NOISE CONTROL IN MECHANICAL SYSTEMS

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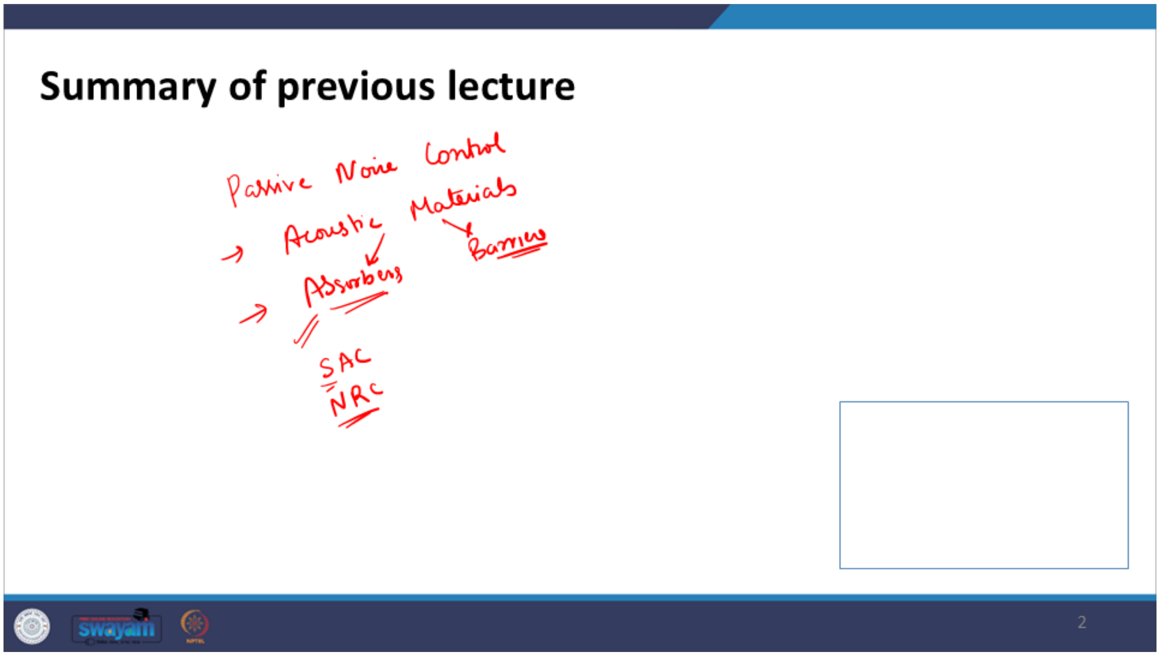
Week: 8

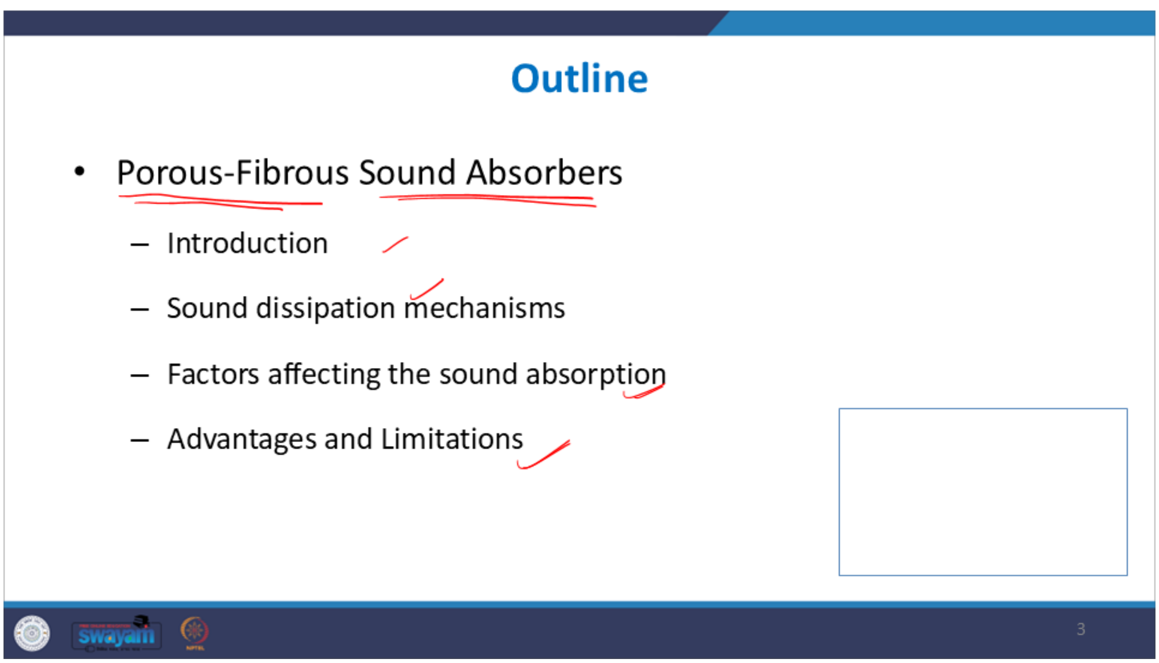
Lecture: 37

Lecture 37: Porous fibrous sound absorbers

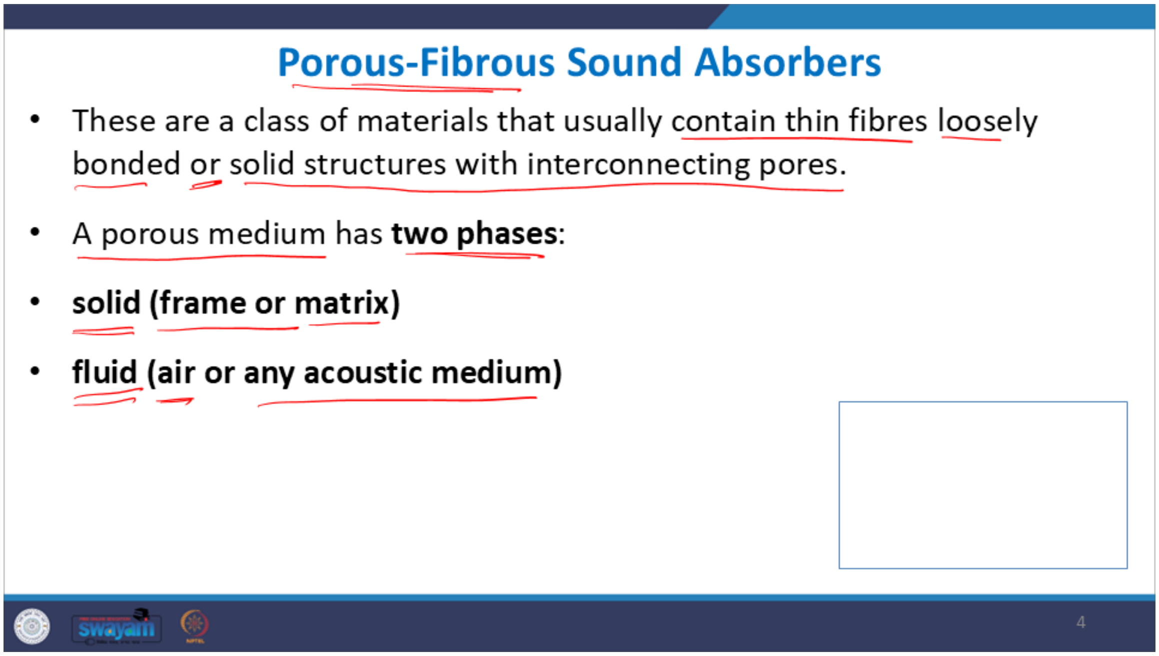
Hello and welcome to this course on noise control in mechanical systems with me, Professor Sneha Singh from IIT Roorkee. In today's lecture, we will discuss porous fibrous sound absorbers.



So far, we have begun our discussion on passive noise control, and in passive noise control, materials are usually used for path modification. So, the various kinds of acoustic materials that are used. And then one type of acoustic material could be either an absorber, acoustic materials, or they could be barrier materials, as we had discussed.



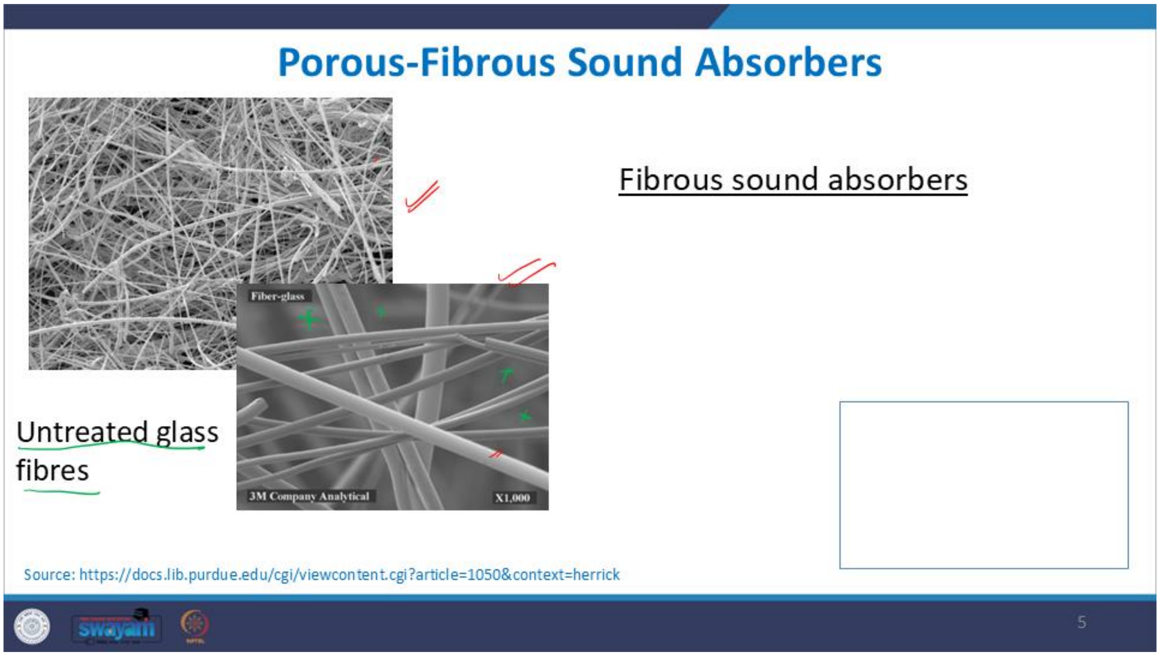
So, in today's class, last class we started our discussion on sound absorbers and the performance metrics such as the sound absorption coefficient and the noise reduction coefficient, which are used to measure how much of the incident acoustic energy is absorbed and dissipated within the material. So, in today's class, we will see the first type of absorber, which is the porous fibrous sound absorber. Okay, so just an introduction to what these absorbers are, what they are made of, their sound dissipation mechanisms, the factors that affect their sound absorption, and some of the advantages and limitations of using these sound absorbers.



So, usually, as the name suggests, porous fibrous means they are a class of materials that usually contain thin fibers that are loosely bonded

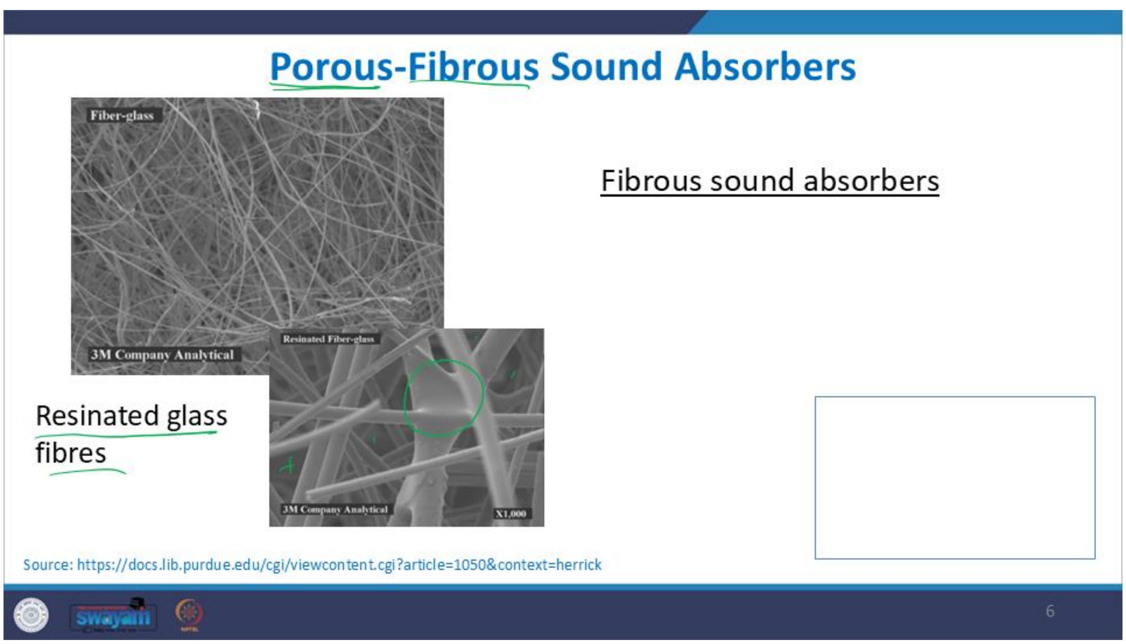
or they contain solid structures with interconnecting pores, okay. And because they are either made of loosely bonded fibers or solid structures with many interconnecting pores, so that is why, on the surface, whenever a sound wave is incident on it, there are many gaps and pores or openings available on the exposed surface through which the incident sound wave has a way to pass into the material, okay. So, the material has fibers or solid structures and many gaps, air gaps, or openings in the form of gaps between the fibers or these interconnecting pores.

So, that is why any such porous medium or porous fibrous medium will have two phases. First would be the solid phase, also called the frame or the matrix, and then you have the fluid phase, which is the air—the most common acoustic medium or any other acoustic medium. Okay, So, these are the two phases; it is a two-phase material.



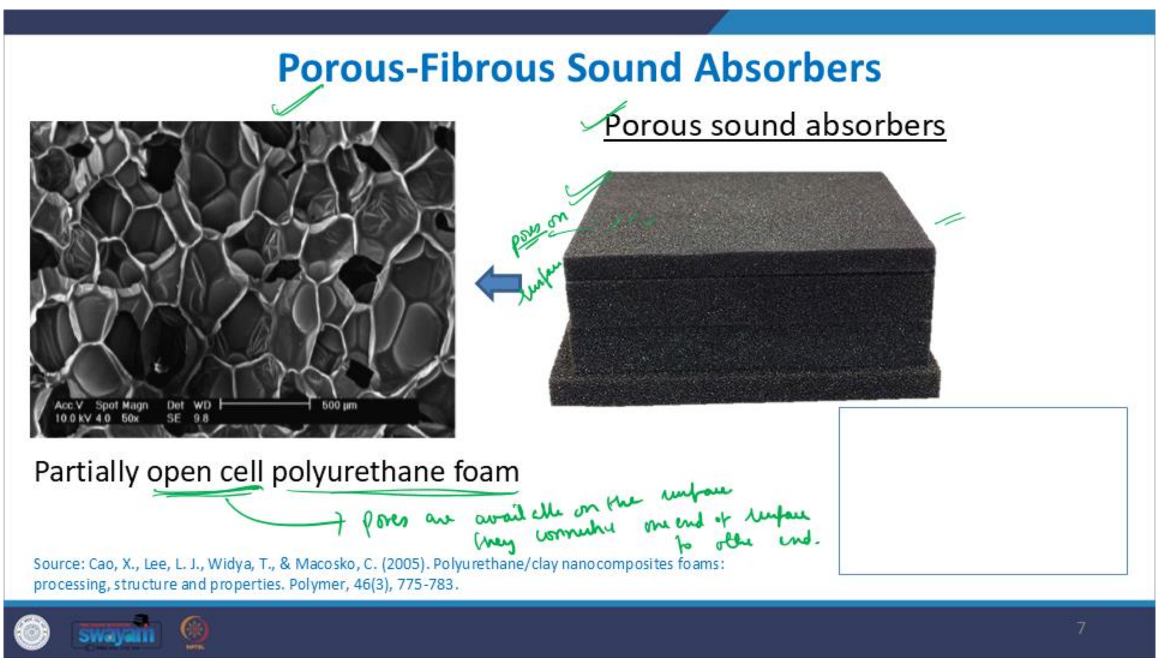
So, this shows a typical picture of an untreated glass fiber. So, these glass fibers that are manufactured are supposedly very good sound absorbers, and this is a magnified SEM image of these untreated glass fibers. As you can see, there are a lot of fibers, but they are quite loosely held together, and you have a lot of air space in between these fibers—okay, a lot of ways through which air can pass through them.

And this is an even further magnified view, which shows these fibers and the air spaces, which I can represent with this particular thing. So, these are those air spaces in between the fibers.



So, as you can see, both air and the solid phase are available, and it is due to these many air spaces or voids that are available in these loosely bonded fibers that the sound wave gets a way or a pathway to pass through. So, this is the example of a fibrous sound absorber. Porous fibrous means a combination of both either porous or fibrous they are studied together because they both have similar sound dissipation mechanisms and similar kinds of absorption properties. So, again, the previous one was an untreated glass fiber; this is a resin-treated glass fiber, which means it is given more sturdiness to the structure because otherwise, loosely bonded material or loose fibers cannot be used as a proper structure, wall, or lining.

So, in order for it to have some shape to hold on, sometimes you add resins or other kinds of adhesives that can be used to bond these fibers so that the material can be woven up or formed into a layer of sturdy material, right? So, these fibers can make up a layer of sturdy material. So, even with resin-treated glass fibers, you see that some of the fibers are getting bonded together here, but still, there are some air spaces through which air can pass.

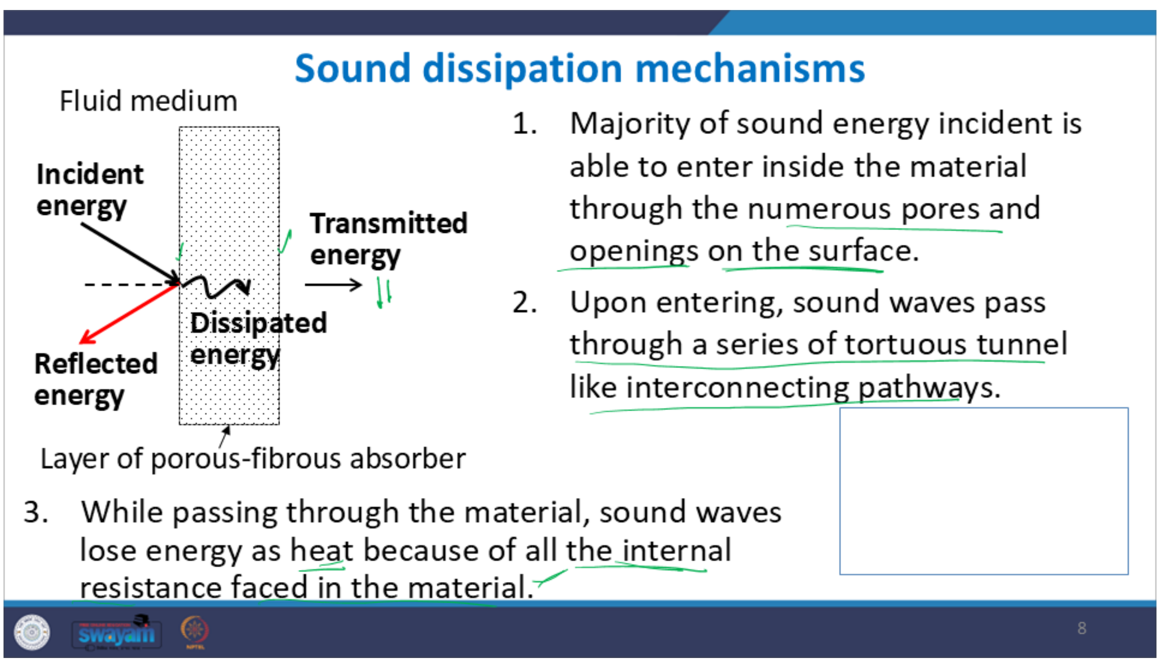


Then, the other kind of porous fibrous absorbers we have are the porous sound absorbers, like various kinds of foams that are available, okay.

So, in the market, if you go, you have a closed-cell foam, which is, you know, the foam. It is still a foam, but, you know, the outside of it, you would not find so many holes or openings or pores on the outside surface. Okay, the outside surface would be closed, and the inside would be a porous foam. Okay, so that is called the closed-cell foam. That is usually made, for example, in your sofa coverings. You know, if you want to make the sofa sets and various other things, especially for outdoor use, you know, kind of purposes, there you have these closed-cell foams so that, you know, water or other dust particles cannot enter into the material. So, the surface is closed from the outside, but on the inside, you have pores. But those closed-cell foams, they are not acoustic materials, or they are not good absorbers because, for a good absorber, you need a way for the sound waves to enter the material.

And that is why open-cell foams are used as sound-absorbing materials. This shows a magnified SEM image of an open-cell polyurethane foam. This is a This is a small, this is the SEM view, this is a regular view in which you can see these various foams, and on the surface itself, you see a lot of grainy texture. So, a lot of, you know, pores are available on the surface itself, okay.

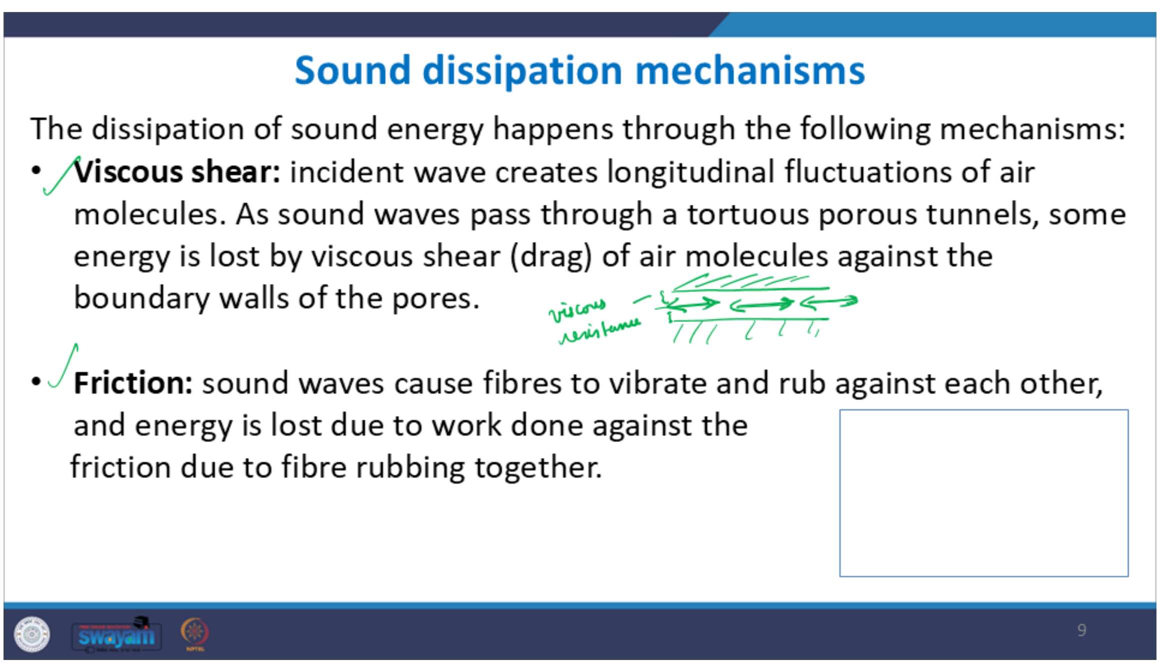
So, open-cell means, you know, pores are available on the surface, and they connect one end to another end. of the surface to the other end, okay. So, open-cell foams act as absorbers because they have so many such grainy textures of pores on the exposed surface. So, they provide the means for sound waves to enter inside the material, and then the sound waves get dissipated, okay.



So, let us study what the dissipation mechanism is when such fibrous and porous materials are being used.

so now you know that how the sound wave enters because you know these materials be it fibrous or porous materials they have a lot of pores or you know lot of voids air gaps in their exposed surface itself okay it's not a rigid surface but it has got a lot of grainy texture a lot of pores and a lot of voids through which the sound wave is entering into the material okay so now what happens what leads to the dissipation so the once a material. The reflection gets minimized because it allows most of the sound waves to enter inside it, but what happens inside so that this energy gets dissipation and the transmission at the other end could also be reduced. So, what happens let us see step by step. So, majority of the sound energy that is being incident it is able to enter inside this material to the various numerous pores and the openings that are available on the surface. and that is why open cell foam acts as an absorber not the closed cell foam so once the sound energy incident is able to enter inside the material

Then upon entering they pass through a series of such tortuous tunnel like interconnecting pathways you know because of these various kind of you know randomly arranged fibers or various kind of randomly interconnecting ports a lot of you know series of tortuous tunnel like path they have to go through. And while they are passing through this most of their energy gets loosed as heat. okay because of whatever is the internal resistance they are facing within the material and hence the energy gets lost and by the time they reach the other end so from here till here this transmission also drops what is the internal resistance that is faced what is leading to you know the loss of the sound energy as heat the two most common you know mechanism or the two most common phenomenon that lead to the dissipation of sound energy in this material is the

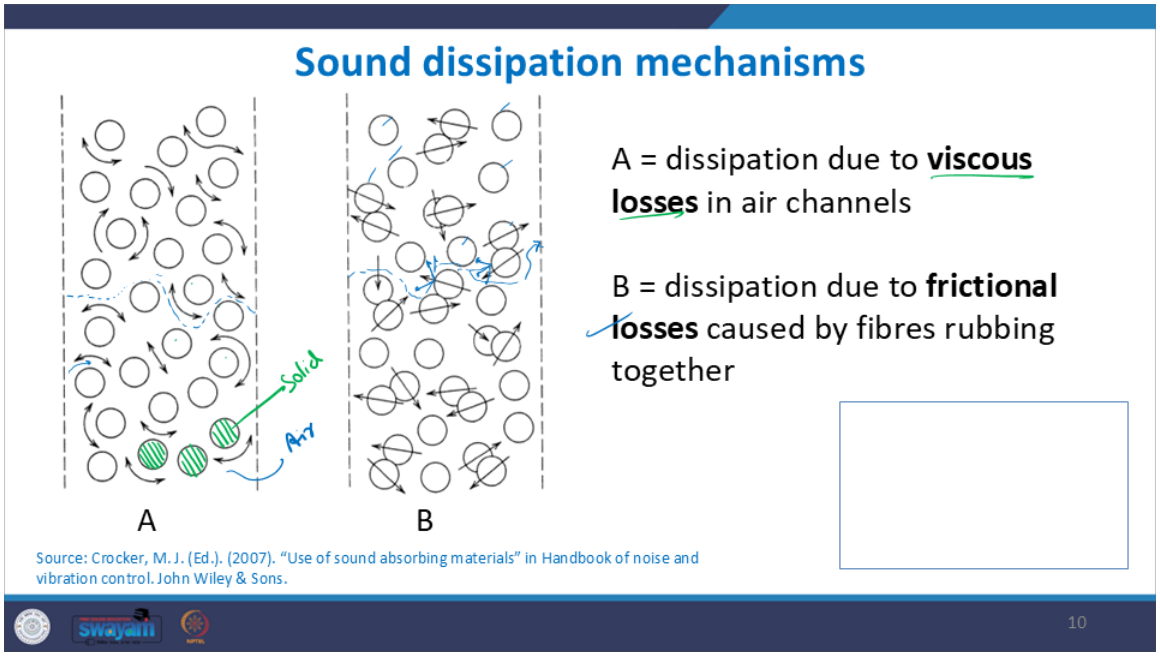


viscous shear and the friction and you know experimental studies and empirical studies they have shown that you know these are the most contributing phenomenon they are the two most common or they have the majority of you know sort of they have the most influence in dissipating the sound energy although there are other phenomenon as well but they are the most influencing one So, viscous shear what happens when the incident wave it is you know incident.

So, sound wave is what it is like you know sound wave is simply the longitudinal fluctuation of the air particles ok. So, once the sound wave is entering into the material and going through this tortuous porous kind of tunnels these you know longitudinal sort of fluctuations are happening then energy gets lost due to the viscous shear or the drag that is faced by the air vibrating or oscillating air molecules against the boundary walls of the pore. So, the concept is very similar like for example, you know suppose you have some rigid you know wall structure. and a fluid such as air is flowing through this rigid wall structure.

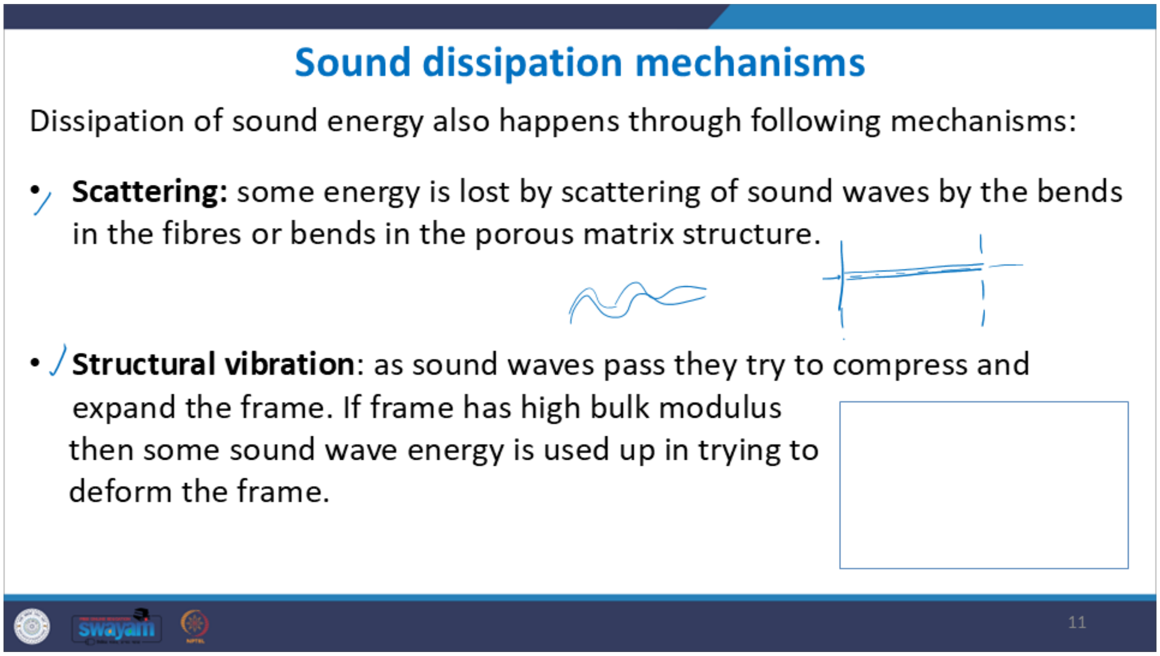
So, near the wall, it is going to face, you know, viscous resistance, ok. Which is, you know, simply the resistance to the flow of a fluid along the solid wall near the solid wall. So, whenever the sound waves are flowing, they are going to face resistance due to this viscosity of, you know, the pores or the solid structure, and that will resist the flow of air particles, and here the air particles are longitudinal oscillations flowing back and forth through these various air channels like this, ok. And because there are some numerous such channels, ok, you have numerous such small channels, and hence the viscous resistance becomes important and dominant.

In the same way, you know, in the sound waves, they are moving through the structure, they can cause the solid structure or the fibers to vibrate and rub against each other, and some of the energy can also be lost due to, you know, friction because of the fibers rubbing against one another.



So, you can see it here, you know, in the first case, we have the viscous losses happening. So, suppose, you know, these are the various fibers or various solid structures, so these circles are the solid medium of that porous fibrous material; all of this is the solid medium, solid phase, and this one over here, let us say, is the air phase, okay. So, the air molecules, they are vibrating and moving through this structure, but whenever they are passing near the walls of the solid structure, they are facing viscous resistance whenever crossing through these walls, and there are a lot of such walls because you have a lot of

a lot of, you know, thin fibers, or you have a lot of these interconnecting, you know, tunnel-like pores. So, the chances of, you know, the fluid flow through these various solid structures is a lot. So, they face a significant amount of, you know, viscous losses while the air molecules are fluctuating back and forth near the walls of these solid frames or the solid fibers, ok. In the same way, you know, here, what happens when the sound waves are moving, and these fibers are loosely bonded together. Then, because of the movement, the fluctuating movement of the sound wave, sometimes the fibers also are set into vibrating motions, they are rubbing against each other, and frictional losses are happening.

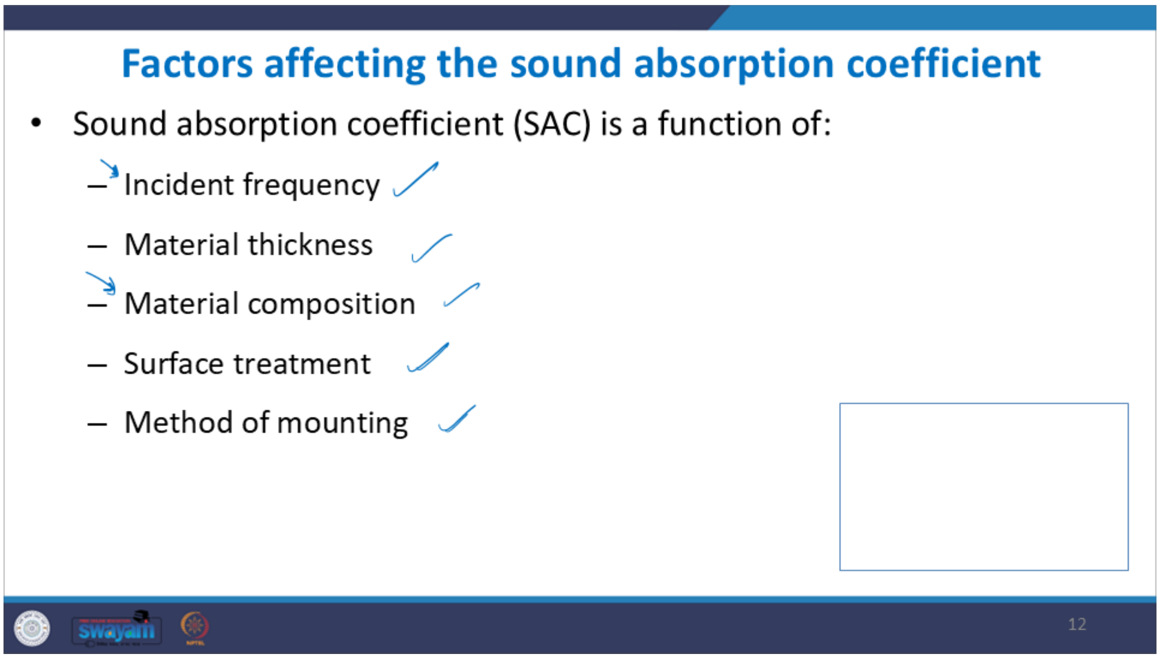


Some other phenomenon that takes place, so although viscous shear and friction, they have a greater impact on reducing the sound energy. Some of the other phenomenon are you know scattering and the structural vibration. So what happens in scattering? Some energy is lost. whenever you know the sound wave is hitting the bends in the fiber or any kind of bends in the porous matrix structure then scattering happens now we know that here whatever is our you know porous material the pathway is not straight it's not like the sound wave is going through a straight pathway these are very at various tortuous like pathways you know like for example here also it's not like the sound wave is going straight if I had to create a pathway for the sound wave okay

So, it might not be going straight, it might be taking a tortuous kind of a pathway, you know, not a haphazard kind of a pathway, okay, like this. So, not straight, but haphazard. So, whenever they are going and they are hitting some material, some scattering is happening here. And again they are going they are hitting some material again some scattering is happening. So the waves while passing through whenever they encounter any kind of bends or any kind of sudden obstruction in the form of the fibers or the solid frame they undergo scattering and there also some energy gets lost within the material.

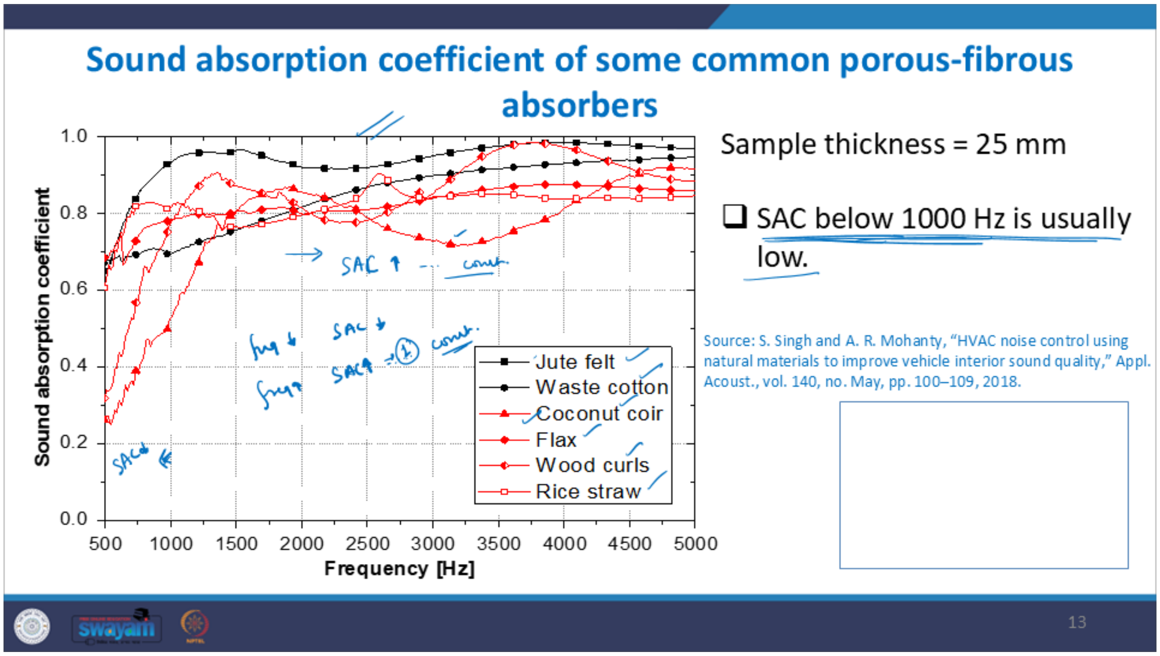
Then the structural vibration the sound waves they are trying to once because they are longitudinal fluctuations of air particles and they are passing through a solid frame like structure. Then they try to compress and expand the frame and if the frame has got a sufficiently high bulk modulus then some of the work would be done by the sound energy in trying to you know compress or expand the frame okay and that will also use up the sound energy and dissipation will happen. But these phenomenon are you know usually rare for that you need that kind of a frame, but viscous shear and friction are more contributing towards you know the absorption of the sound.

Now, what are the factors which affect the sound absorption coefficient in these materials?



you know SAC depends on first of all the incident frequency then the thickness of the material, the material composition, the surface treatment and the method of mounting of these materials so let us see you know first incident frequency and material composition how are they affecting. Okay.

So, here I have a diagram from my own paper which we published in 2018 where we were comparing the sound absorption coefficient of various common porous fibrous absorbers and we had you know jute felt, waste cotton, coconut coir, flax, wood curls and rice straw. So, various kind of natural you know plant based porous fibrous absorbing materials were made and their SAC was compared you can see that with frequency. the values definitely change and what you observe is that typically at a frequency below 1000 Hz, SAC is low and as the frequency increases SAC increases and then becomes constant almost like that. So, the variation you can observe with frequency at low frequencies you know the SAC is typically low in value you know.

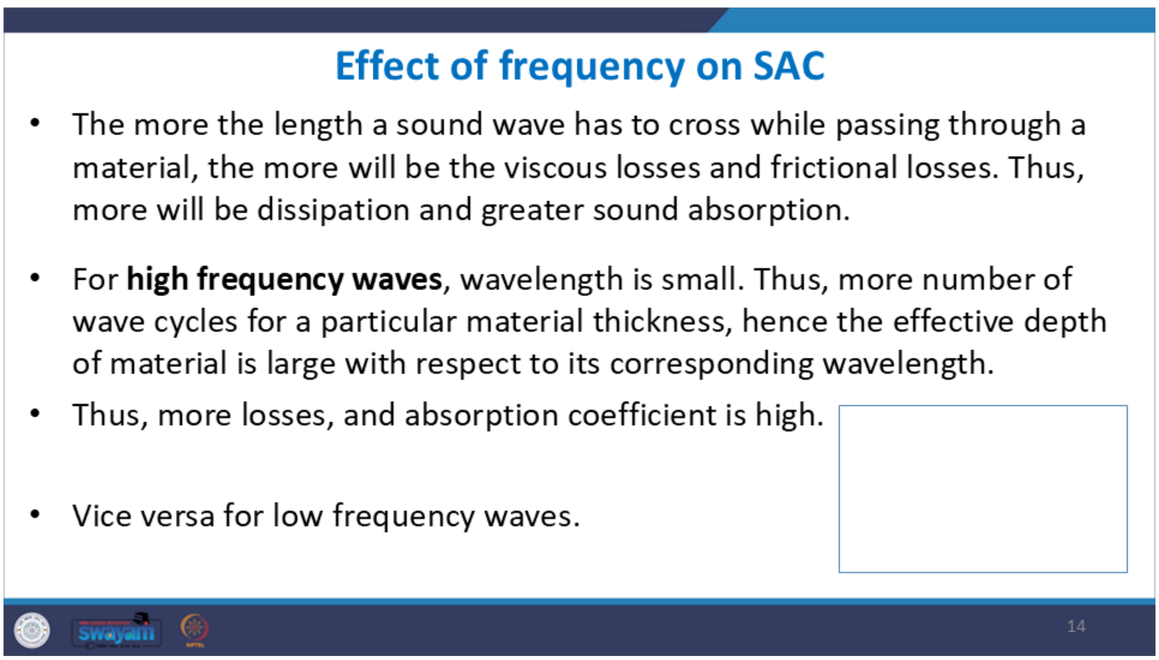


So, frequency is low SAC is typically low in value and as the frequency increases SAC increases and then almost becomes constant approaching 1 because SAC cannot be greater than 1. So, finally, it increases and reaches up to 1 and becomes constant you know till it becomes 1. So, like that you know a typical pattern you can observe sometimes you can also observe some dips. So, what you see is that there is a variation with respect to frequency and it also depends on the type of material you are using. For example, typically here it shows that the jute felt composite is having higher overall higher SAC compared to you know material such as you know the coconut coir here.

So, depending on how close what kind how you have made that particular composite what kind of you know. density of fibers you are using, the density of your you know fibrous material, the kind of resin treatment you are giving them etc. So, based on how it is made up and overall built the SAC is going to change and at the same time with frequency also it is going to change where typically SAC is low very low below 1000 Hertz. So, why this happens? Why we are observing low sound absorption coefficient and the low frequencies?

So, here you can think of it this way you know whatever phenomenon you know whatever sound dissipation phenomenon we observed viscous shear friction and all of that. So, here you know the more a sound wave is made to pass through the more you know it resistance happens ok. So, they as they are passing through this material you know. so they are facing all these resistance due to the viscosity and the frictional losses and all that and they keep losing the energy as they go through the material so obviously if the thickness of the material is more they have to you know go through a long pathway and per unit length they are they keep losing their dissipation you know they keep losing their energy.

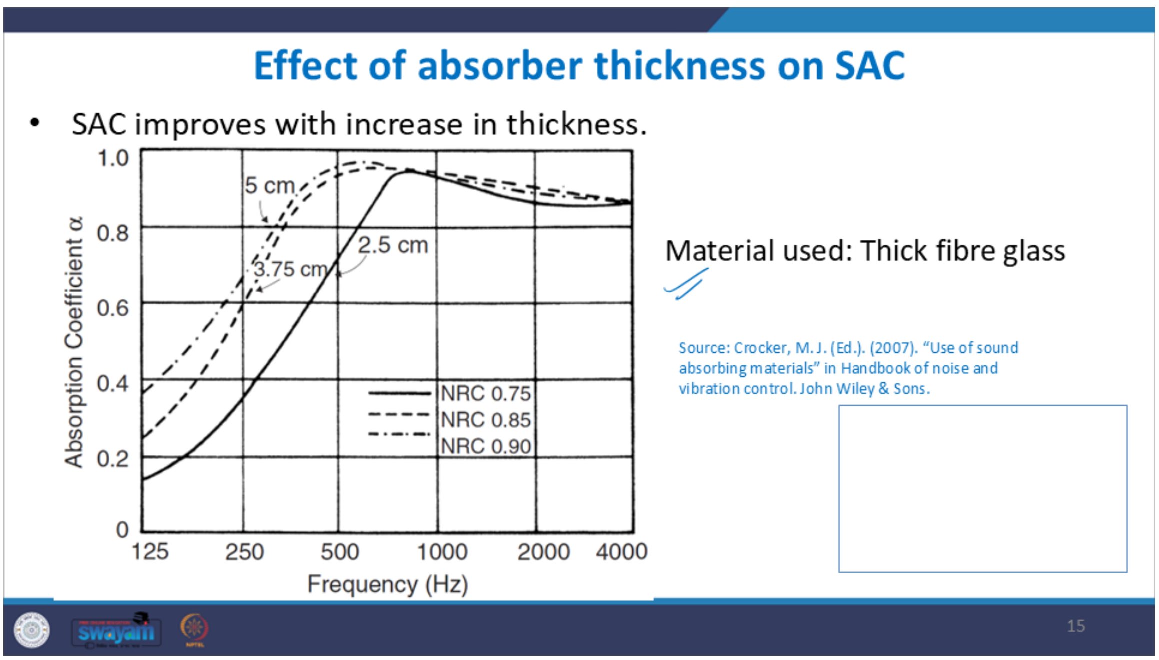
So, suppose if the dissipation rate is roughly constant per units per unit length of the material they are covering and as you increase the thickness of the material what will happen? The you know with increasing thickness more and more energy will get dissipated till it reaches some optimum value and then the thickness does not have an effect. In the same way suppose we have got a typically you know low frequency high frequency sound waves which means that for these high frequency sound waves the wavelength is going to be small. So, which means that if the material thickness is constant.



So, that the amount of length they have to cover through the material is constant, but the high frequency waves are there. So, which means that the wavelength is small with respect to the material thickness. So, more number of wave cycles for that particular material thickness and hence more is the dissipation because crude wave saying this could be that let us say I have got a certain thickness of a material and I am passing a very high frequency wave through it and roughly 1 lakh wave cycles are passing through that material. So, a lot of waves overall are passing a lot of wavelengths of that material is passing through

And a lot of dissipation is happening because for every fluctuation, some kind of dissipation is happening. But if we have a low-frequency wave, then instead of the 1 lakh wave cycles, I just have 1000 wave cycles passing through the same material. So, with fewer fluctuations, the rate of fluctuation is low, and hence, as they pass through this material, the dissipation is also low. The effective material. So here, the thickness of the material with respect to the wavelength of the wave becomes important—how thick the material is in comparison to the wavelength of the wave. Okay, if the material is very large compared to its wavelength, then more dissipation will happen because more wave cycles are passing through and experiencing losses there. Okay, and vice versa.

So here, you can see with the same logic: as you increase the thickness, the SAC sort of goes up because you are increasing the pathway of resistance, and with whereas as they pass through the material, their energy is getting lost continuously while passing through the material. So, the more material they have to pass through, the more energy gets dissipated until it reaches some optimum level, beyond which the thickness will not have that much effect. So, this is the typical pattern that you would observe: with the increase in thickness, usually the SAC will rise, and then after it reaches a certain optimum level, the material thickness will not have that much effect. Then, what is the effective surface treatment on the sound absorber?

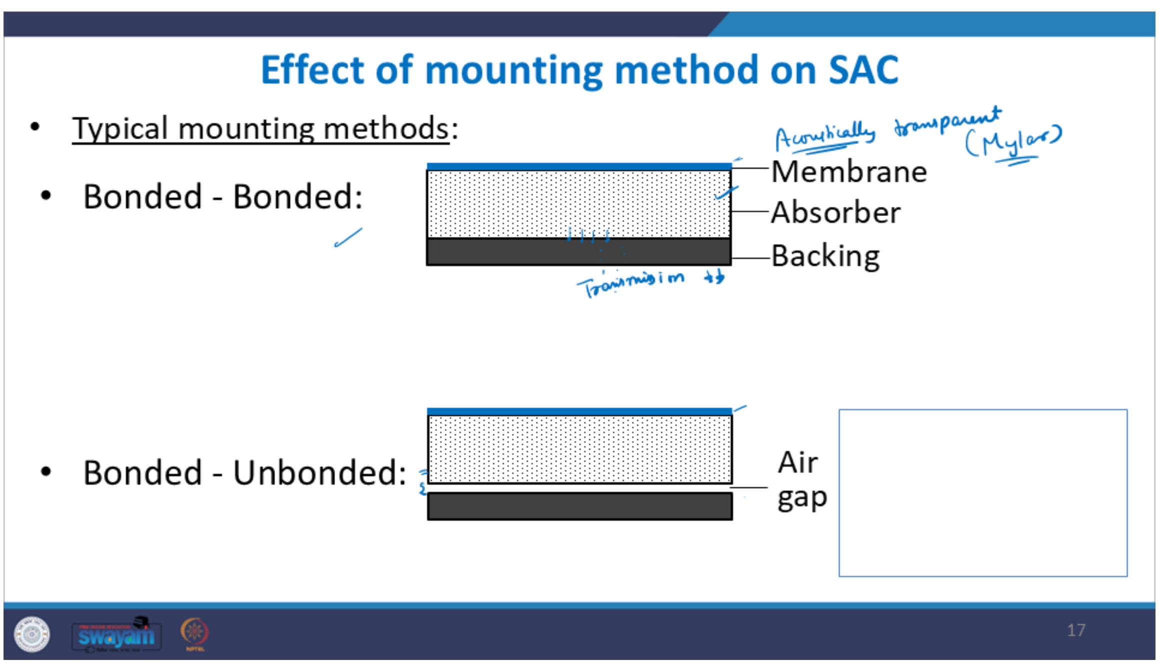


So, now you know that For absorption to happen, the first thing these materials need to do is allow the waves to enter inside them. Only when the sound waves can enter into this medium a porous, fibrous medium—will they undergo all these dissipation mechanisms, and the wave energy will get lost within the material as heat. So, the transmission will be reduced, and at the same time, reflection will be reduced because the waves are not reflecting back but rather entering into the material. But if, suppose, you close up the pores let's say you paint the surface of the material or smoothen the surface, which leads to the reduction in the pores or the air gaps at the surface—then what will happen?

The material will slowly start behaving like a reflector instead of an absorber because the waves are hitting the material, but now you have painted or varnished the surface. Now, they no longer are getting any pathway or open pores through which they can enter inside. So, they simply reflect back. So, once they reflect back, their absorption goes down. So, such kind of surface treatment is definitely not encouraged you know because you know it leads to the reduction in the absorption you know.

So, any means any kind of surface treatment that leads to you know covering up of these pores and the holes it will make the you know absorption go drastically down.

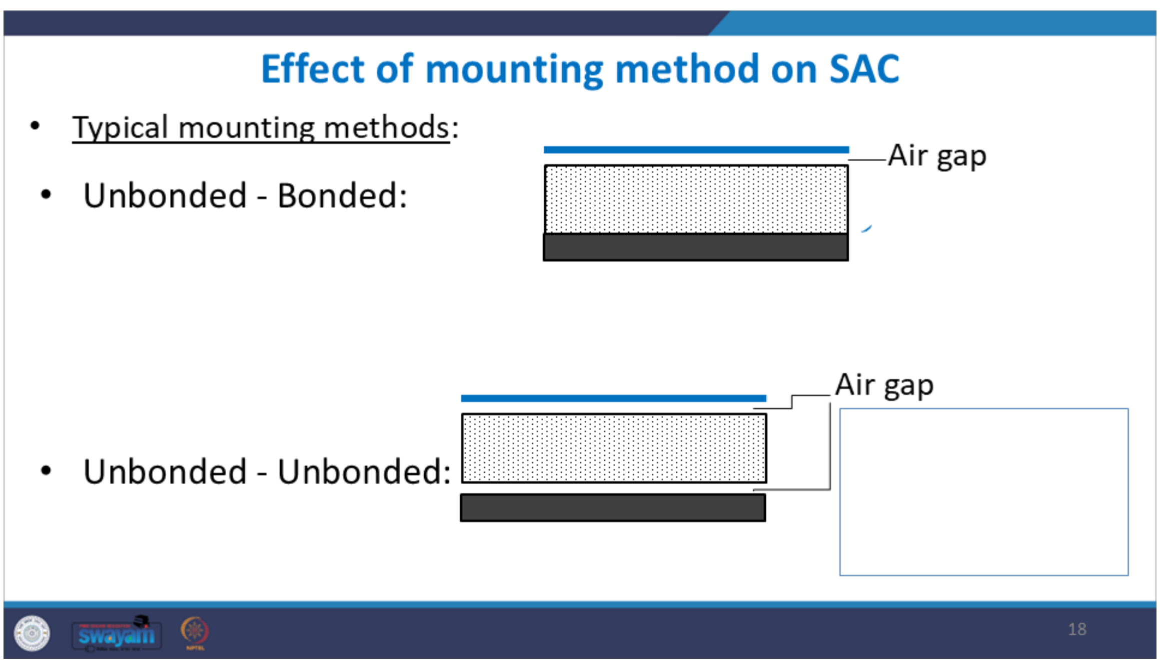
Then also the effect of mounting method you know mounting method effects absorption. What are the typical mounting methods you know? Typically you know what you have is an absorber lining and on top of it you know install a acoustically transparent membrane. So, in the last lecture I told you how is a typical sound absorbing treatment, what happens there?



On the top of the material sometimes you have an acoustically transparent membrane such as a Mylar film. So what happens? It stops the entry of dust and the smoke particles so that you know the pores do not get clogged and remain free. but it allows the sound waves to pass through okay so that is why we have this protective layer of film on the top so that you know dust and air particle the dust and the smoke particles and impurities that do not clog the pores and only sound waves can pass through it There are various such acoustically transparent films and then you have the absorber followed by a backing so that you know whatever sound transmission reduced or whatever finally it reaches the backing and further reduction takes place so that almost the transmission goes down even further and that is why you have a barrier backing to make the transmission go down even further.

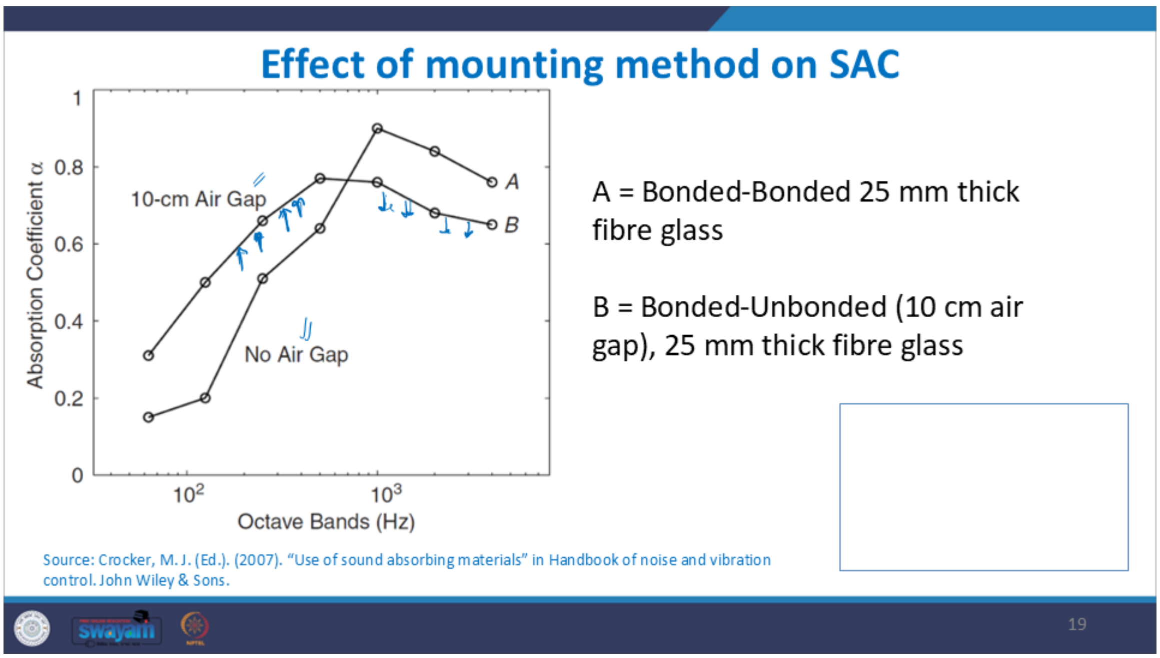
The other kind of treatment is the, you know, bonded-unbonded, where you have an air gap introduced. So, you have a, you know, film at the exposed surface of the absorber, then you have some air gap, and so, immediately following the absorber, you do not have a barrier backing, but rather you have some air gap in between.

Then you have unbonded-bonded, where, you know, the exposed surface is not covered with a protective membrane. Okay, But it has a barrier bonding at the backside and unbonded-unbonded, which means that, you know, there is an air gap at the exposed surface where the sound wave is incident, and there is also an air gap at the reflected end of the absorber. And depending on, you know, what kind of mounting conditions you are using whether bonded-bonded, bonded-unbonded, and so on—and what is the depth of the air gap you are using, what is the kind of barrier backing you are using.



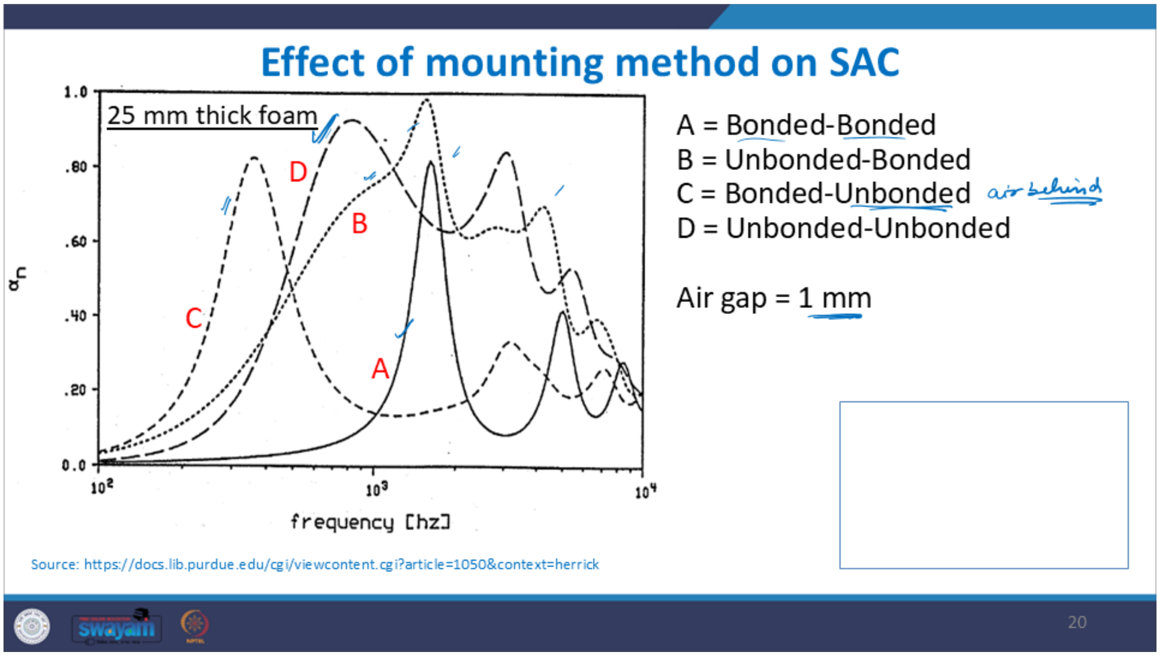
So, depending on these conditions, also, the sound absorption coefficient changes.

So, let us see a graph, you know, what happens here—you have got, you know, material with no air gap, directly a barrier backing, and now you have an air gap between the barrier backing, and what is happening is that when there was no air gap, the values at the low frequencies were low, but with the introduction of the air gap, some of the low-frequency absorption has enhanced, but it has come at the cost of reduction of the SAC at the higher frequencies with the introduction of the air gap. at the back of the. So, this is the condition of bonded-bonded and bonded-unbonded.



So, one case is where you do not have any air gap this one versus bonded-unbonded, where you have an air gap between the porous layer and the barrier at the back—some air gap is there, which is 10 centimeters.

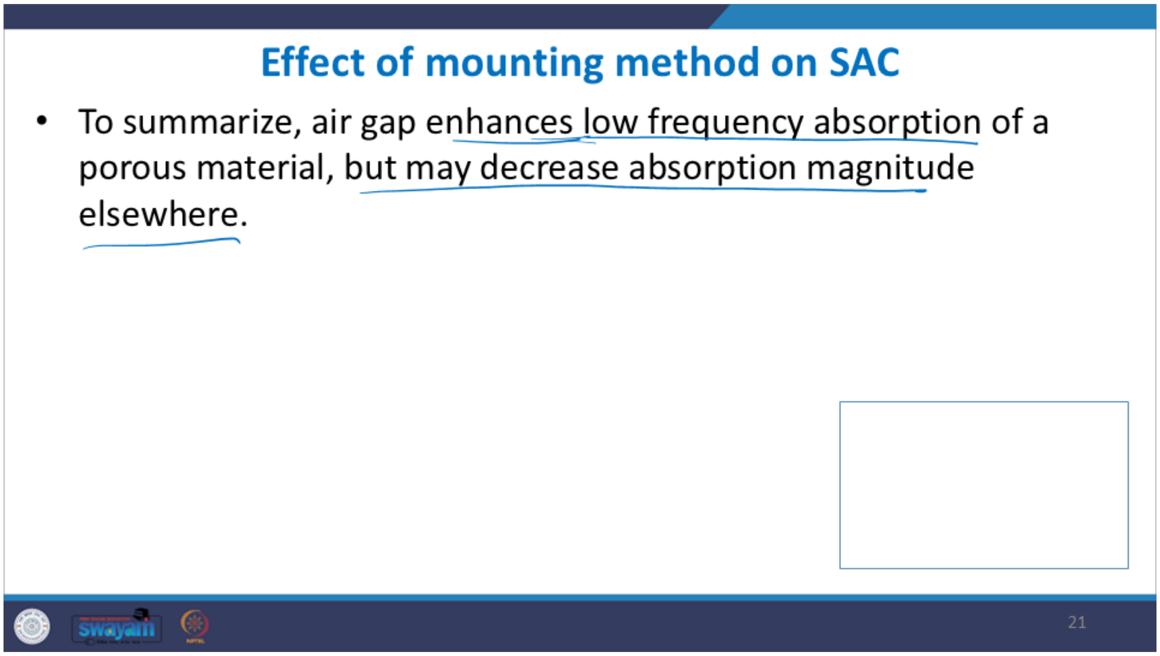
In the same way, these are the four different graphs. What you have is, in all these graphs, you just have a 1 millimeter of air gap, okay. So, overall, it is not affecting the thickness of the entire sound absorber you are creating out of the membrane, the porous material, and the barrier backing. So, all of them combined together, the thickness is just increasing or decreasing by 1 millimeter.



when you are introducing an air gap. But what is happening because of it suppose it is bonded bonded it is giving you this kind of a peak. When you have an unbonded bonded thing then suddenly you have a much you know higher SAC value and then when it is bonded unbonded which means an air gap which is behind the porous material before the barrier backing. Again similar thing what happens the peak shift towards the lower frequencies. and then when you have unbounded unbounded it is something like that here higher peak again towards the lower frequencies.

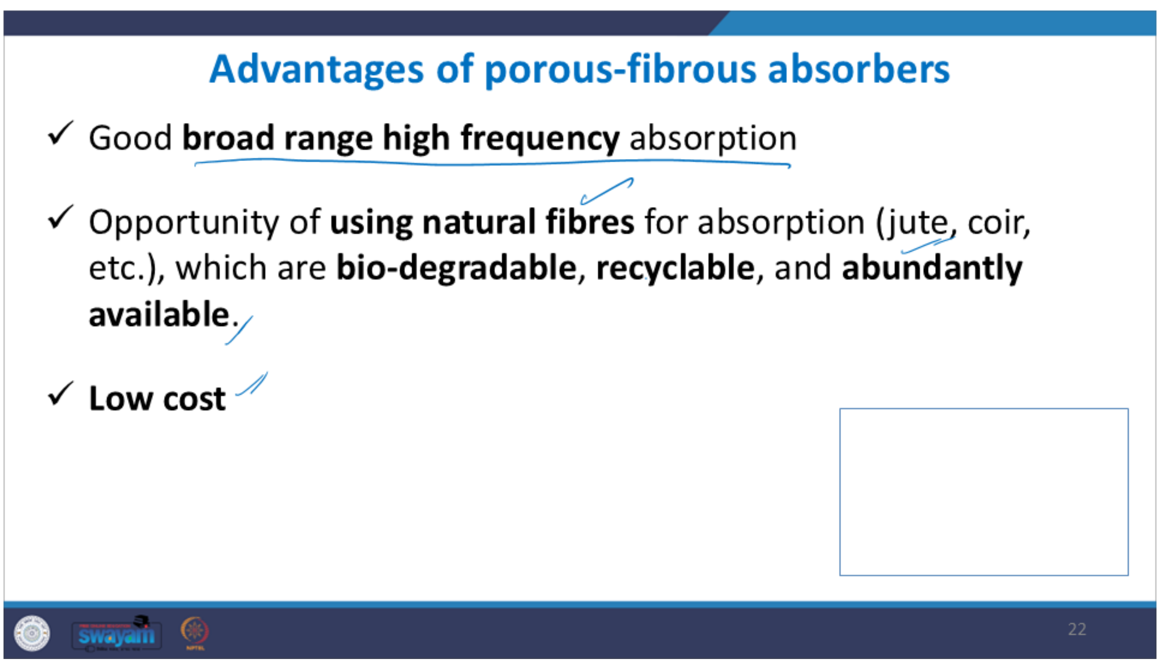
So, you know various kind of treatments can be seen and you can see how you know tailoring the air gap either at the exposed surface or behind the porous material how this mounting condition can change the SAC of that particular material.

So, to summarize from whatever we have you know typically mounting method does affect SAC and if air gap is introduced it is said to typically enhance the low frequency absorption, but this enhancement at the low frequencies can come at a cost of decrease in the absorption magnitude. at the other you know higher frequency zones or at the other places where it was initially high.



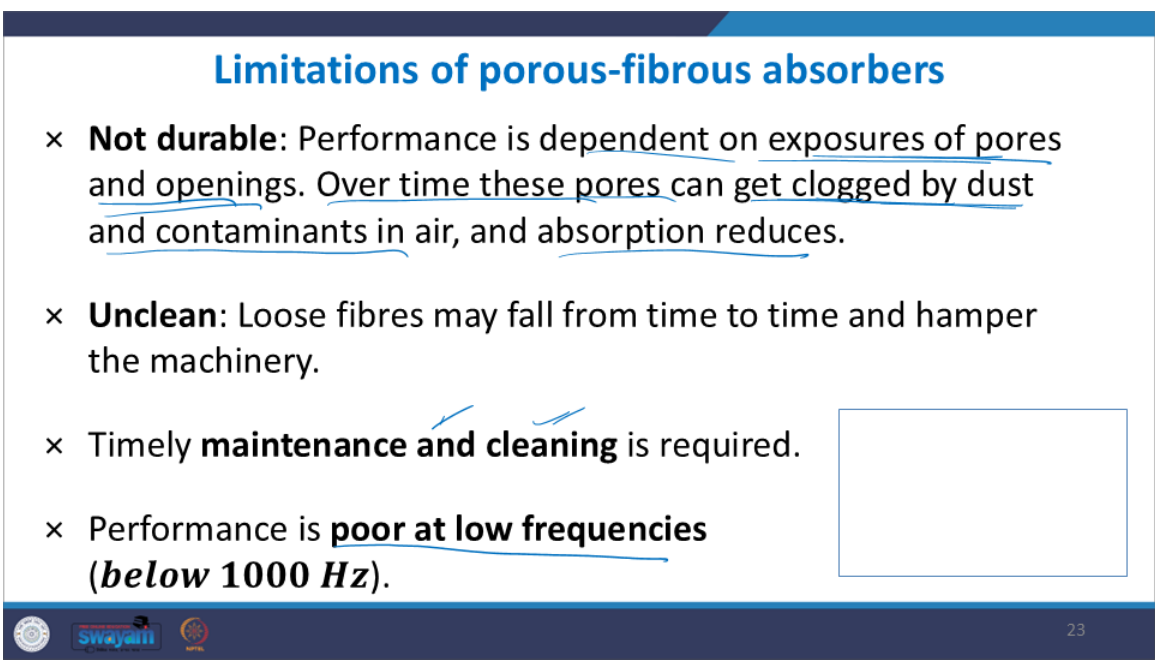
So, we know that in the porous material one of the you know shortcomings is that SAC is below SACs at low frequencies are usually very low. You can introduce air gap to make the situation slightly better where you know with the air gap.

You can enhance the values of SAC at the lower frequencies, but then that will reduce the absorption coefficient elsewhere, okay. So, these are, you know, the typical, you know, kind of absorption treatments and let us see some of the advantages and the disadvantages of these kind of absorbers. So, you know, they are very good for broad range high frequency absorption. So, if you know proper treatment is done and a material is made.



So, let us see these kinds of values here. You would say that usually, you know, the absorption coefficient is quite high—it is almost above 0.8 in a large range, you know, beyond 1000 or 1500 hertz till 4000 hertz or so. So, for a large broad range, you have got higher values of SAC that can be achieved. So, broad-range high-frequency absorption is possible. We do not have sharp peaks, but there is a broad range of, you know, consistently high values.

Then we also have the opportunity of using natural fibers such as jute, coir, etc., which are biodegradable, recyclable, and abundantly available materials. When you use these kinds of things, you can basically create sound-absorbing materials that are biodegradable in nature, recyclable, environmentally friendly, and also very abundantly available in nature. That is why they are very low-cost as well. All of this is, you know, sort of advantages with the porous fibrous absorbers. But obviously, there would be some disadvantages, and as a noise control engineer, then you have to decide based on what your application is. You know, what is your application? Whether they suit your application or not? So, what are the limitations we have? They are not durable, which is the performance is dependent on the exposure of the pores and the openings on the surface. Okay, on the surface, the pores and the openings must be there. But over time, these pores—suppose you don't have protective films or anything—and over time, these pores are exposed to the air. They are bound to get clogged by the dust and the contaminants in the air, and with time, you know, the absorption is going to go down. So, they are not very durable.



And they are unclean. Again, you know, if you are using loose fibers, then after a certain time, the fibers can fall off from time to time. They can hamper whatever machinery you are using these materials in, you know. So, they are not very clean. Fibers are there which can fall off, or even if you are using a porous structure, it can get damaged, and you know, slowly, you know, it starts to fall off. Then, timely maintenance and cleaning are definitely required because, you know, because of the tendency of the pores and the openings to get clogged with persistent usage due to the contamination from the air. Whatever contaminants are present in the air, they can clog it. And the last kind of limitation is that they have poor absorption at low frequencies, typically below 1000 hertz.

So, suppose your application requires You know absorption at the mid-frequency and the high-frequency ranges, okay? So, I think in that case, the porous fibrous absorbers could be your best bet. They could be your best solution because they would offer a relatively good sound absorption coefficient over a broad range of mid and high frequencies, and you don't need to do any additional treatment. One thing you would just need to see is that, you know, they should be timely maintained and cleaned, but they would always be a low-cost solution for you for mid and high-frequency noise control. But if it is a low-frequency or more targeted noise control, then you can think of other solutions for sound absorption. So, with this, I would like to close this lecture.

Thank you for listening.