Pavement Materials
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Lecture 31
Modified Bitumen

Hello everyone, welcome back. Today we are going to start discussing about modified bitumen. In the last lecture, if you remember we have covered discussing about the grading of bitumen.

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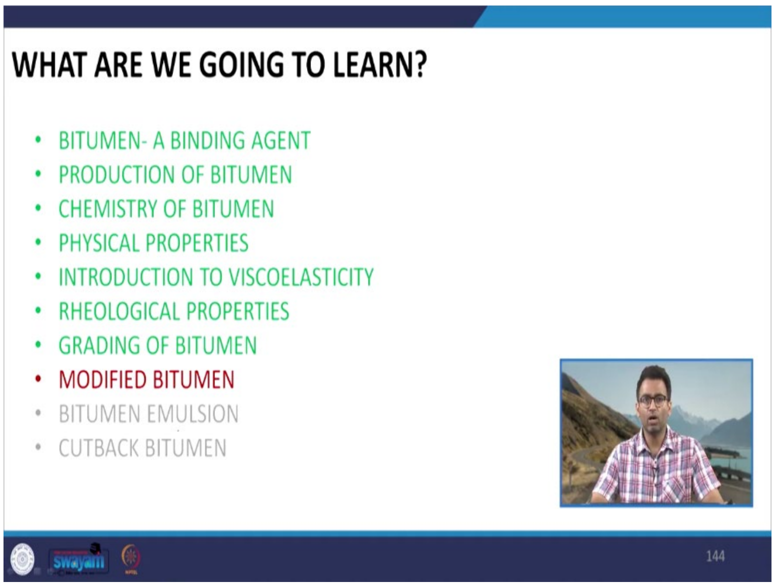

And in the last lecture specifically, we completed our discussion on grading of bitumen by discussing about the super pave grading system. So, let us start discussing about modification of bitumen today.

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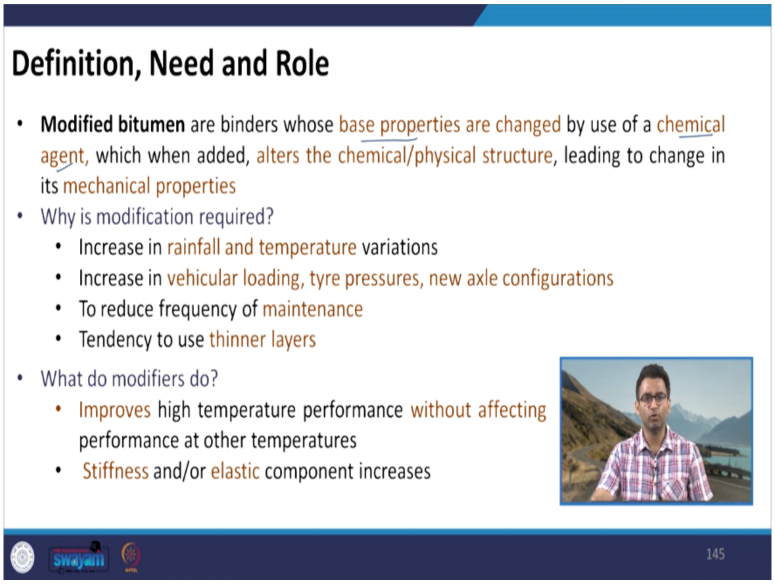

So, let us first see, what do we mean by modified bitumen, how do we define a modified asphalt binder or a modified binder or a modified bitumen. And let us also see that what is the need of modification, why do we need to modify the conventional asphalt binder and what is the role of this modification process.

So, if we want to define modified bitumen, we can define it as binders whose base properties are changed by use of chemical agent which when added alters the chemical or physical structure leading to change in its mechanical properties. So, this definition tells us that the modification process involves incorporation of some form of chemical agent to the base bitumen to the unmodified or the conventional bitumen.

And when we add these chemical agents, either they get chemically reacted with some of the components of the base asphalt binder or mostly, which we will discuss it is a form of physical interaction where the modifiers get dispersed inside the structure of the conventional bitumen and this further leads to change in its response to any given loading condition. And the idea here is to improve the response or to reduce the resistance to deformation.

So, why do we need modification? For most of the purposes conventional bitumen performs satisfactorily in the field. For example, if we talk about India, conventionally for the construction of state highways and national highways earlier we used to use VG 30. And now, there is an increase in the use of VG 40 bitumen which are conventional unmodified bitumen.

However, in extreme situations, for example, at locations where we have more rainfall, where the temperature variation is large, let us say we have locations with high temperatures or we have locations where the vehicular loading is exceptionally high and the vehicles the trucks which move have high tire pressures.

Let us say that new axle configurations have come because of which the stresses because of the vehicular loading has increased or probably there is a need to reduce the maintenance activity to save the cost incurred or also there can be a tendency of the designer to use thinner layers, which may not perform well when it is made up using conventional bitumen.

So, in all these cases, modification of bitumen is required. We tend to change the properties of the base bitumen so that it can give us satisfactory performance in these extreme situations of either environmental variations or vehicular loading or the need of change in either maintenance or design thickness of bituminous layer.

So, what do these modifiers actually do? So, these modifiers they have a tendency to improve the high temperature performance without affecting performance at other temperature. So, this is the normal tendency. So, what happens at higher temperature or when the time of loading is very high? When these type of situations occurs, so bitumen, it tends to deform and these deformations may be unrecoverable.

The tendency of unrecoverable deformation increases when the temperature is specifically high or the time of loading is very high. So, in those situations, these modifiers they will either improve let us see the elasticity, which means once the load has come and the load has moved away, the material will recover back, which means the amount of unrecoverable deformation will be low.

Most of the deformation will be recovered after the load has moved away. Other than this, the modifiers can also increase the stiffness at higher temperatures. So, if it increases the stiffness, which means the strain tolerance of this material increases, which also will help in better load distribution of the mix made up of modified binders, and it will also help to tolerate higher amount of strain before failure.

So, we have to understand this difference in increasing the stiffness and increasing the elastic component. Increasing the elastic component is more crucial, when we anticipate higher amount of strain because, ultimately what we desire when this higher amount of strain comes, and once the load moves away, the material should be able to come back to its initial position.

On the other hand, when we talk about stiffness, here we are increasing the strain tolerance, but let us say if the amount of strain is very, very high, so, here we are increasing the form of brittleness in the material. So, it may happen that when the strain will exceed the limiting value, the material can have a tendency to crack. So, however, both these attributes can be achieved through modification of the bitumen.

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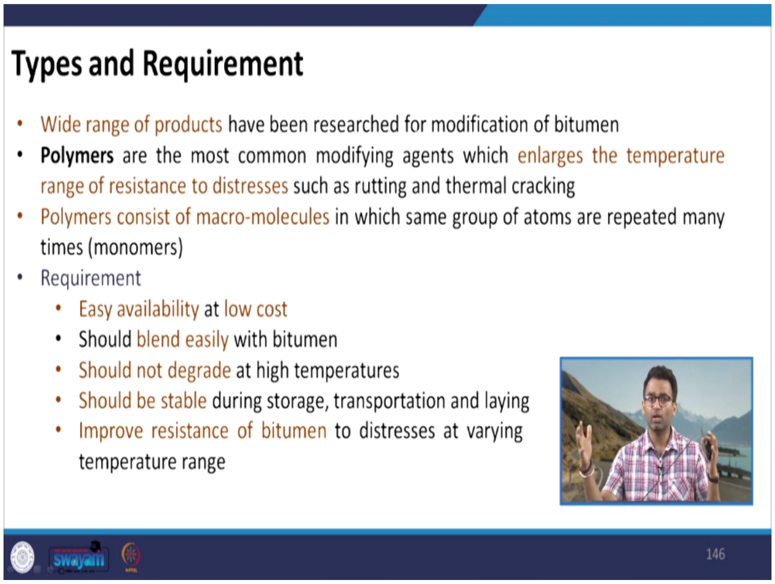

If we talk about different forms of modifiers that are available, we have a wide range of products that have been researched for modification of bitumen. And of course, we will not be discussing about all these huge range of products that are available, we will talk about the common modification techniques and the common modifiers that are being used for the purpose of manufacturing modified binders.

Out of these wide range of products a representative list of which I will be showing you in the next slide. Polymers have been found to be very successful as modifying agents and to improve the resistance of the bitumen to distresses such as rutting and thermal cracking. Polymers, if you see the definition, it consists of macromolecules in which certain group of atoms they keep on repeating and this set of molecules which is formed by this repeated group of atoms they are basically monomers and one polymer can have different monomer groups in it depending on the type of polymer.

Whatsoever be the modifier or whatsoever be the polymer we are trying to use, there are certain requirements which should be satisfied before they can be successfully incorporated for modification of bitumen. So, some of these important requirements includes that these modifiers or polymers if we are specifically talking about they should be easily available and the cost should be low.

So, usually the cost of modified binders are higher than the conventional binder and then we have to do a cost benefit analysis in the project to see that, whether we are able to reduce the maintenance caused by use of modified binders or if we are able to achieve lower thickness of the veering cores by using the modification technique.

So, definitely an important component is that the ultimate cost it may be the initial costs or the long-term cost, we should have some monetary benefit by using the modified binder and of course, it should be easily available for mass production. Also, it should have the ability to blend easily with the bitumen because as I mentioned, most of these polymers as I mentioned have physical interaction with bitumen rather than chemical interaction.

Therefore, it is important that when these polymers or any form of additives, they are blended in the bitumen, they can stay in a homogeneous manner, even during the storage which means for a longer period of time, it should not get separated from the system otherwise the advantage of modification will be lost. So, one of the important criteria is it should easily blend with the base bitumen for which we are doing the modification.

Then, these polymers when they are added or the modified binder, the final modified binder, they should not degrade at higher temperatures. Now, there are evidence It says that some of the polymers, when they are heated to very high temperature around the temperature in the mixing plant, let us say 160, 170 or 180 degrees Celsius, some of the polymers may get degraded.

So, these degraded polymers after degradation, we are not able to take out or achieve the desired benefit for which we have actually use this modifier. So, they should not degrade at high temperatures. Also, they should be stable as I mentioned during storage, transportation and laying which means, we should be able to store them without getting a separation in the face of bitumen and this polymeric system or the additive system which we are using.

The final goal for which we are using the modification is to improve the temperature range where the resistance to deformation can be increased. So, ultimately after modification what we want is a better viscoelastic response from the bitumen in terms of resistance to cracking and resistance to permanent deformation.

So, an ideal modifier or a polymer is said to be the one which increases the stiffness or resistance to permanent deformation at higher temperature without degrading the performance at intermediate and low temperature and some of the polymers are also able to improve. So, they have two side benefits at higher temperature they will increase the stiffness and at lower temperature, they can help in increasing the elasticity of the bitumen and thus will promote more resistance to fatigue cracking.

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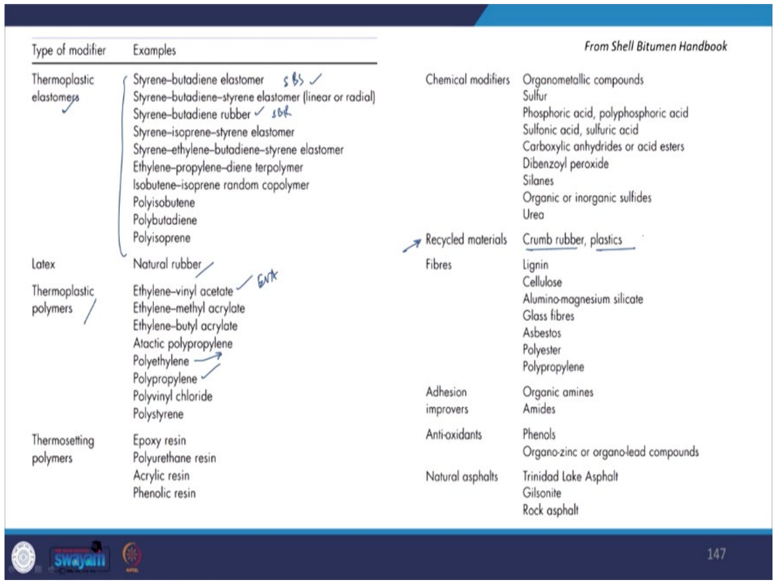

From Shell Bitumen Handbook

Type of modifier	Examples
Thermoplastic elastomers	Styrene–butadiene elastomer Styrene–butadiene–styrene elastomer (linear or radial) Styrene–butadiene rubber Styrene–isoprene–styrene elastomer Styrene–ethylene–butadiene–styrene elastomer Ethylene–propylene–diene terpolymer Isobutene–isoprene random copolymer Polyisobutene Polybutadiene Polyisoprene
Latex	Natural rubber
Thermoplastic polymers	Ethylene–vinyl acetate Ethylene–methyl acrylate Ethylene–butyl acrylate Atactic polypropylene Polyethylene Polypropylene Polyvinyl chloride Polystyrene
Thermosetting polymers	Epoxy resin Polyurethane resin Acrylic resin Phenolic resin
Chemical modifiers	Organometallic compounds Sulfur Phosphoric acid, polyphosphoric acid Sulfonic acid, sulfuric acid Carboxylic anhydrides or acid esters Dibenzoyl peroxide Silanes Organic or inorganic sulfides Urea
Recycled materials	Crumb rubber, plastics
Fibres	Lignin Cellulose Alumino-magnesium silicate Glass fibres Asbestos Polyester Polypropylene
Adhesion improvers	Organic amines Amides
Anti-oxidants	Phenols Organo-zinc or organo-lead compounds
Natural asphalts	Trinidad Lake Asphalt Gilsonite Rock asphalt

If we see the list given in the Shell Bitumen Handbook, it has outlined various modifiers that have been researched in the area of bitumen. So, you can see we have thermoplastic elastomers, now, this is a group of very successful modifiers which are used for preparation of modified bitumen. Now, of course, there are various options or types of modifiers under the thermoplastic elastomers, but out of these many modifiers some of the common in this list includes styrene-butadiene-styrene we will discuss about it.

So, we can have a styrene-butadiene-styrene elastomer, this is the most common elastomer which is used for preparation of modified bitumen. We also have styrene-butadiene-rubber SBR which is again a very common modifier or elastomer used for modification of bitumen. We also have natural rubber here, but this is not very popular for modification of bitumen rather than this we have other form of rubber which we call as crumb rubber, which we get from the waste tires that is more common for modification of bitumen.

Under the thermoplastic polymers, again, we have various options, but the more common modifiers which are typically used includes a ethylene-vinyl acetate, we call it EVA. We also have polyethylene which can be a waste polyethylene or a virgin polyethylene. So, it can both be a reclaimed polyethylene or a virgin polyethylene.

We also have a polypropylene which have been studied for modification of bitumen. Then again, we can see that we have a long list here depending on the type of modifier. For example, if you see here they have specifically mentioned about recycled materials, which I was just discussing, we have crumb rubber and we have plastics years. We also have fibers.

Now, these fibers sometimes they are used for modification of bitumen and sometimes they are also used in dry state for modification of the asphalt mix in general. We also have adhesion improvers, we have anti-stripping agents we have anti-oxidants that are used for modification of bitumen. And of course, the final objective of including these modifiers are very specific.

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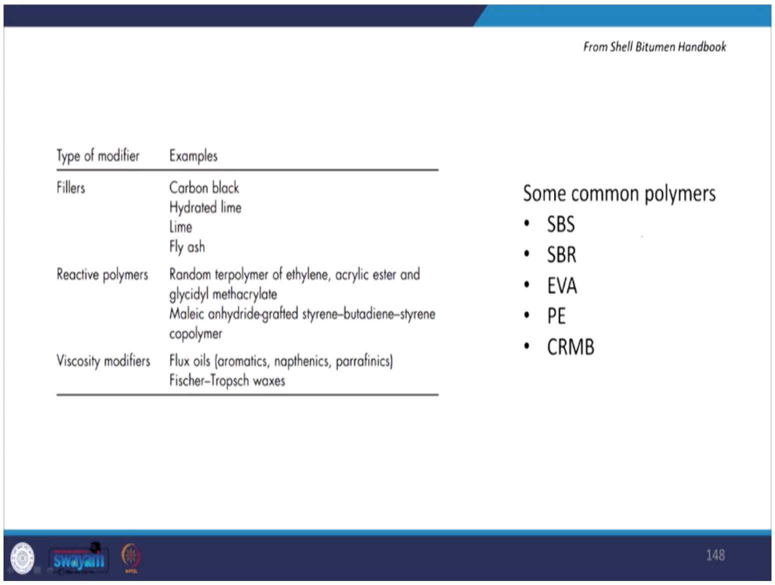

If we see that some of the common polymers as I mentioned that polymeric modification is more common, some of the common polymers they include SBS, SBR, we have EVA, we have polyethylene, we also have crumb rubber. Now, when we talk about modification, the final manufacturing task is not very straightforward and not very simple.

So, we have to understand that we are trying to mix two materials with different densities and which do not have specific chemical interaction. So, we are trying to achieve a physical interaction. And we are trying to make a structure which also remains stable. So, we have to understand that what are those factors, which will affect the dispersion of these polymers within the bitumen and will help in improving the stability of the structure.

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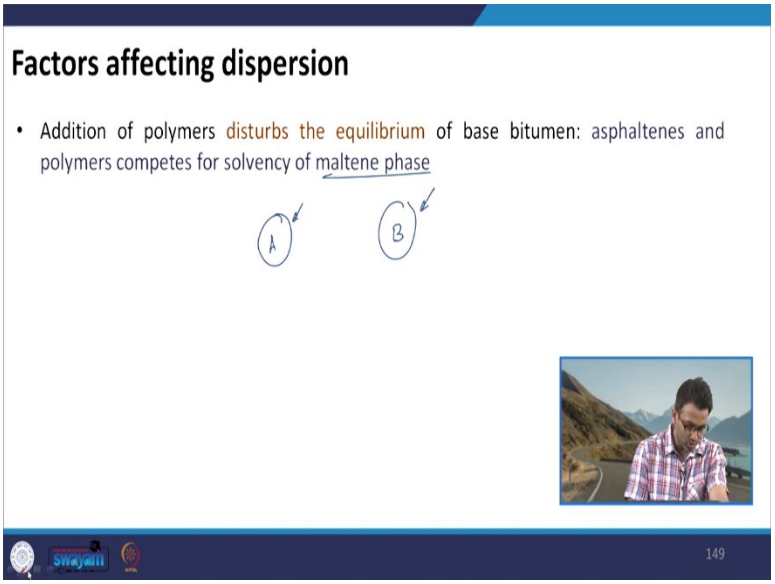

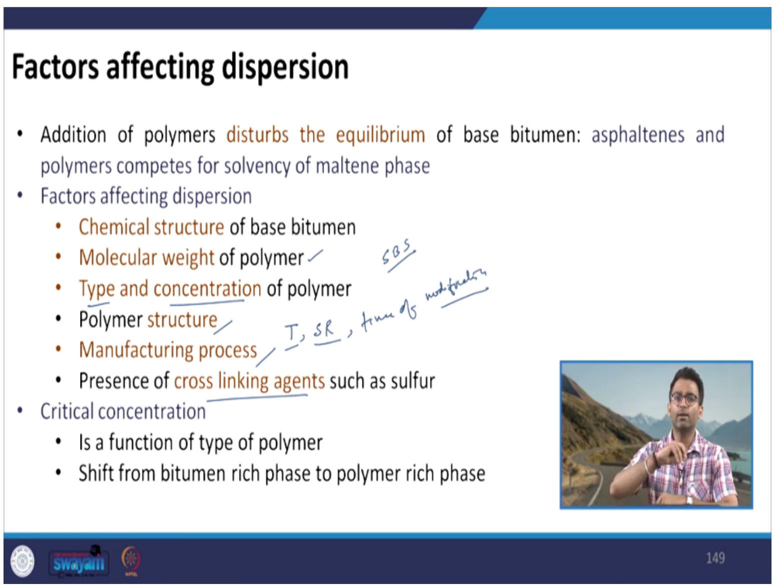

Generally, the addition of polymer it will disturb the equilibrium of the base bitumen because base bitumen is in an equilibrium state. Now, I am adding something from outside which will disturb the equilibrium. So, what typically happens let me try to explain you in this way, let us say we take the example of styrene-butadiene-styrene which is one of the elastomer.

So, when the styrene-butadiene-styrene is added in hot bitumen, the polymer and the asphaltene. Now, since we have some background of the chemistry of bitumen, we will be able to understand this. So, when the SBS enters the bitumen in heated condition, the lighter component of the bitumen, the oily fraction of the bitumen, it starts getting inside the polymer system and the polymer starts swelling.

So, there is an increase in volume. We are trying to disturb the equilibrium which asphaltene had with this system, because we have discussed that we have asphaltenes and we have maltene phase, asphaltene being polar are kept in dispersed state by the presence of raisins and by a combination of saturates and aromatic. So, this is an entire system which keeps the asphaltene molecules properly dispersed inside the bitumen phase.

Now, once this SBS which we have added it, it starts pulling off the oily fraction, the equilibrium of the asphaltene gets disturbed, because of which the modification which we are doing can have certain issues related to dispersion. So, here the asphaltenes and polymers, they compete for solvency of the maltene phase.

And depending on what is the ratio of asphaltene to maltene or the availability of the maltene phase to satisfy the demand of both asphaltenes and the polymers are available, the modification process will change from base bitumen to base bitumen. Therefore, the chemistry of base bitumen is very, very important to finally tell us about the extent of dispersion which the polymer will have in the bitumen.

So, what I am trying to say here is that let us say you have 3 percent polymer, let us say 3 percent SBS or 3 percent EVA which I want to add to the bitumen system, let us say we have two different bitumen's, bitumen A and bitumen B. So, let us say I will just write it here we have bitumen A and bitumen B.

Now, these 3 percent polymer which we want to have, can have different state of dispersion in both A and B depending on the ratio of asphaltene to maltene fraction present in A and present in B. So, depending on the chemistry of the base bitumen, the dispersion characteristics will change significantly in fact.

So, the various factors that affect dispersion includes chemical structure of the base bitumen, molecular weight of the polymer. In the same type of polymer, we can have polymers of different molecular weight, let us say we can have a SBS polymer, one SBS polymer is having linear chain, other SBS polymer is having a radial chain.

So, some polymers can have star structure. So, depending on the structure of the polymer, different type of polymer can have different molecular weights also. Now, higher will be the molecular weight of the polymer of course, higher will be the viscosity of the final bitumen, which we are going to produce, but more difficult it will be to achieve a proper dispersion of the polymer within the bitumen system.

So, molecular weight of the polymer also dictates the extent of dispersion which will occur. Of course, type and concentration of polymer, how much polymer are we going to add. Let us say we talk about elastomers or plastomers. Typically, we cannot go more than 10 percent. But of course, studies have been done by using compatibilizers, where people try to add high dosage of polymers and still they are able to keep the polymeric system stable or the modified bitumen stable in nature.

As I mentioned structure of the polymer the same polymer having different structures will have different dispersion characteristic in the base bitumen. Manufacturing process, now, this is also very important that at what temperature are we adding the modifier to the bitumen. So, temperature is one of the most important components to achieve or to dictate the dispersion of the polymer inside the bitumen structure.

In addition to temperature, another very critical aspect is the sheer rate, how fast we are mixing the polymers with the bitumen phase. Now, for some of the polymers, let us say we talk about elastomer like SBS. So, once a desired temperature has reached, so, let us say in styrene-butadiene-styrene SBS, we have polystyrene blocks and we have butadiene block. So, the glass transition temperature of this polystyrene block is around 100 degrees Celsius.

So, above 100 degrees Celsius, these the molecules will start becoming more mobile in nature, they will have a tendency to deform. So, at this point it becomes very critical that at what shear rate we are basically mixing the polymer with the base bitumen. If you talk about other forms of polymers, let us say EVA other than shear rate the temperature is more important.

Depending on the type of polymer we have to decide that which components plays a more dominant role which manufacturing process or which manufacturing parameter I would say will play a more dominant role in governing the dispersion characteristics. So, this will depend from polymer to polymer. So, ideally temperatures, shear rate and time of modification these factors control the dispersion of the polymer into the bitumen system.

Then comes presence of crosslinking agents. So, as I said it is a form of compatibilizer which helps in making a connection between bitumen and the polymer. As I said, these two have different densities. So, they do not like each other ideally, and this is a physical interaction. So, it is difficult to keep them together in a dispersed state.

So, what crosslinking agents do, I can give you an example of sulfur which is a very popular crosslinking agent specially in elastomeric modification. So, though the actual chemical reaction, if we say it in that way, is more complicated in nature, but we can try to understand it in a simpler way that when sulfur is added to the elastomer plus bitumen system, so, first the sulfur undergoes some reaction with the bitumen content in and it forms mono and polysulfide molecules.

So, these polysulfide molecules they link the SBS structure they form a cover around the SBS structure and this helps to link the bitumen with the polymer and that is how they are kept in a more stable form together. So, the presence of crosslinking agents also will affect the dispersion characteristics.

Now, if you talk about the critical concentration, as I said that some of the polymers like elastomers or plastomers, they are not typically used at concentration higher than 10 percent, some of them are even used at a concentration of around 3 to 5 percent. So, this critical concentration is essentially a function of the type of polymer we are using.

Some polymers can be properly dispersed in the base bitumen at higher dosage also, but some polymers at lower dosage. And the interesting part is some of the polymers, even at a lower dosage of around 1 to 3 to 5 percent can cause a huge change in the rheological properties of the bitumen in the viscoelastic response of the bitumen.

So, that is actually more critical and that is the final objective that we have to add so much polymer that it is in a dispersed state, and finally, we are able to achieve the desired properties for which the modification is being done. And once you start increasing the amount of polymers inside the base bitumen, so typically what is what we observe that there is a shift from bitumen rich phase to polymer rich phase.

So, if we use optical techniques like fluorescence microscopy, to understand the dispersion characteristic of the polymer inside the bitumen system, we will see that the first image which we take at 0 concentration will appear dark black. So, this indicates that this is a pure bitumen which we are seeing.

Then if we start slowly increasing the concentration let us say 1 percent, 1.5 percent, 2 percent. So, slowly we will see some lighter components coming in the bitumen structure, which indicates that polymers have started coming in. And at lower polymer dosage still the dark phase will be more dominant which means it is a bitumen rich phase, but after a critical concentration, the image will become completely lighter in nature, indicating that this phase is more of a polymer rich phase. So, based on these studies, we have to identify that at which critical concentration an interlocking phase can be achieved, where the bitumen and the polymer they can be kept in a stable form.

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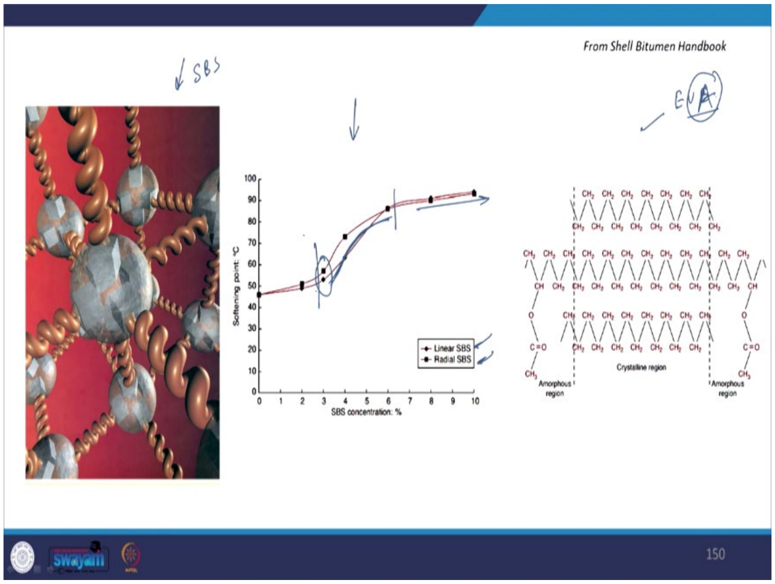

These are some pictures explaining some of the common modifiers for example, this is an animated description of SBS where they show that we have polystyrene blocks and we have a mid-block which is a butadiene segment. Here the polystyrene blocks they impart the toughness to the structure they provide the stiffness to the structure. Whereas, the butadiene segment they provides the more of the rubbery properties to the SBS system.

This is again a structure of EVA ethylene-vinyl acetate, where we have the crystalline region which is the ethylene segments and then we have vinyl acetate segments, which are the amorphous region or the region having more rubbery behavior. And if the vinyl acetate content is less in EVA, then EVA almost behaves like a polyethylene which is a P segment.

This figure shows that how the property will change and how we will see through physical properties that there is a change from bitumen rich phase to polymeric rich phase and this is a typical S curve which is obtained. This example shows linear and radial SBS. And then you can see that after a critical concentration, there is a form of shift here. And after that we achieve something like plateau after a particular point of time. So, this will also help us to understand or to evaluate the critical concentration of the polymer, which can be used for the modification of the bitumen.

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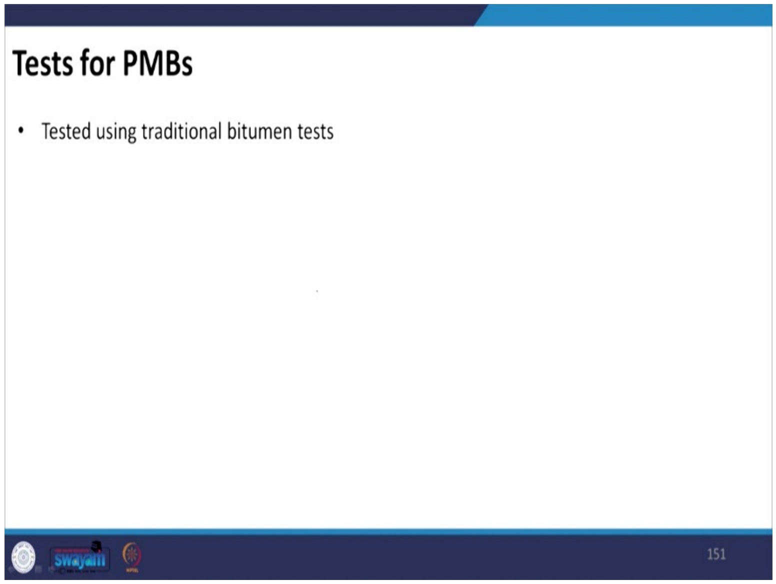

Now, coming to the tests on PMBs or polymer modified bitumen. So, most of the traditional tests which we have discussed in our previous lecture, before we complete our discussion on the test, I just wanted to show you an interesting simple experiment here by which we can understand that what a polymer modified bitumen is and how it can be different from a normal conventional and modified bitumen.

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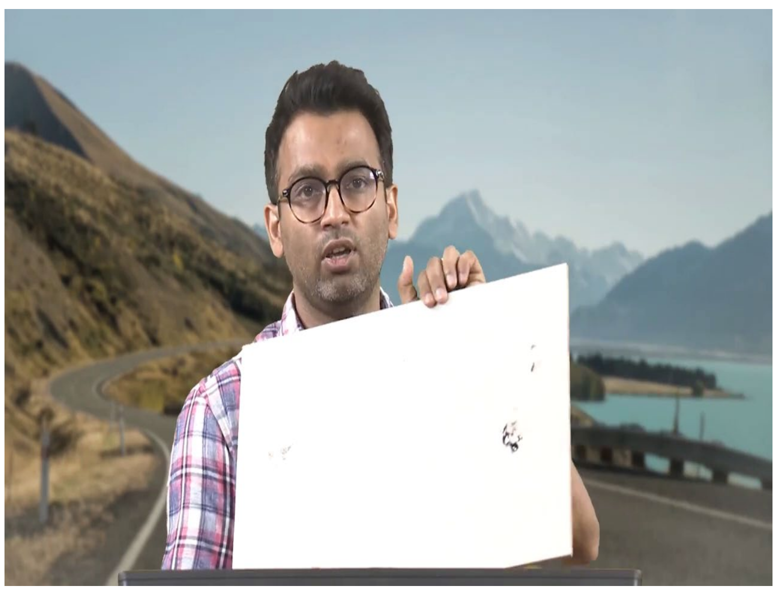

So, here I have a slab with me, if you can see here and I have applied a small drop of glycerin. So, there is a small layer of glycerin here, so, that the bitumen does not stick in the slab and the friction between the bitumen and the slab can be minimized. So, we can understand what we are trying to understand.

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So, I have two bitumen samples here, this bitumen sample is a conventional VG 30 bitumen taken from the laboratory. And this is an elastomeric polymer modified bitumen with me they are almost of same weight here. And as we discussed, we anticipate more elastic behavior from a elastomeric modified binder.

So, what I am going to do, I am just going to stretch both the bitumen and I will just keep it on the slab and after we complete discussing about the test, just visually we will try to see what has happened to the sample and if we can just understand the modification process. So, I have just rolled it so that they become of same size.

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And then what I am trying to do here and just stretching this to some distance, I am just stretching this to some distance, and I am keeping it on the slab. The same I am doing with this I am stretching it almost to the same distance alright. Well I have to apply more pressure because this is a modified bitumen same distance and again I am keeping it on the slab.

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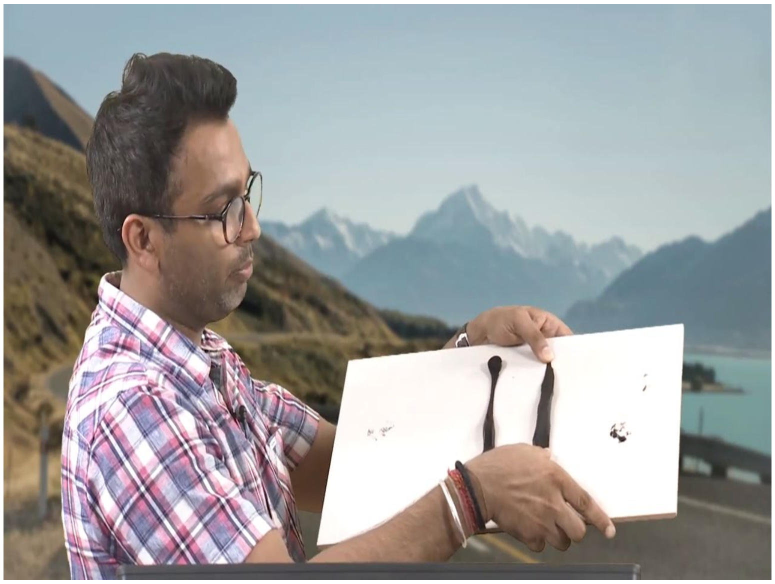

So, you see I am trying to stretch the one which I am not holding is the conventional bitumen and this is the modified bitumen. As soon as I leave this you can see that it tries to contract and it tries to recover. Here, you can see, are initially I stretch to the same length, but now the length is reduced. So, I am trying to keep it here for some time.

So, that we will give an opportunity for recovery to both the bitumen, and we will see how much recovery we have obtained. So, talking about the test. So, most of the traditional test conventional test we have discussed previously also applies for testing polymer modified bitumen. In addition to the conventional test, there are some special or additional tests which can be performed specifically on polymer modified bitumen.

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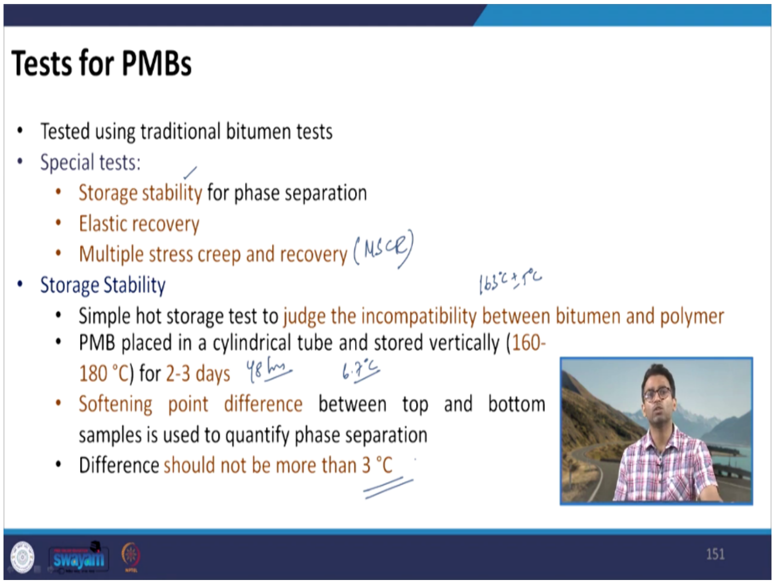

One of the most important tests includes storage stability test, which is done to assess the phase separation. As we have discussed that there can be a tendency that the polymer phase can get separated from the bitumen phase, if the compatibility between the bitumen and the polymer is not proper. So, we want to quantify that and here we can use the storage stability test.

Another important test is the elastic recovery test, which tells us about the extent of modification. Of course, this is an indirect measure of the extent of modification, but again, this is one of the tests. Then, we have multiple stress creep and recovery test about which we have already discussed. So, this I will not cover in detail in this particular presentation, but these are some tests which are typically carried out on modified bitumen.

Talking about the storage stability test about which we have not discussed previously, this is a simple hot storage test, which we can use to judge the incompatibility between the bitumen and the polymer system. So, here what is done that we take an aluminum tube, so, this aluminum tube is about 1 inch by 5 inch in size. So, we take a cylindrical aluminum tube something like this.

And then we place a bitumen sample, we will put the polymer modified bitumen sample into the aluminum tube and we will seal the aluminum tube and will keep this aluminum tube in vertical position around 2 to 3 days at a temperature of around 160 to 180 degrees Celsius. So, typically the temperature which is taken is 163 degrees Celsius plus minus 5 degrees Celsius.

And the time which is taken is around 48 hours typically. So, we will keep it at this temperature for this particular time in the vertical position, then what we will do will take out the sample, we will cool it at around 6.7 degrees Celsius, we will freeze the sample then we will take out the sample and then we will cut this sample in three halves, we will cut the sample in three halves.

So, this aluminum tube is filled with polymer modified bitumen, which I am cutting in three halves. So, I will discard the middle portion and I will take the top portion and the bottom portion, I will extract bitumen out of it and I will do a softening point test for the top portion and for the bottom portion.

And then in order to ensure that phase separation has not taken place, then the difference in softening point from the bitumen sample taken from the top and bottom should not typically be more than 3 degrees Celsius. So, this is a test to ensure that phase separation has not taken place.

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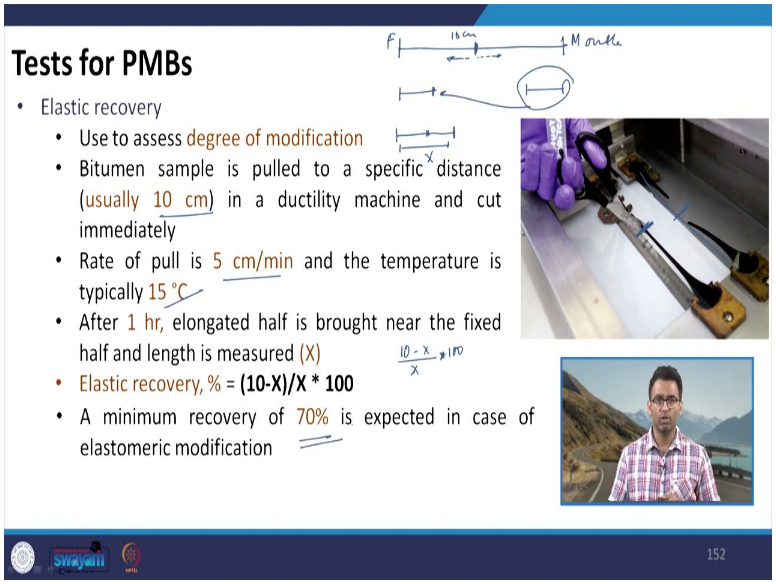

Then we have elastic recovery test. So, this is used to assess the degree of modification. So, here what we do, this is almost like a ductility test which we have discussed previously. So, we have again a briquette here which is filled with bitumen and then we will stretch the briquette at a specific rate and this rate is usually 5 centimeter per minute, but here the test temperature is typically 15 degrees Celsius.

So, we will pull this at 15 degrees Celsius at a rate of 5 centimeter per minute. And immediately after pulling it to a distance of 10 centimeter we will cut it. So, you see they have pulled it to 10 centimeter and then they are cutting it from the middle, we will just cut it from the middle. And then we will keep the sample inside the water bath for 1 hour.

So, after 1 hour, of course, since this is a polymer, if this is a polymer modified bitumen after 1 hour we will see that this cut portion has again tried to recover. So, what we will do we will bring this end closer to this end, so we will bring the elongated half near the fixed half and then we will measure the length.

So, just to explain you let us say this is what we pulled to 10-centimeter, we have made a cut here, and let us say that this is the fixed end and this is the movable end. So, after we have made the cut, the sample will try to recover or will try to go back to its initial position. So, let us say that after 1 hour, this has come here, and the sample from this side has come here. Then what we will do, we will bring this half closer to this half.

So, what we are doing we are bringing this here and then we are bringing this half here and then we are again measuring this particular distance which is X. So, elastic recovery is the amount of recovery which has taken place and of course, it can be quantified using the formula $\frac{10-X}{X} \times 100$. And specifications which we have in India especially, it requires that the minimum recovery should be at least 70 percent in case of elastomeric modification.

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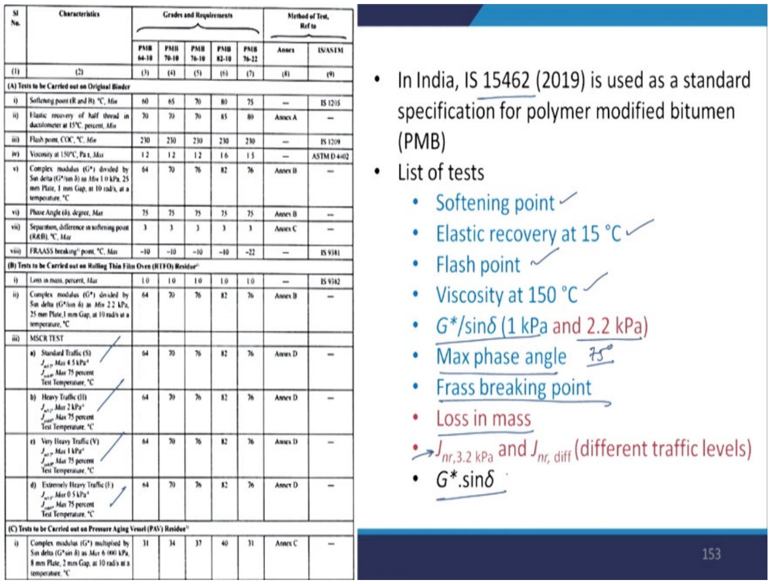

Sl No.	Characteristics	Grades and Requirements					Method of Test, Ref to	
		PMB 64-10	PMB 70-10	PMB 76-10	PMB 82-10	PMB 76-22	Annex	IS/ASTM
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(A) Tests to be Carried out on Original Binder								
i)	Softening point (R and B), °C, *Min*	60	65	70	80	75	—	IS 1205
ii)	Elastic recovery of half thread in ductilometer at 15°C, percent, *Min*	70	70	70	85	80	Annex A	—
iii)	Flash point, COC, °C, *Min*	230	230	230	230	230	—	IS 1209
iv)	Viscosity at 150°C, Pa s, *Max*	1.2	1.2	1.2	1.6	1.5	—	ASTM D 4402
v)	Complex modulus (G*) divided by Sin delta (G*/sin δ) as *Min* 1.0 kPa, 25 mm Plate, 1 mm Gap, at 10 rad/s, at a temperature, °C	64	70	76	82	76	Annex B	—
vi)	Phase Angle (δ), degree, *Max*	75	75	75	75	75	Annex B	—
vii)	Separation, difference in softening point (R&B), °C, *Max*	3	3	3	3	3	Annex C	—
viii)	FRAASS breaking point, °C, *Max*	-10	-10	-10	-10	-22	—	IS 9381
(B) Tests to be Carried out on Rolling Thin Film Oven (RTFO) Residue								
i)	Loss in mass, percent, *Max*	1.0	1.0	1.0	1.0	1.0	—	IS 9382
ii)	Complex modulus (G*) divided by Sin delta (G*/sin δ) as *Min* 2.2 kPa, 25 mm Plate, 1 mm Gap, at 10 rad/s at a temperature, °C	64	70	76	82	76	Annex B	—
iii)	MSCR TEST							
	a) Standard Traffic (S) $J_{nr3.2}$, *Max* 4.5 kPa⁻¹ J_{nrdiff}, *Max* 75 percent Test Temperature, °C	64	70	76	82	76	Annex D	—
	b) Heavy Traffic (H) $J_{nr3.2}$, *Max* 2 kPa⁻¹ J_{nrdiff}, *Max* 75 percent Test Temperature, °C	64	70	76	82	76	Annex D	—
	c) Very Heavy Traffic (V) $J_{nr3.2}$, *Max* 1 kPa⁻¹ J_{nrdiff}, *Max* 75 percent Test Temperature, °C	64	70	76	82	76	Annex D	—
	d) Extremely Heavy Traffic (E) $J_{nr3.2}$, *Max* 0.5 kPa⁻¹ J_{nrdiff}, *Max* 75 percent Test Temperature, °C	64	70	76	82	76	Annex D	—
(C) Tests to be Carried out on Pressure Aging Vessel (PAV) Residue								
i)	Complex modulus (G*) multiplied by Sin delta (G*sin δ) as *Max* 6 000 kPa, 8 mm Plate, 2 mm Gap, at 10 rad/s at a temperature, °C	31	34	37	40	31	Annex C	—

So, this is again a snapshot from IS 15462 which we use in India as a specification for polymer modified bitumen. Most of the test here we have discussed previously and again some of the tests we have discussed today. So, if you see the list of test on unaged condition, we have softening point test, elastic recovery test, flash point viscosity at 150 degrees Celsius, G*/sinδ which corresponding to 1 kPa we have to find out the temperature, maximum phase angle.

So, it says that phase angle should not exceed 75 degrees. Then frass breaking point which is for low temperature performance. On short term aged condition after doing RTFO aging, we have to find out the temperature corresponding to G*/sinδ at the rate 2.2 kPa, then we have to also assess the loss in mass.

And similar to what we saw in PG^+ specification, here also the grading of the binder, this is almost inspired from a similar PG grading system where we have to ensure that the Jnr at 3.2 kPa the unrecoverable creep compliance at 3.2 kPa does not exceed a particular value and this value depends on the traffic level. So, here also we have standard traffic, heavy traffic, very heavy traffic and extremely heavy traffic.

And here too the Jnr difference which tells us about the stress susceptibility should not be more than 75 percent. And after PAV aging, the value of G*.sinδ should not be more than 6000 kPa. So, almost similar specification about which we have discussed in our previous presentations. So, this is about IS 15462. And with this we come to the end of this lecture and before we conclude here today, let me show you what has happened to our sample.

(Refer Slide Time: 37:53)

If you can see here. So, you can see that the conventional bitumen which was stressed is still in that position. I do not think that a very little recovery might have happened, I anticipate that the temperature of this room is around 26 degrees Celsius, 25-26 degrees Celsius now, and you can see that the stretched polymer modified bitumen sample has recovered almost I think more than 90 percent here, if I remember correctly the shape from where we started.

So, this tells us that how polymer modified bitumen has better recovery or better resistance to deformation or improve response to deformation in comparison to the unmodified or conventional bitumen. So, with this, we conclude here today. And in the next lecture, we will talk about emulsion and cut back bitumen. After completing which we will be completing our module 3 in this course of pavement materials. Thank you.