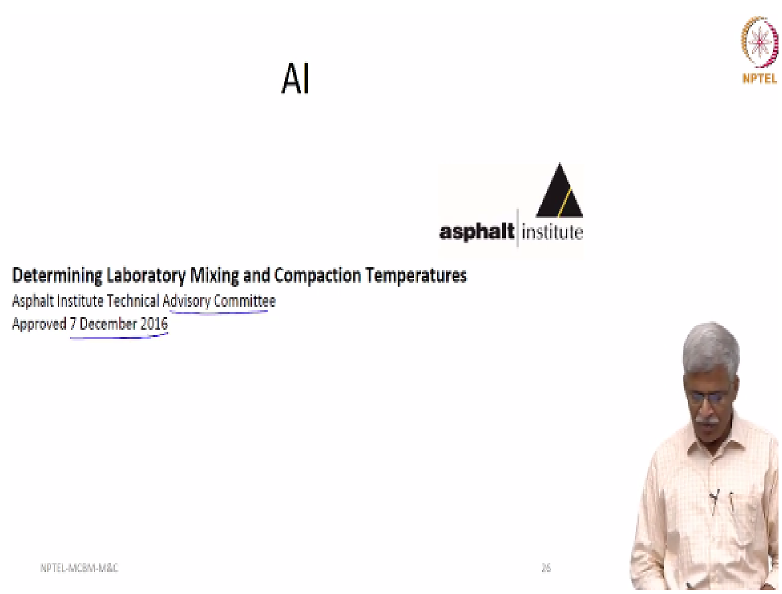

The viscosity values also will vary. So, to do to solve this problem there was some kind of an adversary committee that was appointed, and they came out with the some kind of recommendations in December 2016.

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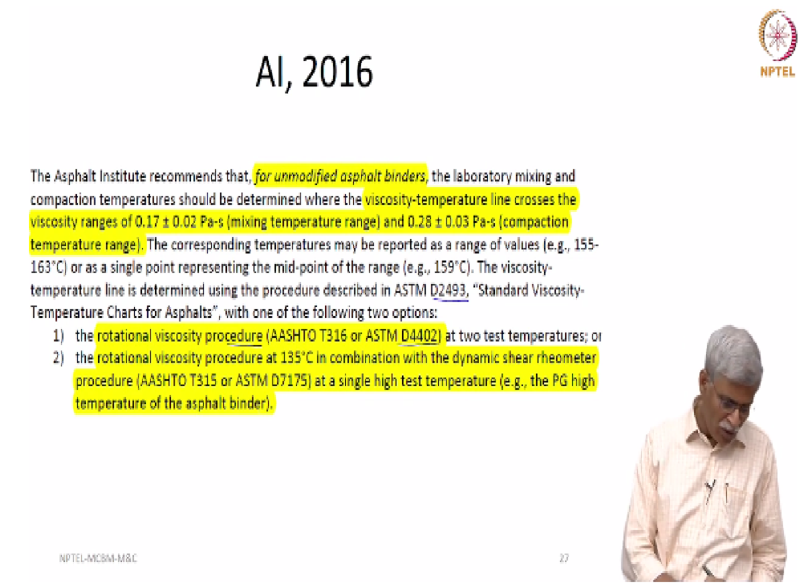

And this is what basically they have said, and I have highlighted the important thing and I am just going to read out some of this information. So, if it is going to be an unmodified binder there is no issue viscosity ranges or 0.17 + or - 0.02 Pascal second. On 0.28 + or – 0.03 Pascal second. The corresponding temperatures may be reported as a range of values say let us say 155 to 163 degrees centigrade.

Or you can say a mid-value as 159 degree centigrade and there is a ASTM standard 2493 which is used for how to draw the chart for a viscosity temperature chart with a rotational viscosity procedure that is given in ASTM D4402, or you can use dynamic shear Rheometer to find out this measurement.

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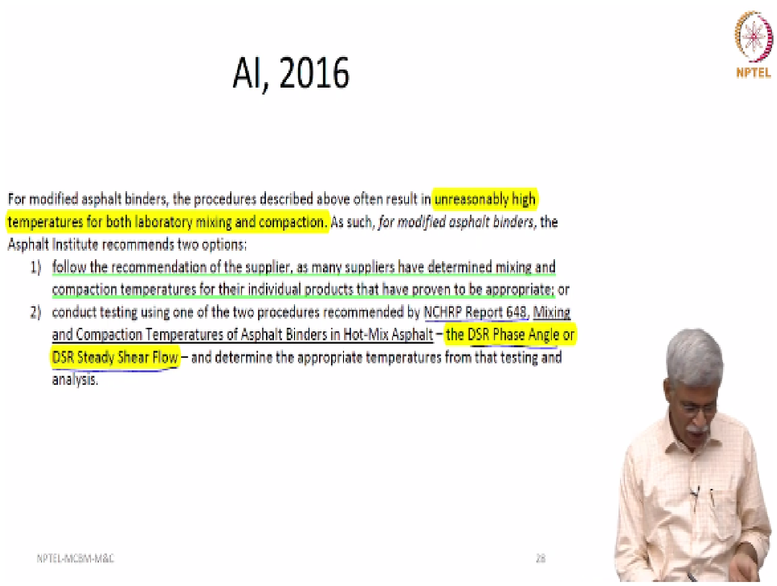

Then what really happens but when you use modified binders, whatever is the procedure that has been explained above the Asphalt institute says very clearly, it gives an unreasonably high temperature for both laboratory mixing and compaction. So, there are only two options they give you. If you need to understand this very very carefully the first option is, just ask your manufacturer, please tell me what is the mixing and compaction temperature?

And so if they are just going to tell you that, whatever you use for modified, unmodified binders just add 10, 15 degree centigrade extra to it just go ahead and use that because you have absolutely no idea about how to find. The second option is there are procedures that are written and in fact this NCHRP report 648 is only about finding out the mixing and compaction temperature of Asphalt binders in Hot-Mix Asphalt, what is really called as the DSR phase angle method or the DSR Steady Shear Flow method.

And in fact, now is the point for you to understand that even for a thing that you thought as simple as finding the mixing and compaction temperature you need to understand dynamics Shear Rheometer. So, if you have to understand and interpret the results from a dynamic Shear Rheometer, you need to know pretty good non-Newtonian fluid mechanics, viscoelastic fluids. How to analyze the data, all those things has to be found out, only then you can even determine all these things.

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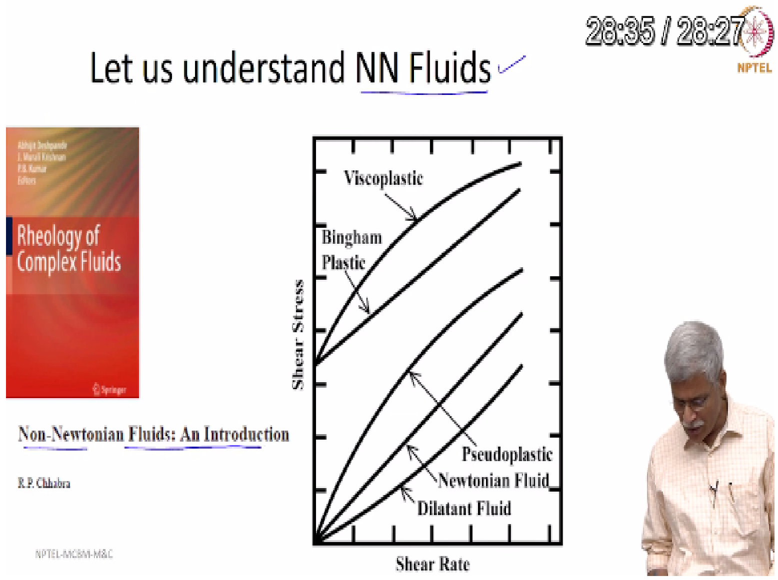

So, what we will do is we will now take a short break and try and understand what non-Newtonian fluids and the reference for this is a chapter written by Professor Chhabra an introduction.