Acoustic Materials and Metamaterials
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Lecture - 15
Sound Absorbing Materials

So, welcome to the lecture 15. This is the last lecture for this week and in today's lecture we will begin our discussion on Sound Absorbing Materials. So, these are this is the third type of acoustic material and probably the most common one.

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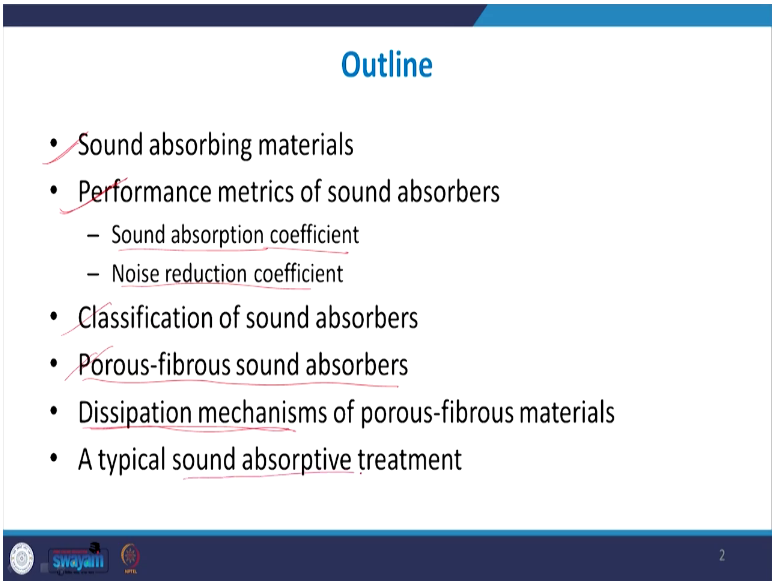

So, the outline for this course is we will discuss about what is sound absorbing material. Then the various ways to measure the performance of sound absorbers. These are the metrics that we will study this is sound absorption coefficient and noise reduction coefficient and then we will begin with classifying the sound absorbers and then there are different types of sound absorbers.

So, we will we will start the discussion with our first kind of sound absorbers which is the porous fibrous sound absorbers. And we will see what mechanism is used for dissipating noise in such porous fibrous sound absorbers and the typical way of treatment with this absorber.

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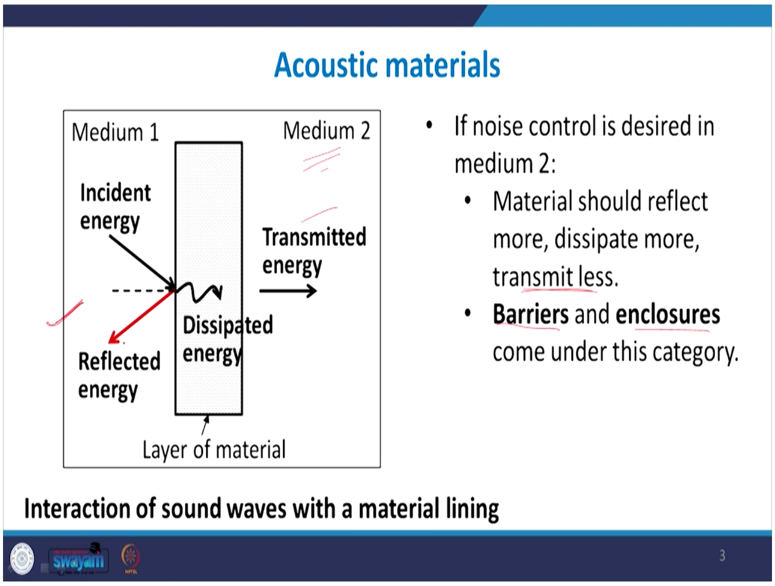

So, let us begin. So, acoustic materials in the very beginning lecture of this. I had described to you that when a layer of materials is placed and some target sound is incident on it. So, this is the schematic. So, usually so incident energies incident on the layer of material some portion gets reflected, some gets transmitted and some of it can also get dissipated while passing through the material.

So, when some when the noise control is desired only in medium 2 then the best way to do is using some barrier material or blocking material where it is designed to reflect more and transmit less. So, most of it gets reflected away. So, that is a blocking material.

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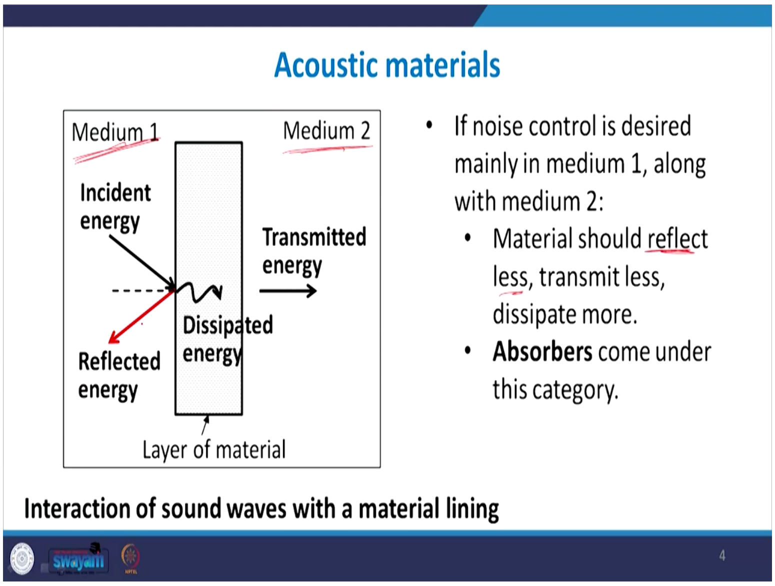

However, when we need to desire noise control primarily in medium 1 and also in medium 2 in that case we need a more sophisticated material that can do both the job. So, here the material needs to reflect less. So, it should allow most of the sound to enter into the material and then when the sound enters into the material then it as passing through the material it can get dissipated as heat.

So, the way the material will be designed is that it can offer a lot of resistance to the flow of sound wave. And therefore most of the sound wave energy can then be lost within the material as heat. So, both reflected wave and transmitted wave can be reduced and that is where the absorbers come into place. So, they are very good for there are more efficient way of noise control.

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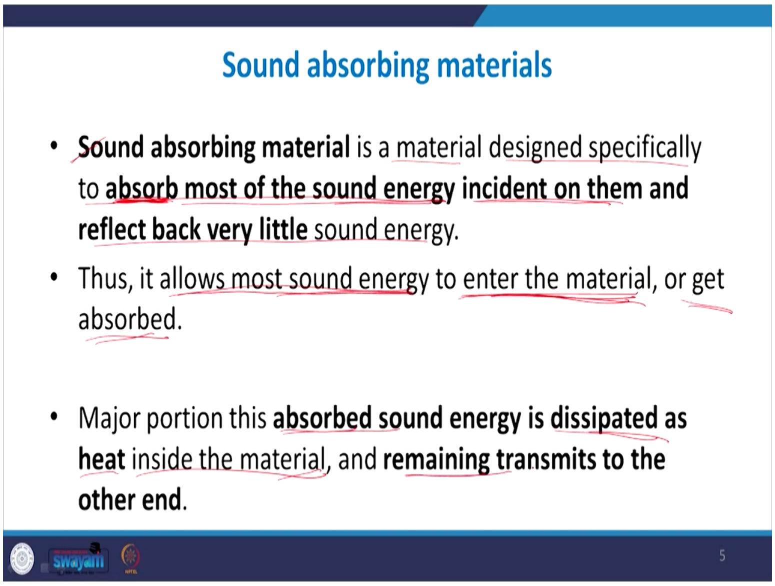

So, how they defined sound absorbing materials. So, this is typically a material that is designed specifically to absorb most of the sound energy that is incident on them and reflect back very little sound energy. So, as I said that reflection should be controlled. So, to control the reflection what is the primary criteria that the material should be able to allow the sound to enter.

If the sound wave cannot pass through the material then obviously, this means that it will get deflected and deflection will be more. So, the first criteria of such material is that it should be able to be the way it is designed it should be able to absorb the sound and by the means by the meaning of absorption we mean that the energy that is incident is able to enter into the material. So, it allows most of these sound energy to enter inside the material or simply get absorbed into the material and when.

So, the so in that case even if we have a window in a room. So, that will also allow all the sound waves to pass through it nothing will get deflected. But that would not that would not be a sophisticated sound absorbing material why because although it is a reducing the reflection, but it is maximizing the transmission. Everything is getting transmitted and the way these absorbers work is that they work in midway. They reflect they allow everything to enter inside it and then the dissipation takes place inside the material itself and then very less amount of transmitted wave gets out of the material.

So, whatever sound energy that is entering the material most of it then gets dissipated as heat inside the material while passing through it and then the remaining one gets transmitted to the other end.

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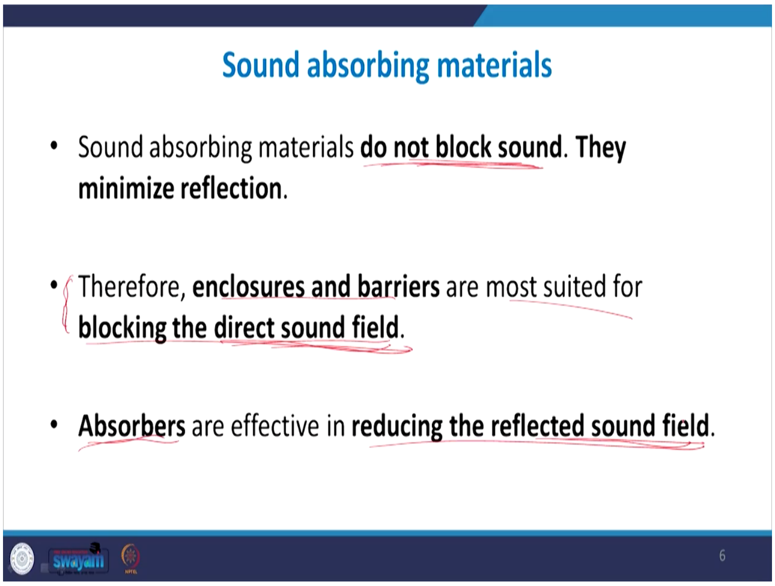

So, one thing that need that needs to be here clear is that these materials are not blocking materials. So, they are not blocking the sound per se because they are doing the opposite. A blocking material is something which does not allow the sound waves to pass through it. This material is actually allowing the sound waves to enter. In fact, the more sound waves enter the less will be the reflection. So, on the exposed surface most of the sound is actually entering into the material. So, they are not actually blocking it there they are doing the other way round.

So, they do not block the sound. So, most of the sound is actually enters into the material, but when it enters then dissipation can take place. Now as you know that enclosures and barriers they are more suited for blocking the direct sound field. This discussion was done in our previous lectures why direct sound field absorbers are most effective in reducing this reflected sound field because their purpose is to minimize the reflection.

And if we need and for many high end treatments we combine the absorbing material with a blocking material. So, we saw in the case of an enclosure that for a personnel enclosure we have a hard material to block the sound and then we also have a lining at the other end which is of a absorbing material. So, both reflection is controlled and transmission is controlled in that way.

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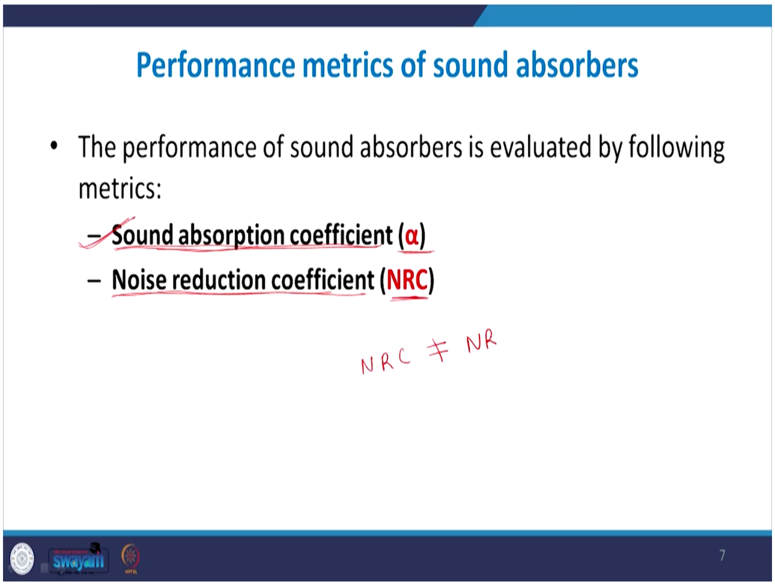

So, they can be combined together. Now the way the performance of these sound absorbers is measured is using 2 different metrics. We have sound absorption coefficient this is I think one of the most occurring metric in our cost. We have already discussed about it 3 times before and the other metric is the noise reduction coefficient on NRC. Now please remember here that this NRC is not equal to NR.

So, we had already discussed a metric called noise reduction which is what is the SPL before passing the material minus the SPL after passing the material, but that was the noise reduction, but noise reduction coefficient is completely a different thing altogether which we will discuss today.

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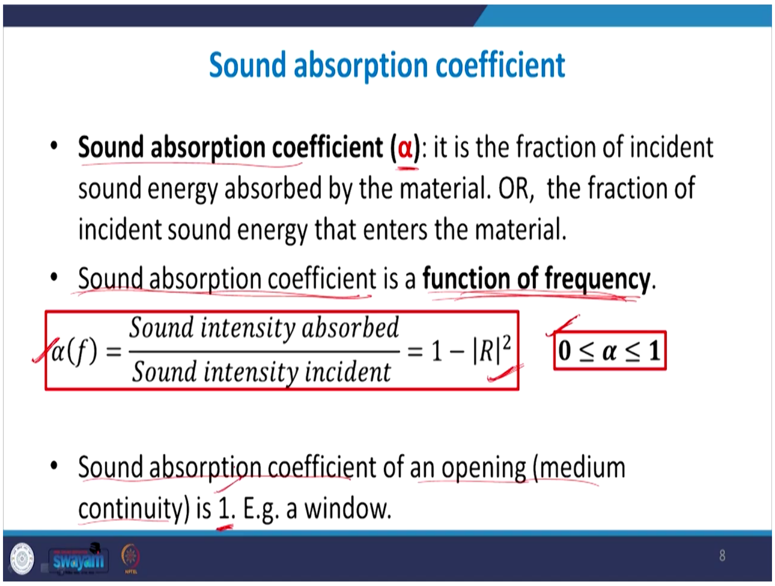

To restate what is sound absorption coefficient is denoted by the letter alpha. So, this is the fraction of incident energy that is being absorbed by the material or to put it in other words what is the fraction of incident energy that is actually entering the material. So, let us say we have a material and the total intensity incident on it this 1 and out of that 0.9 of 0.9 or simply

90 percent of the incident intensity is actually able to enter inside the material the material does not block it then in that case the absorb the absorption will become 0.9 and so on.

Now sound absorption coefficient just like other metrics it is a function of frequency. So, this alpha can also be written as alpha f which is alpha the function of frequency which is sound intensity absorbed by sound intensity incident which we have already seen is equal to 1 minus mod R square which is 1 minus the pressure reflection coefficient square. So, we have discussed about this metric in the very first lecture on acoustic materials as well as on the lecture on sound propagation at medium boundaries.

And this is now we are restating this metric again and again. Now by definition as you see it is whatever sound it is the fraction of the incident intensity that is being absorbed or that is entering the material. So, obviously by definition if only 1 Watts per meter square is available. It cannot absorb more than that because that is the highest amount of intensity that is available to it which is the intensity incident on it.

So, by definition itself this has to be a value which is less than 1. So, alpha is usually a value between 0 to 1 and it gives you the fraction of energy being absorbed. So, what will be the sound absorption coefficient of a window in a room? Window in a room is also acting as a media as a particular surface.

So, in that case because the impedance just inside of the window it is a air and just outside the window also it is a air. So, it is a medium continuity and there will be no reflections the sound will propagate through treating this as a continuous homogeneous medium. So, window is like. So, the sound absorption coefficient for this window by the definition is going to be 1.

So, whenever there is a medium continuity there is no blockage between the medium then the absorption is always fully 1 or the sound wave propagates to uniformly. But that does not mean that is a good absorber because it is allowing everything to pass through. So, the transmission coefficient in that case will become one which is not desired.

So, we both need to reduce the reflection and transmission. Now we have defined this alpha here. So, as you see this is just mentioned as a fraction and intensity is what. It is the energy incident per meter square. So, obviously by definition this alpha is simply intensity that is incident. It is the intensity absorbed per meter square sorry the energy absorbed per meter square divided by the energy absorbed per the energy incident per meter square.

So, it is a ratio of the intensities and intensities are the energy per time per unit time or simply power per meter square. So, it is power absorbed per meter square divided by power incident per meter square.

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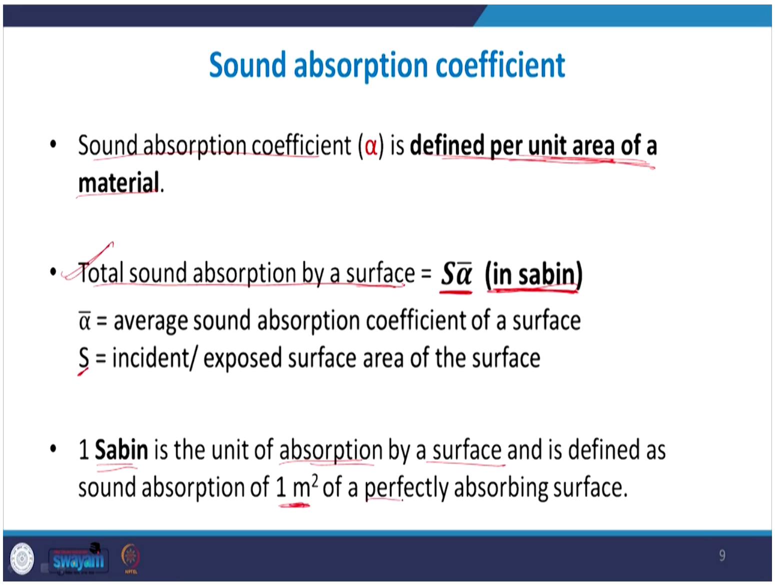

So, alpha comes out to be per unit area of the material. So, we have whenever we have a sample and we are measuring the sound absorption coefficient value for a particular material sample. So, by definition this alpha gives us the value of what is the absorption per meter square surface area of the material that is exposed to the incident intensity. So, if this is per unit surface area of the material then if suppose we have a surface of surface area S.

So, the total area of the surface is S which is actually exposed to the incident wave then the total sound absorption in that case will become whatever is the average sound absorption coefficient multiplied by the surface area. So, this will be the expression for the total sound absorption that takes place through a particular surface we multiply the surface area into whatever is the average absorption coefficient of that surface area and the units for that is sabin.

So, this is the unit for the absorption by a surface and it is defined as what is the sound absorption of 1 meter square of a perfectly absorbing surface.

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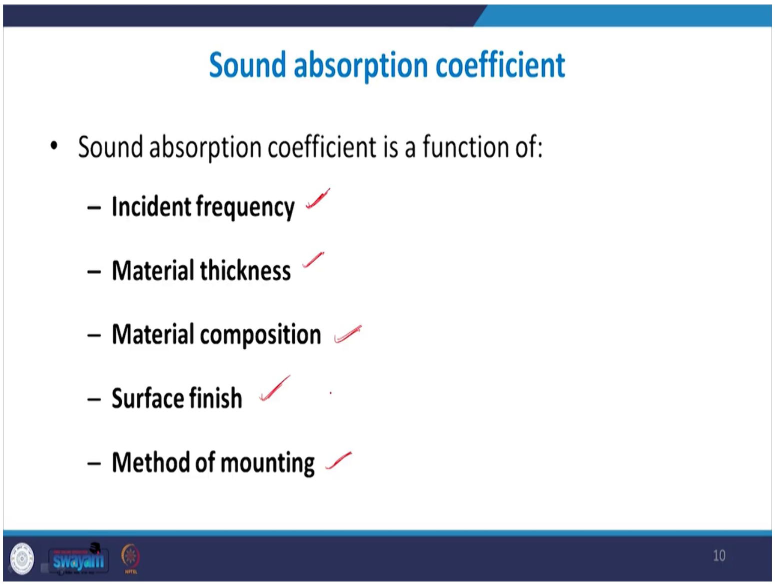

So, the alpha value now depends on many factors. It depends upon what is the incident frequency. It also depends on the material thickness. So, when we were discussing about the alpha value for the particular material then nothing was mentioned about what is the surface area of the material or the thickness. So, now we know that when alpha value is mentioned that means, that it is considered for a unit surface area of a material, but what about the thickness.

So, thickness also is fixed because alpha depends on the material thickness also. So, when alpha value is given for any material or any graph you see of alpha usually the thickness of the material is also mentioned along with it. So, it depends on frequency, it depends on the thickness of material. It also depends upon what material we are using what type of material it is, the surface finish of the material and what is the method by which this material has been put together.

So, we will discuss these particular factors one by one individually in depth when we discuss about porous fibrous sound absorbers. So, for now let us just see these factors and we will discuss about them as we start discussion on porous fibrous absorbers. So, as I had said there are 2 main metrics that are used for evaluating the performance of a sound absorber. So, first is alpha value that is the sound absorption coefficient. The second one is the noise reduction coefficient NRC.

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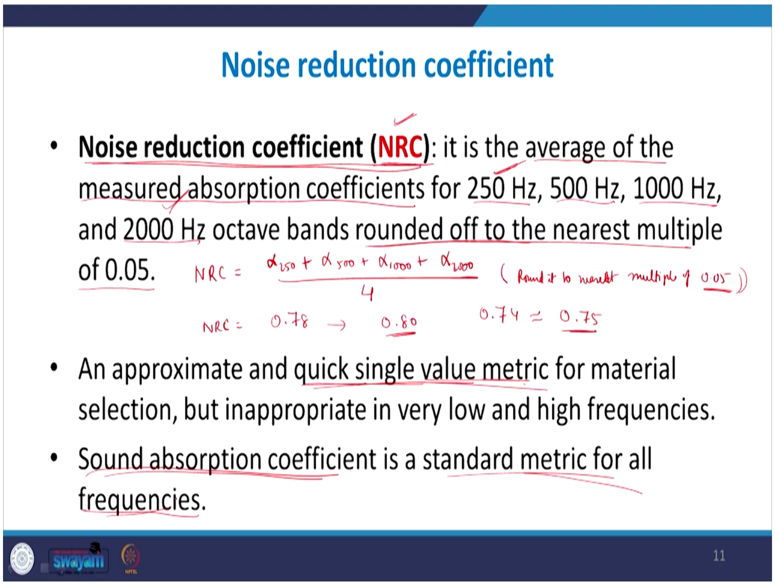

So, this NRC is defined as what is the average of the measured absorption coefficients for 250 Hertz 500 Hertz 100 1,000 Hertz and 2,000 Hertz octave bands and then it is the value that is obtained is rounded off to the nearest multiple of 0.05. So, NRC can be written as the alpha or the absorption coefficient at 250 less the absorption coefficient at 500 plus absorption coefficient at 1,000 and 2,000 and the average of this value.

So, it is a single value measure and then whatever we get we rounded to nearest multiple of 0.05. So, let us say if you are getting some value as 0.78 then it can be rounded off to 0.80. Similarly a 0.74 value can be rounded off to 0.75 and so on. So, it should be a multiple of this. So, that is the way it is defined. So, as you see here that NRC is a single value whereas, alpha is a set of large it is a large set of values for every particular frequency.

So, depending upon how many frequencies or how what is the sampling frequency we are taking or how many observations we are taking we can have a range of values of alpha for every individual frequency, but NRC becomes just a single value measure. So, because of this nrc is very useful for a quick glance over what kind of material it is. So, it is a very; it is a very quick single value metric and can be quickly used to glance through various materials. So, some designer has come or we have gone to some plan to industry and there we have a selection of 200 different materials.

So, going through the alpha value for every frequency of this material will obviously be very tiresome. So, quickly we can just see that these are the most sensitive frequency ranges 250 to 2,000. So, within that what is the average value. So, with a single value you can define and rank the various materials, but obviously more in depth analysis is not possible with this. So, specially if we have to find what is the absorption at very low frequencies or at high frequencies then NRC cannot be used because it is only for this sensitive mid frequency range.

So, in that case sound absorption coefficient will be a much better value for evaluating the frequency. So, they both have different purpose. Now that we have defined what is a sound absorbing material and what it does, it does it what it does is that it allows most of the sound to pass through it. So, the deflection is minimized and while passing through dissipation happens and therefore, transmission is also minimized.

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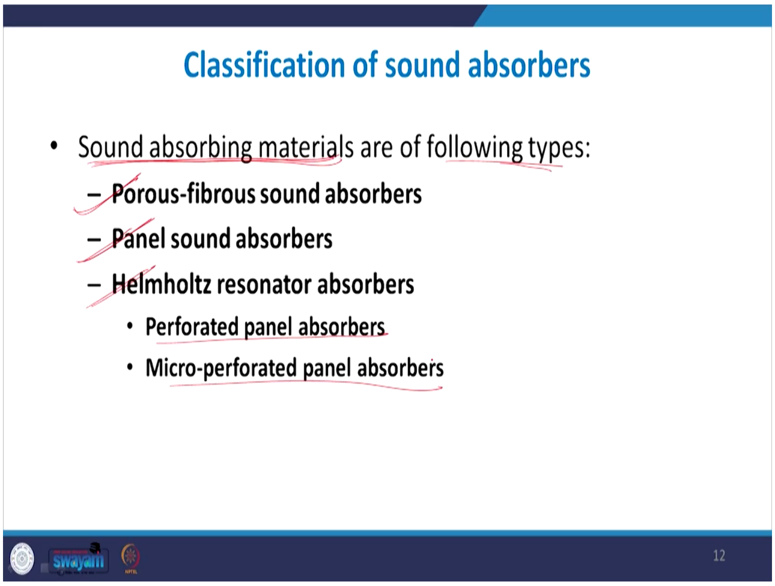

Now, various types of sound absorbers that exist are. So, traditionally these sound absorbing materials they are classified into porous fibrous sound absorbers, panel sound absorbers, Helmholtz resonator and then we have perforated panel and micro perforated panel absorbers which are subcategories of this Helmholtz resonator. So, let us begin our discussion on the first type of absorber which is the porous fibrous sound absorber.

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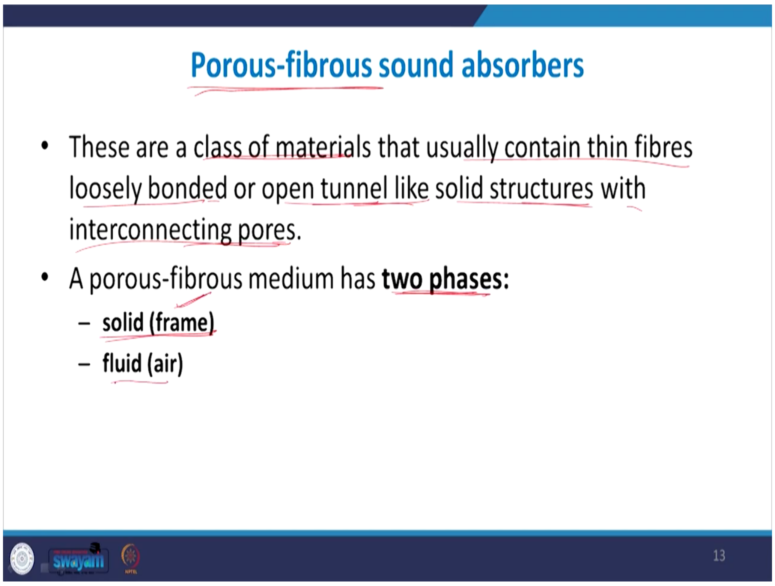

So, porous medium if you have seen a household sponge for example, then you see that it has got a solid phase, but then there are lots of pores and openings throughout the material that constitutes a second phase which is the fluid phase. So, this is a typical example of a porous medium.

Similarly, if you have seen for example, a jute bag or a gunny bag made out of jute. So, in that case there are lots of fibres and you have a bag, but is it completely solid. No, there is fiber part which is solid, but then there are gaps in between the fibres which are sort of openings which have the fluid phase which is the air phase. So, it is a combination of both solid and air phase. So, that is the description.

So, that is why we are studying porous and fibrous mediums together because they both they have this they both serve the same purpose and they both dissipate the sound in the same way.

So, this is simply a class of materials that contains thin fibres that are loosely bonded together or they contain a open tunnel like solid structures with interconnecting pores. So, in every case they have 2 phase; one is the solid phase which we call as the frame of the material and the fluid phase which we call as the air. To give you some examples here.

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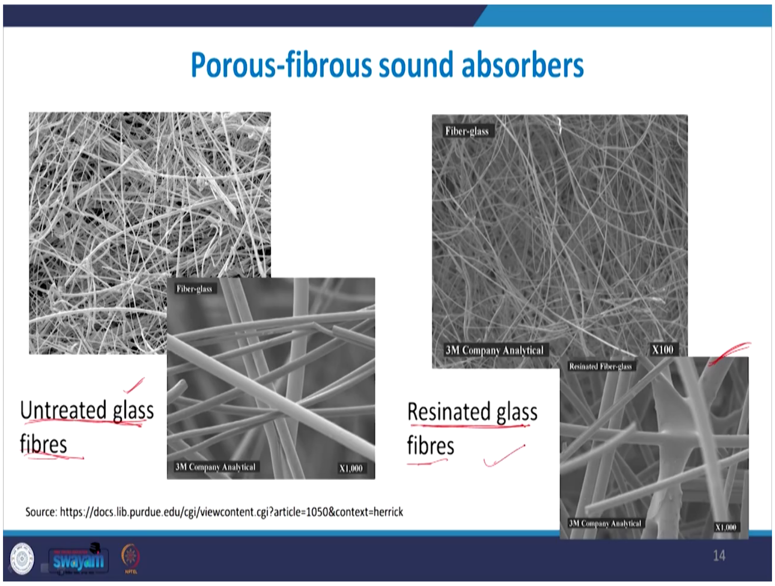

So, this shows the SEM image often untreated glass fiber. So, this is the most common of the porous material a porous fibrous material. So, here it is not treated. So, the fibres they are just loosely held together. So, obviously it cannot be to make it into the form of a layer of material some bonding needs to be done. So, when it is when resin is added to it then we get the resinated glass fibres. So, here the fibres they are loosely bond together and then they are woven into a fabric.

So, what we get is we get a fabric and we get these fibres which are bonded together, but obviously, there will be gaps and holes throughout. So, these act as the openings or pores. So, this is the image for the resonating glass fibre. This is one of the most common sound absorber used for a industrial purpose.

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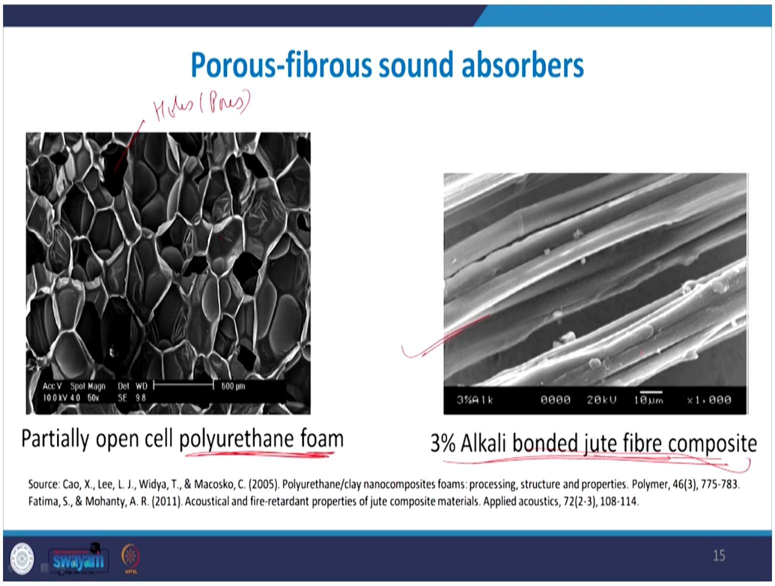

Some other sound absorbers that are used are the foam polyurethane foam which in the commercial term we also call as sponge. So, this is our first a sponge or a polyurethane foam. So, here what you see is that you have a solid phase, but then there are holes in between them these dark areas are the holes or the pores. So, you have both solid and air phase. This particular figure shows the fibres of a jute fiber composite which has been bonded with some alkali 3 percent.

So, here also the bonding is done because if you have loose fibres then it does. It can serve no purpose it needs to there needs to be some bonding to make it into the form of a structure or a material. So, the fibres some resin is added or bonding resin is added then they are woven together into a fabric of material and this is the sort of material we get. So, we have a structure is provided due to these bonded fibres and then the gaps in between these fibres become the air phase.

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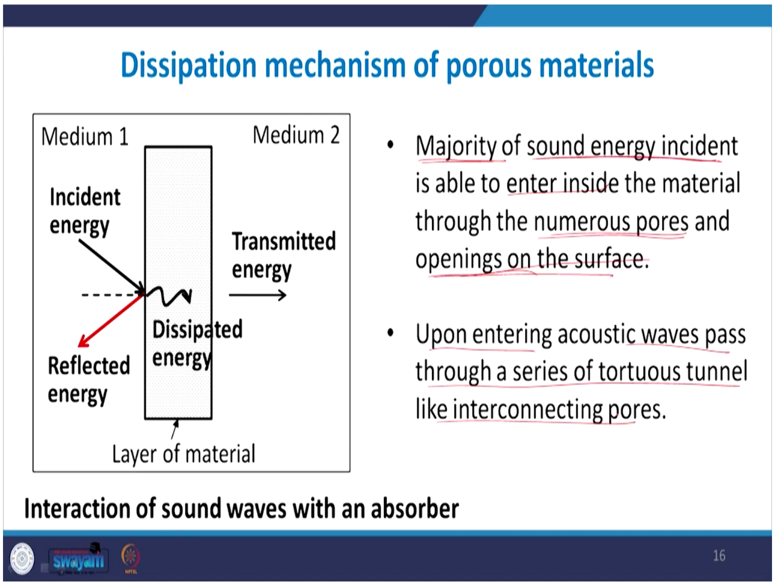

So, what is the dissipation mechanism in this kind of media. So, in this kind of media as you know as you can already guess that in this particular kind of a material it has lot of pores and openings there is lots of gaps. So, when that particular material surface is exposed to some incident light then the light can pass through. It is not a hard cement wall or a material where there is no gap which can block the sound. So, this material has a lot of pores and openings.

So, the advantage of this is that whenever sound and intensities incident on them then most of it can pass through these pores and openings. So, as it is allowing most of it to enter the material. Therefore, reflection is minimized and absorption is maximized. So, here this is the mechanism majority of the energy incident or the sound energy incident is able to enter because of whatever pores and openings that are present on the exposed surface of the material.

So, when most of the sound is able to enter the material reflection is minimized and then when it enters then it passes through a series of such a tortuous tunnel like interconnecting pores now how does some reflection is minimized. Now, let us see how does dissipation take place.

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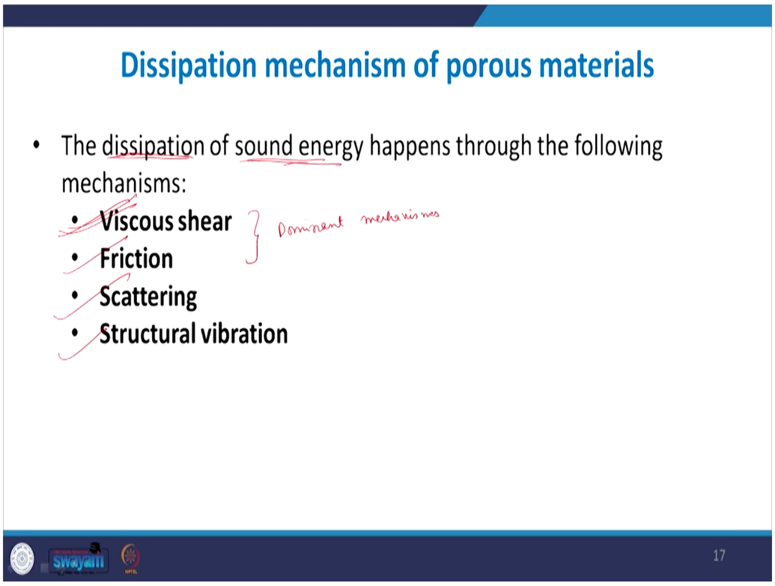

So, the dissipation takes place. So, once most of the sound energy has already entered inside the material then the dissipation can take place to these various mechanisms which is viscous shear, friction scattering and structural vibration and these 2 are the more dominant ones. These are the more dominant the dominant mechanisms for dissipation of sound energy.

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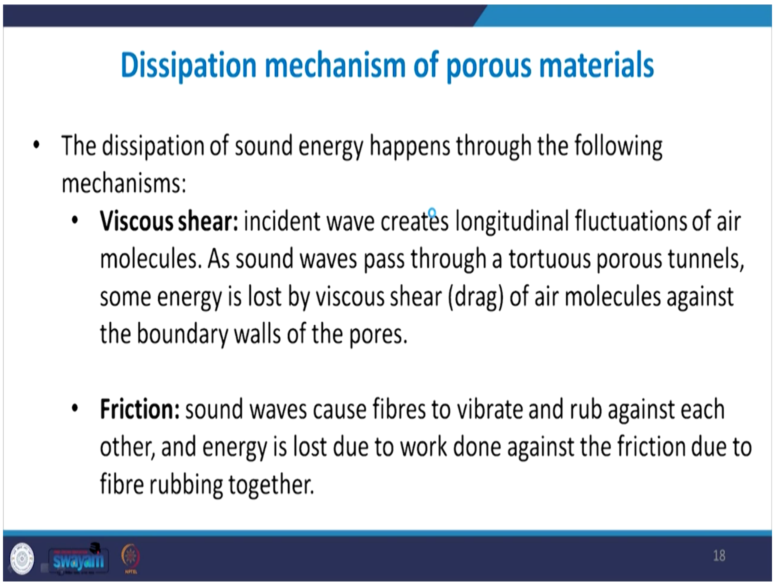

So, viscous shear let us discuss them one by one. So, when the incident wave they are passing through. So, sound energy is incident and then this sound wave then passes through the pores and the openings of the material. So, within this pores what does it mean. It means that the air molecules they are oscillating to and froth. So, they are having this longitudinal vibration and this is this longitudinal vibration of the air molecules what is going through in the which is making the sound wave propagate. So, sound wave propagation involves a longitudinal oscillation of the air particles. So, when the air particles they are going through then they can pass to the pores.

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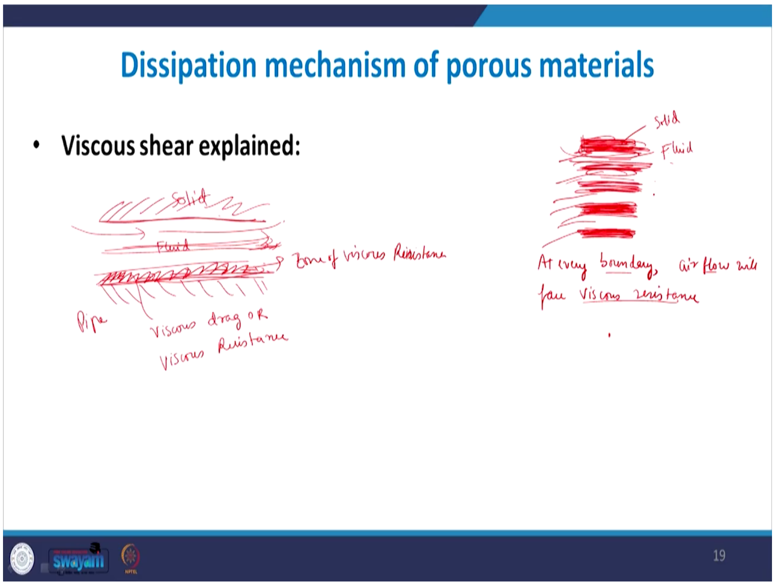

So, I will explain it to you in this particular figure. Let us say to explain you what is viscous shear let us say we have a solid boundary. So, let us say we have some pipe and this shows the side view of a pipe. Then when this is the solid phase and this is the fluid phase.

So, when the waves are entering. So, here they face no resistance, but just near the boundary of the solid and the fluids. So, this is solid fluid interface. So, just near the boundary the phase something called viscous drag or viscous resistance. So, here the solid when the fluid is passing through effectively what it means is that these solid it tries to lower down the speed of the fluid it low it tries to lower down the speed of fluid.

So, just like friction acts between 2 solid surfaces. So, when we have one solid block sliding over another solid block. So, we get friction. In the same way when we have a fluid layer sliding over or gliding through a solid surface then we get viscous resistance which is similar to a friction in solid case. So, here it is trying to oppose the motion of the fluid over it. So, it can face viscous resistance here.

So, it only. So, this is the zone of viscosity or viscous resistance. So, it only acts near the boundaries and this raises no resistance, but what if we have a material where we have lots of pores. So, let us say this is the material. So, I am going to draw the solid part by shading and fluid part by gap between them. So, this is sort of a fibrous medium and there are lots of gaps and this becomes the solid part, this becomes the fluid part.

So, as the air is passing through. So, there will be some viscous resistance phased here there will be some viscous resistance phased here. So, at every boundary they will be so. At every boundary the airflow will face viscous resistance. And, therefore as you increase the number of such openings in a particular material, the more will be the viscous resistance to the flow of the air and that is why such materials which have lots of pores and openings. So, we they we have lots of zones where viscous resistance takes place.

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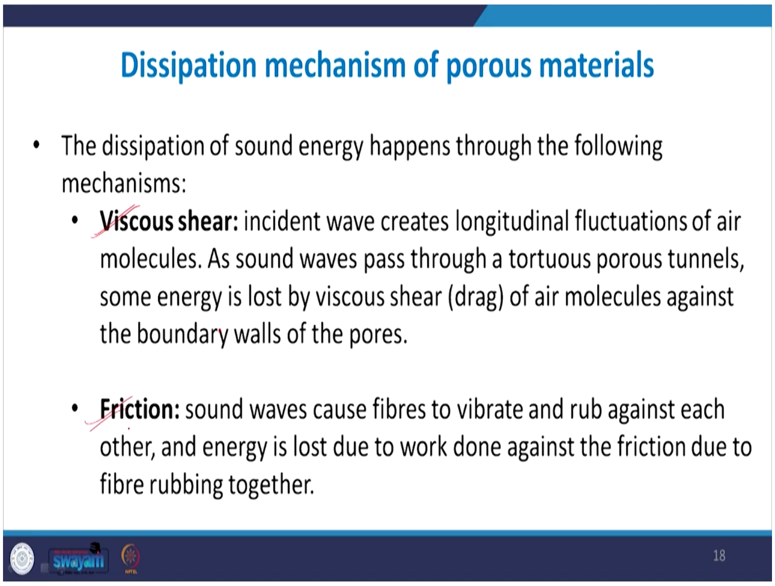

The second form of dissipation is in the form of fiction. So, as the sound waves enter and let us say the fibres they are loosely bonded together they are not solid like a solid table or anything. So, when the sound wave is passing through as a longitudinal oscillation that the fibres through which it is passing by they will come into contact with it and they will also start to vibrate.

And when these fibres they vibrate they can rub against each other and when they rub against each other then we have fictional resistance. So, we have solid fluid resistance and then solid resistance. So, we have friction due to the rubbing of fibres together. The third mechanism is scattering.

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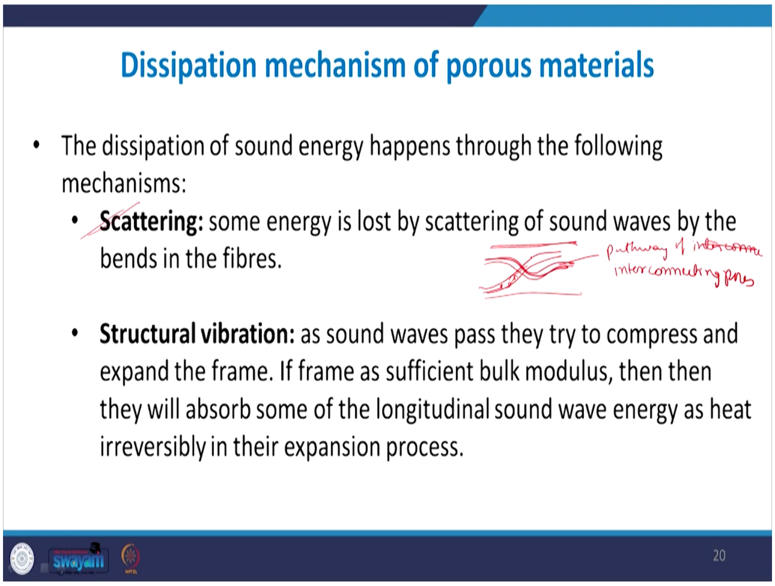

So, if suppose we have a material and it has got quite a torturous pore which means that this is the material and this is the flow of a pore the pore is something like this. So, it is a series of some interconnected this is the pathway of interconnecting pores. So, which means that the same material it has to pass through a long winding pathway and that pathway can have many sharp, many twists and turns and when the sound wave is passing through these turns and twist scattering can take place.

So, some energy can also be lost in scattering. And a quick example of this is let us see we have a long hose or a pipe which is hollow and we blow through it or we put some noise inside it and we blow through it. Then it follows a straight pathway and you can hear a loud noise from the other end also. But if you twist the same hose twist and turn it into lots of bends in that case when you blow from one end.

So, whatever noise is coming from one end then the sound that you hear at other end would be quite attenuated because most of it will be lost because it is passing through a very twisty and very torturous path and lots of scattering has happened in between. The last form of mechanism is structural vibration. So, what it means is that when the wave when the sound waves they have entered into the pores or the openings and they are compressing and expanding because sound wave is a series of compression and expansion of air.

So, as they compress and expand in the nearby surrounding structure will also try to compress and expand a little in the response to the air compression and if the solid part has got a sufficient enough bulk modulus. So, it will be the resistant to compression and expansion. So, for every compression and expansion the sound waves itself will have to do some work to make the to make this structure expand and compress and the work done will be lost as heat in order to when the structure vibrates along with the sound wave.

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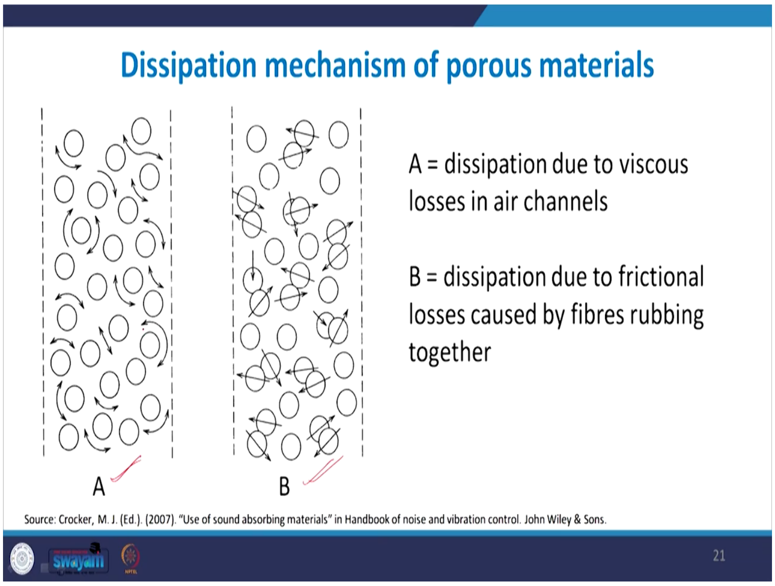

So, the 2 common dissipation mechanism which is viscous and resistance is shown here through this diagram. So, viscosity acts around all the boundaries of the pores and then whenever 2 fibres are rubbing together it is friction.

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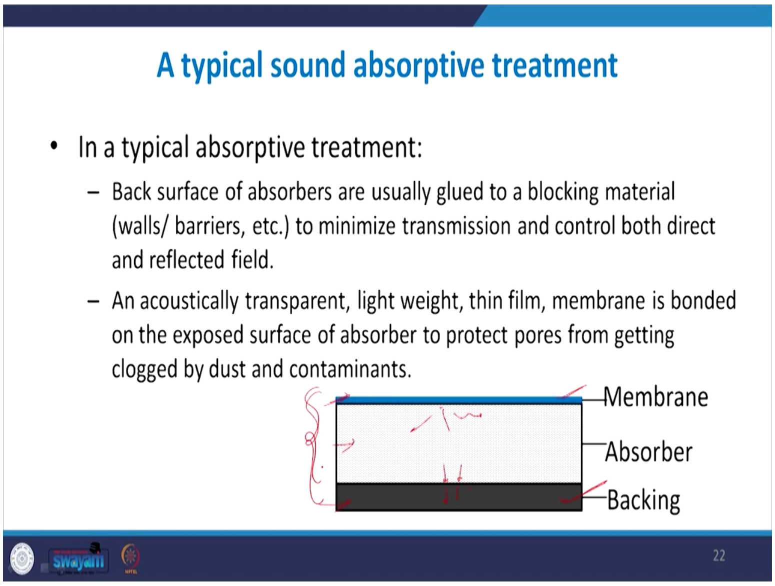

So, now that we know what is the dissipation mechanism in a sound absorptive material. I will give you a typical sound absorptive treatment which constitutes. We have an absorber it is backed by a hard backing material and there is a membrane that is placed on the top. Why a membrane is placed on the top because it wants to protect the openings and the pores because if these openings and pores itself get clogged due to dust and contaminants then sound would not be able to enter and the reflection the things will get reflected and no absorption will take place.

So, to protect these pores and openings and acoustically transparent thin film is added then we have the absorber and this is followed by a backing. This backing is sometimes added why because when the sound waves pass through they get dissipated, but some of it will also get transmitted from the other end. To further minimize the transmission a blocking material is added at the end of it.

So, this is a typical treatment for the good sound absorption that that minimizes the reflection and also minimizes the transmission. So, with this I would like to close the discussion on sound absorb sound absorbers. Next class we will also be dedicated to some more study on the porous fibrous sound absorbers.

Thank you.