Acoustic Materials and Metamaterials
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Lecture - 16
Porous-Fibrous Sound Absorbers

Welcome to the lecture 16, this is our fourth week and we will continue our discussion on Porous Fibrous Sound Absorbers. So, last class we studied what are porous fibrous medium which consists of both a solid phase and a air phase and the various form of dissipation mechanism for this porous fibrous materials.

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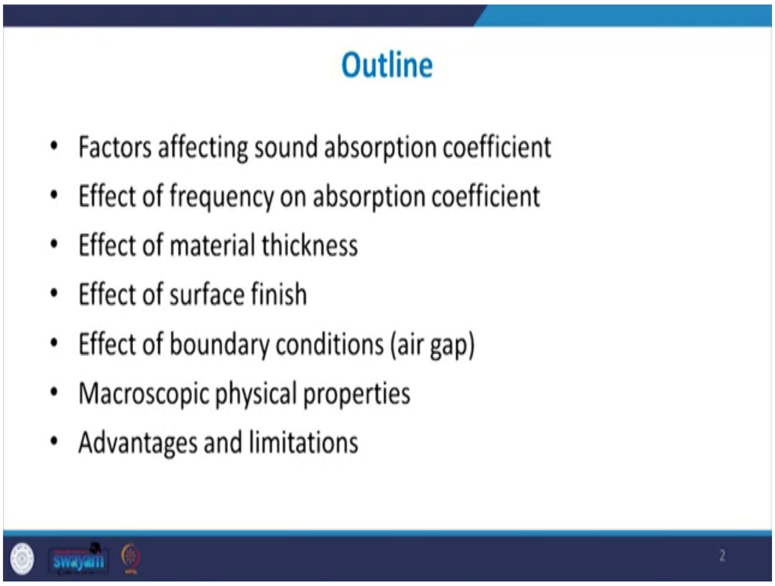

And today we will discuss about; what are the factors that effect the sound absorption coefficient of this porous materials and how they effect the sound absorption coefficient, which will be followed by what are the various physical properties of a porous material that makes it a better sound absorber.

And we will end with a discussion on the various advantages and limitations of using these porous sound absorbers.

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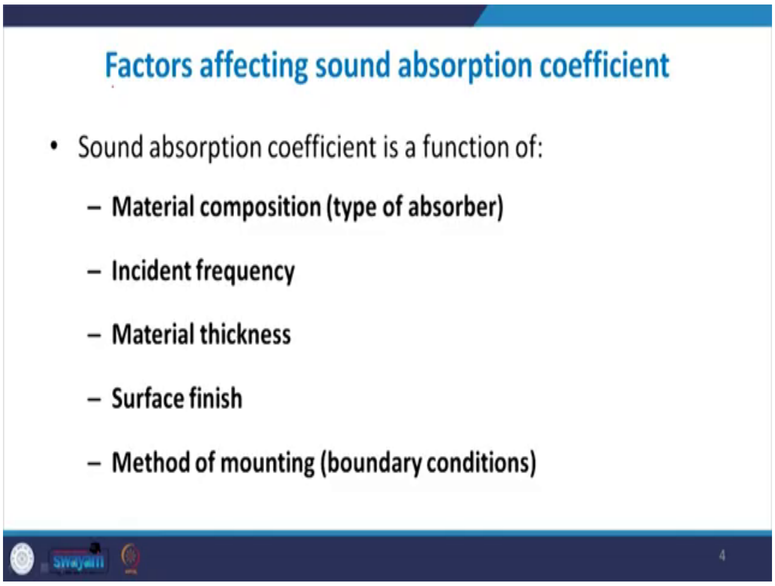

So, to quickly glance through, now what are the factors affecting. So, the factors affecting porous sound the sound absorption coefficient which we discussed in our last class. So, we had briefly mentioned here, I had briefly mentioned was that, sound absorption coefficient is a function of the material that we are using, so, what is the type of material or it is composition then what is the incident frequency, the material thickness, the surface finish and what is the method of mounting or the boundary conditions available.

So, we will discuss these factors one by one on how they affect the alpha value of a porous sound absorber. So, let us discuss what is the effect of frequency.

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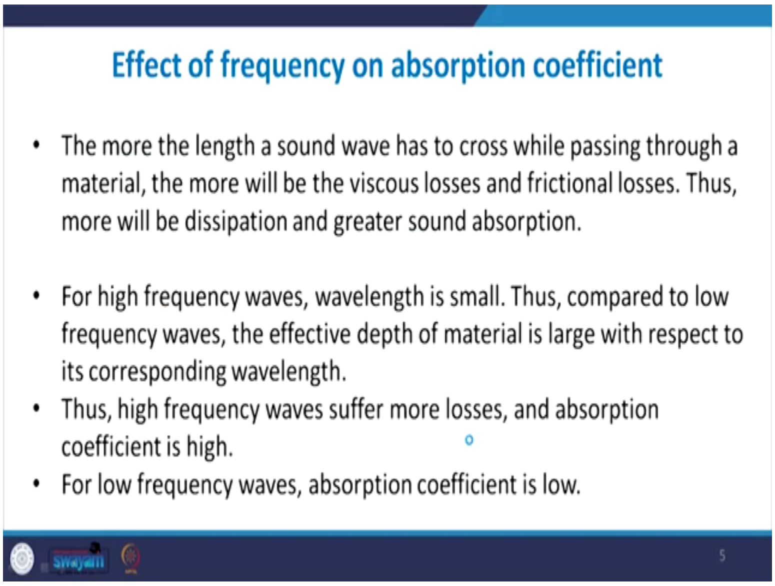

So, as you know that, when the sound wave is incident on a layer of material; then it has to pass through the material and it undergoes a lot of it has to pass through a lot of twists and turns and these pores and openings and viscous losses and frictional losses and other such losses take place and most of the energy gets lost while it and by the time it reaches the other end of the material and it gets transmitted.

So, if we increase the depth of the material; then obviously, more the same sound wave will have to pass through more depth and therefore, more losses will take place, because it will all be dependent on how long it is passing through the material or through what is the effective length through which it is passing.

If a sound wave for example now, if a sound wave has got high frequency; so high frequency sound waves and their wavelength is going to be small. So, which means that, for a small wavelength sound the effective; so if we have the same thickness material. So, we have two materials of same thickness and a high frequency sound is incident on them; then the effective wavelength is small. So, that same wave length which means that, compared to the wavelength the depth of the medium is quite large. So, the sound wave it has to pass through a much larger depth and therefore, more losses will take place.

Whereas, with the same thickness of the material, if the incident frequency is low; so the corresponding wavelength is going to be large. So, as you increase the wavelength of the material; this as you decrease the frequency, you increase the wavelength and as a wavelength increases, the effective depth of the material seems to be smaller and smaller and the wave can quickly pass through without going through some effective losses.

And suppose we have a very high wavelength, let us say 10 hertz or 20 hertz and the wavelength could be 34 meters for that; for a 10 hertz wave, the wavelength will be 34 meters and we only have let us say a 10 centimeter thickness. So, it is effectively a very small portion of a complete wave cycle. So, effective to for that particular wave this material appears to be very thin and it can easily pass through without going through sufficient losses.

And if we have a high frequency, let us say 10000 hertz; then that same things 10000 hertz which means it will be 0.034 or it is 34 centimeters and then we have a few centimeters material. So, for that particular same material thickness will now occupy a major portion and then the same sound wave has to pass through a effectively much more depth. And that is why when frequency is high, absorption is more; because the sound wave has the effective depth becomes more compared to the wavelength of the sound and vice versa.

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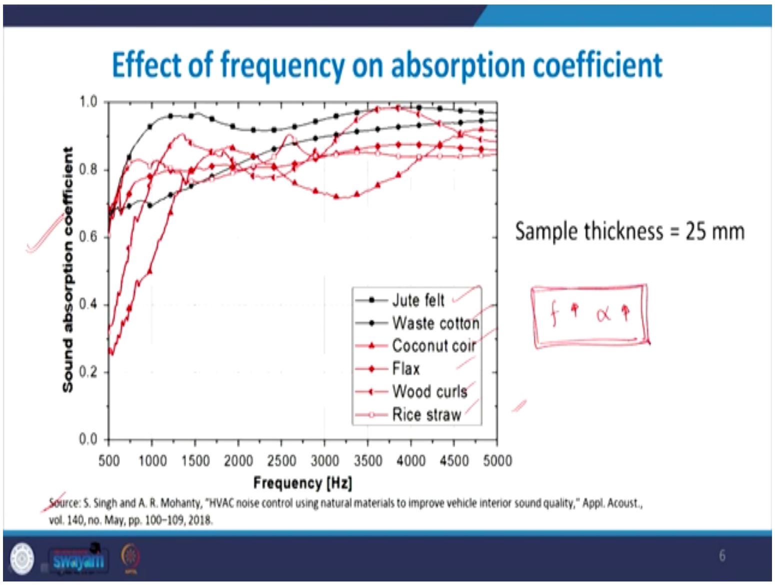

So, this is a graph that shows you the variation of sound absorption coefficient with frequency. So, this has been taken from one of my previous research work and the source is given here for the paper. Here we had compared the sound absorption coefficient of different type of materials with frequency. So, you can see the effect of both material as well as frequency in this.

So, as you can see if the material is different, some materials can be a better absorber and some materials can be competitively less absorbing. So, the graph for different materials is different; but a constant pattern is observed throughout all the materials is that, as you increase the frequency the absorption coefficient is increasing. So, as frequency increases, alpha increases; this is the general pattern that is observed and the reasoning for this I have already mentioned to you.

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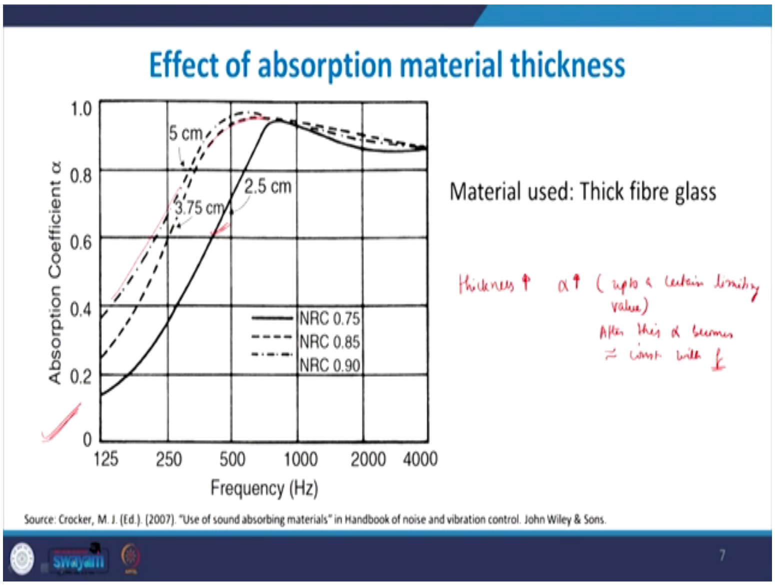

Now, let us see what is the effect of absorption material thickness. So, the same reasoning that I gave for frequency can be applied to this material thickness. So, if we have a certain material with a certain thickness. So, as you increase the thickness of the material; which means that, the same sound wave will have to pass through a much larger distance. And therefore, as it keeps passing through the material, the losses keep increasing and increasing; but there is obviously, a limiting value to this, beyond a certain range it cannot absorb more.

So, as the value of alpha approaches above 0.9 in general, then after that more absorption does not take place. So, effectively what happens is, if you see this graph here; then you have this original material here which is of 2.5 centimeters, then you increase it is thickness. When you see, suddenly the alpha value has increased; but after it has reached a certain limiting value it becomes a smooth curve.

Similarly here alpha increases beyond and after that it reaches to a constant value. So, the pattern observed here is that, as thickness is increased, alpha increases up to a certain limiting value after which the curve becomes constant, approximately constant with frequency. So, that is the pattern observed.

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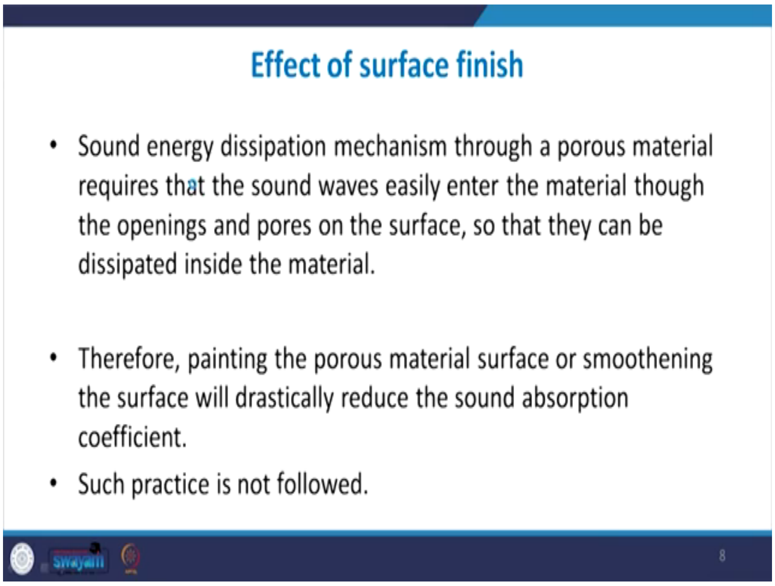

Then what is the effect of surface finish. Let us say we have a porous fibrous sound absorbing material and we paint the entire surface or we polish the surface; or we if we increase the surface finish, we make it more smooth, we paint it or we smoothen it through some other means.

Then that will mean that, in that process most of the pores and the openings it will get blocked. We are smoothening the surface which means; we are blocking the pores, we have painting the pores, and we are blocking the pores. It was the pores that was giving this roughness to the material. So, in that case when the pores get blocked, so what will happen? The sound waves will not be able to enter properly. So, the reflections would be more. So, the criteria for a sound absorber a porous sound absorber was that, it should be able to allow most of the sound energy to enter inside it, so that further it can be dissipated.

But now due to painting that surface, it is behaving more like a hard deflecting surface and the sound wave is not even able to enter and it gets reflected back. So, alpha value is going to drastically decrease. So, that is the effect of surface finish. So, if you take a look here. So, as you, so what happens is that; when you paint the surface, it drastically reduces the sound absorption coefficient. Why? Because now the sound waves would not be able to enter the material easily and therefore, such practice is not followed.

So, whenever noise control is done using this kind of material, then these kind of materials are not painted or smoothened; it is used in it is raw form, because otherwise the purpose of using this material will be lost, if you paint this particular material.

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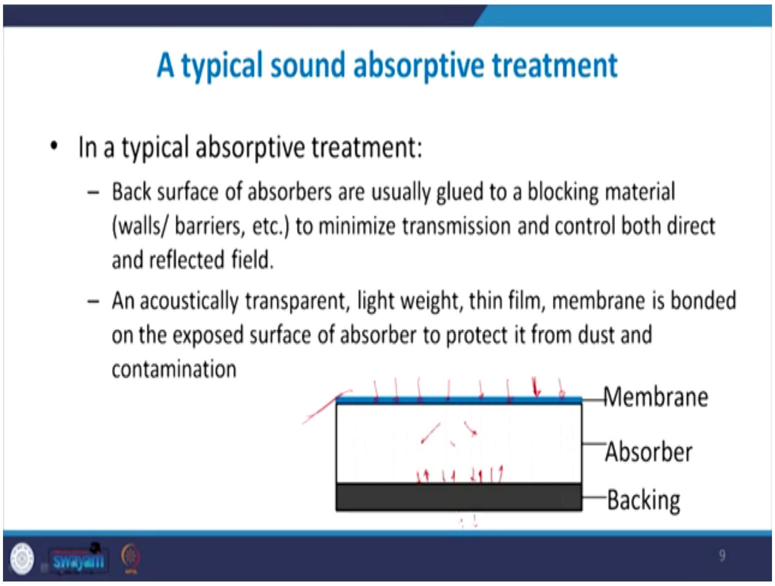

So, in the last class I had given you a typical sound absorption treatment where we have a absorber, we place a thin membrane on the top of it and then backing material at the back.

And the purpose was that this is acoustically transparent thin film, so it should not be able to block any sound wave; sound wave should just pass through. The only purpose of this particular film is to protect the openings and the pores; because as the sound wave, suppose we have installed a particular absorber in a manufacturing plant or in any building as well. So, with time because the sound wave keeps passing through these materials, it can get blocked inside the pores or the fibers; and more and more dust can get collected.

So, if you see for example, let us say for example, I will take give you a common desert cooler; it has got a layer of fibrous material at the back, but that needs to be always cleaned, dried and put again. Because that layer of fibrous material at the back it gets contaminated, because in that desert cooler we have a constant air flow, it is a cooler. So, when the air is flowing through the; obviously, the contaminants that are present within the air whether it is dust particular or smoke particles, they will also pass through and over the long run they will contaminate and they will get blocked. So, the material will become dirty and the performance is going to reduce.

In the same way, the same thing will happen with a sound absorbing medium with the long run or continuous use; the contaminants present within the air particles such as dust and smoke and block these pores and that is why some protective layer is added at the top and a backing is given at the back to further minimize the transmission.

So, because absorbers they do not block it, they allow the sounds to pass through and some energy gets dissipated and whatever is transmitted can then further be reflected back for more dissipation and overall the transmission can be very low. So, this is a typical absorptive treatment.

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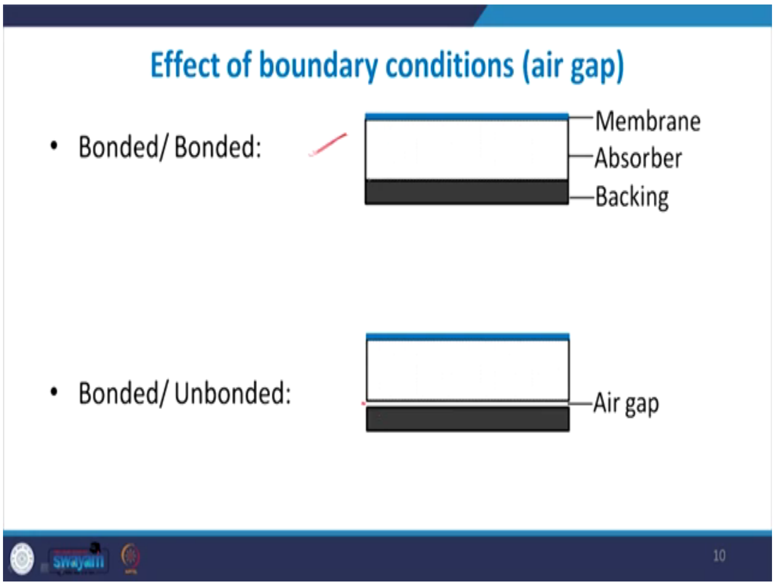

So, the way this treatment is done is it was found that, if you have the same material and if you introduce some small air gap in between this treatment. So, this was the original treatment and then a small air gap is introduced between the absorber and the hard backing.

So, this is bonded bonded this is bonded unbonded.

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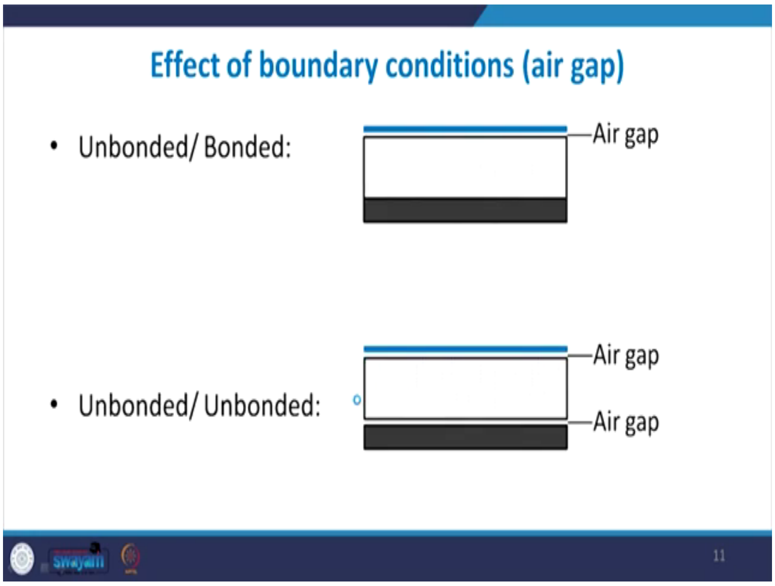

Similarly, we can have unbounded bonded treatment and a unbonded unbonded treatment. So, the only difference here is that, overall the material thickness is the same; only a small amount of air gap is added between the 2 tree, between either the membrane and the absorber or between the absorber and the hard backing.

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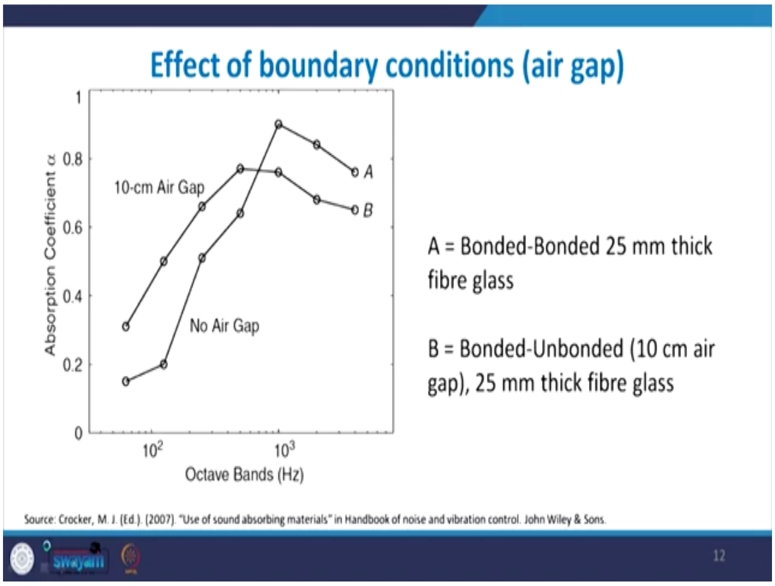

So, when this happens or a air gap is introduced, then this is the sort of graph we get. So, remarkable thing was observed is that, even introducing a small air gap can lead to some changes in the alpha value. So, this is I will show you a few patterns of what happens. So, he had we had a material which is a; the material was a 25 millimeter thick fiberglass composite. So, this is without any air gap, this is bonded; so we have a material followed by some hard wall. This is the material followed by a air gap between the material and the wall. So, it is bonded unbounded, as 10 centimeter air gap has been put.

Then suddenly what you observe is that, this low frequency absorption has enhanced. So, a common limitation of all these porous materials; when we go through these graphs here. So, whatever graphs we have studied, whether it is this graph or whether it is this graph. So, this graph or this graph; if you follow these two graphs you see that, low frequency absorption is always very less and they only perform better beyond 500 or 1000 hertz.

But if we introduce the air gap then we see that this low frequency absorption can be enhanced; but the overall absorption magnitude at the high and reduces. So, this becomes a more broader form of absorption both at low and high frequencies.

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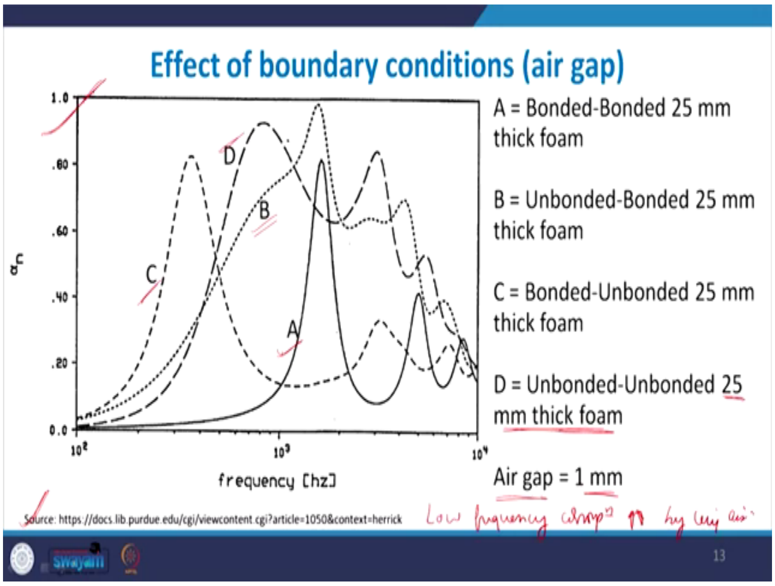

Then this is the, this data has been taken from an experiment conducted in Purdue University, the source of this is provided here. So, here the four different treatments were tried for a thick foam. So, a 25 millimeter foam material was used and the air gap introduced in each case was 1 millimeters.

So, if you see here, if 25 millimeters is the thickness and we introduced just 1 millimeter a gap; then the thickness can increase to just 26 or 27 millimeters. In that case, just by increasing the total overall thickness of the treatment by introducing a very small air gap, alpha values can be changed remarkably.

So, here you see is that this is the case for a bonded, then this is for unbonded bonded, this is for bonded unbounded, and this is for a unbonded bonded case. So, the overall pattern again we observe is that, low frequency absorption has increased by using air gap from both these graphs we see here.

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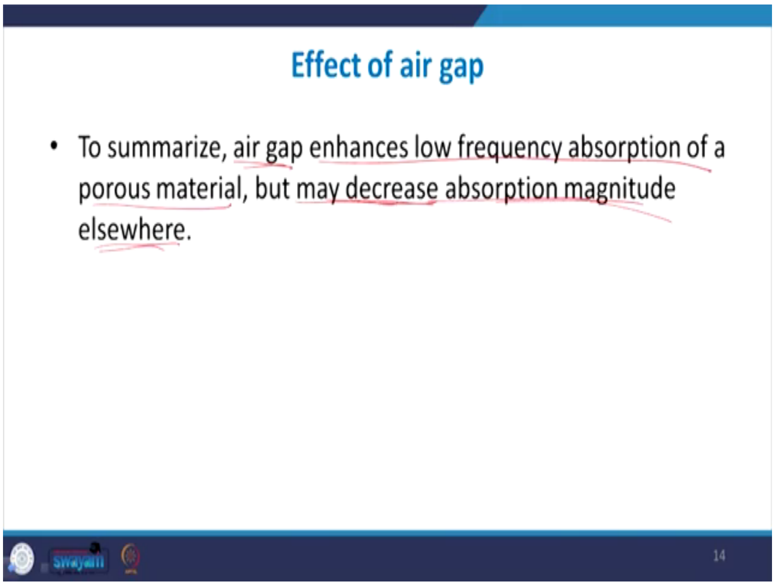

So, to summarize air gap can enhance low frequency absorption of a porous material; but it may end up decreasing absorption magnitude elsewhere depending upon what is the width of the air gap.

If a large air gap is there, then there will be a large decrease in the magnitude; if a small gap is there, they may not be significant decrease in the magnitude and so on. So, depending upon when and where and what thickness of air gap is applied; the overall magnitude main reason degrees, but in general the low frequency absorption can be slightly enhanced by putting in an air gap in between the material and the backing.

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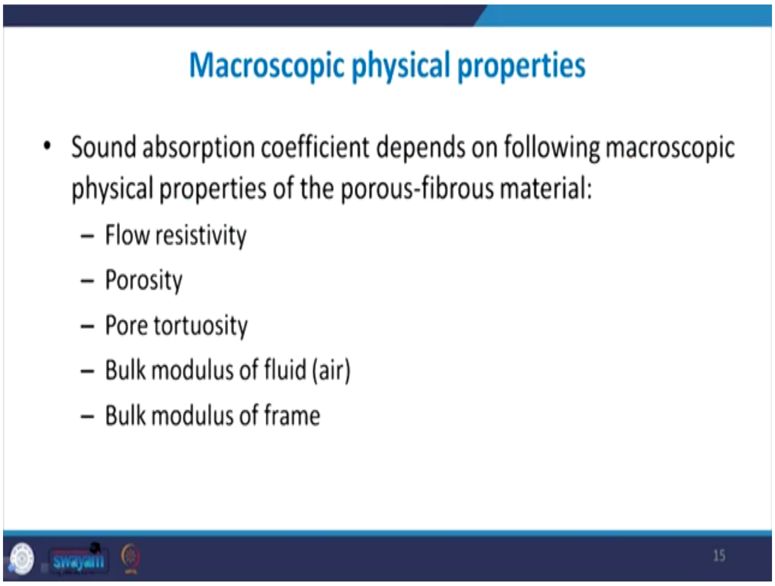

So, now that we have studied these properties and what are the how these effect the alpha value.

So, at the beginning itself I had told you that, the alpha value also depends upon the type of material we use. So, how it is made up of what composition were using. So, what are these material characteristics which make it a good absorber or what are the physical properties that make a material a good absorber. To study that, I am going to come and discuss about a new topic that is called as a macroscopic physical property. So, these are those physical properties which together determine whether the material is going to be a good absorber or not.

So, what are those various physical properties; these are the properties which determine what should be the alpha value of a material. So, they are flow resistivity, porosity, pore tortuosity, bulk modulus of the fluid, and the bulk modulus of the frame. So, we will study the definitions of these one by one; I will not going to a in depth detail on how these properties actually effect the alpha value, this is just for a general knowledge that there are certain properties which actually together determine whether a material will be a good absorber or not.

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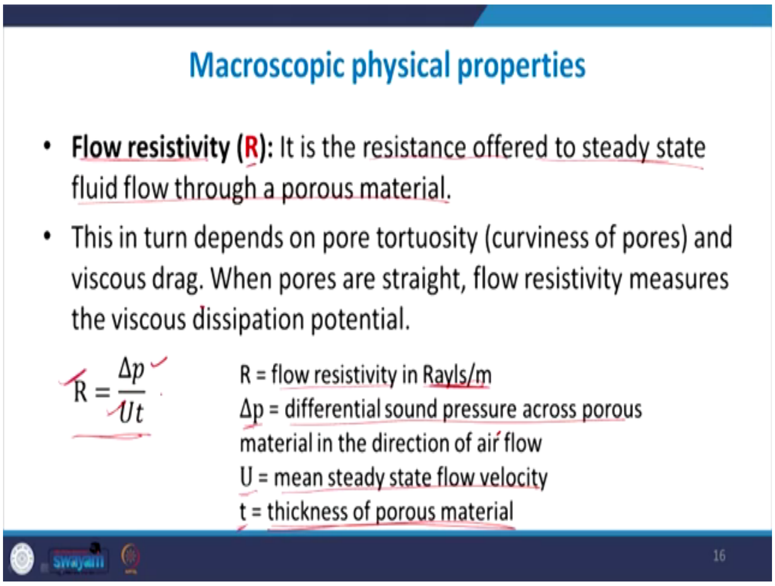

So, the first property is flow resistivity which is denoted by this symbol R here. So, by the name itself you can guess this is the resistance offered by a material to the steady state fluid flow through a porous material. So, what is the resistance that material is offering to the steady state flow of fluid through it, such a steady state flow of water or steady state flow of air?

This is given by this expression here. So, R is given as del p by U t; here R is the fluid resistivity which is measured by this particular unit, del p is the differential sound pressure across the porous medium, U is the mean steady state flow velocity of the fluid which is flowing through the material and thickness t is the thickness of the porous material. So, this is the total definition of the flow resistivity. So, if you see it in terms of electrical analogy, then the resistance of a the resistance is given by voltage by current. And in terms of acoustics we studied about a similar term called impedance, which is like a complex resistance and that was also given by the pressure difference or the pressure by velocity.

So, the same thing has been applied here, we have this pressure net pressure difference which acts as the voltage and what is the mean velocity which is the current flowing through and this gives us the resistance to the flow; and t thickness is multiplied to it, because it depends on the thickness of the material as well.

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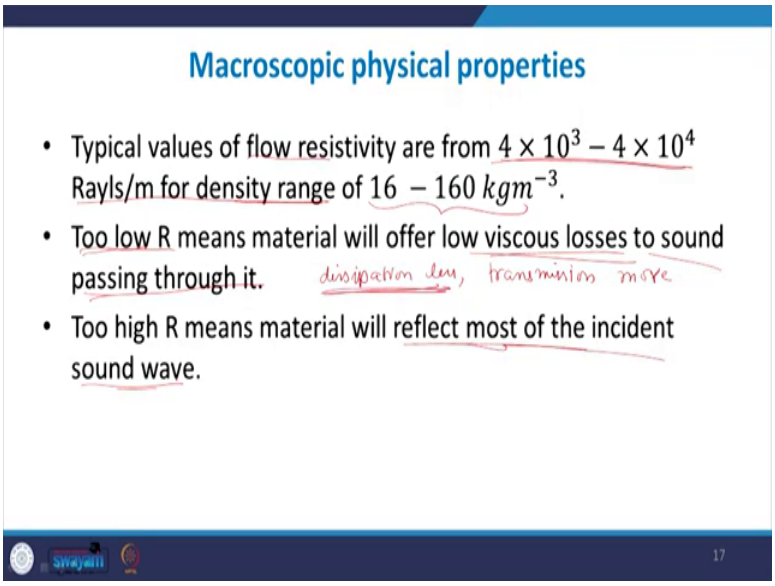

Now, typical values of flow resistivity is given here, this is for most of this covers most of the porous fibrous materials in this particular density range.

So, if suppose the R is too low, now resistance to flow is too low which means that; this material will allow all the sounds to pass through and there will be no resistance within the material. So, both of viscous loss, the viscous loss or and any other form of losses will be less. So, if too low R means, the viscous losses are going to be low; so obviously, the dissipation will be less and transmission will be more. So, most of the sound is just flowing through without any resistance. So, reflection is obviously less; but transmission is more and dissipation.

So, overall the dissipation within the material is less. But if you have too high value of R; what does it mean that, now it becomes like a hard deflecting surface, it does not even allow any waves to pass through. So, here the reflection will be more. So, a mid value is usually desired, so that sound waves can flow through; but they also get dissipated.

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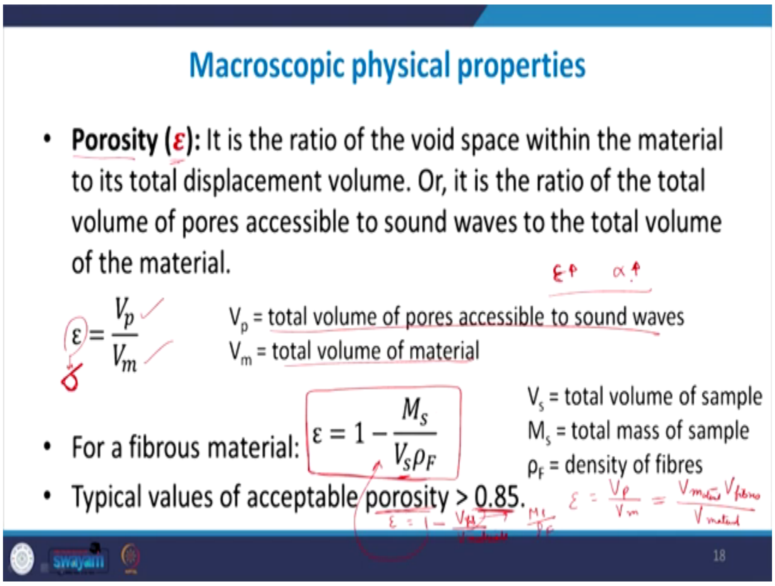

The second property is called as the porosity which is denoted by this symbol here. Sometimes a porosity is also denoted by the symbol sigma; when we study about a different form of absorber, we will be using this sigma as well. So, it is porosity is defined as what is the ratio of the pores, what is the ratio of the volume of pores which are available divided by the volume of the material itself.

So, this is V p by V m which is the total volume of pores accessible to the sound waves by the total volume of the material. So, for a fibrous medium this expression comes out to be this; which is 1 minus the total mass of the material divided by the total volume of the sample into the density of the fibers. So, you can easily work it out from this one also. So, this becomes the volume of the air or the pores by volume of the material, which will be volume of the pores will be simply the volume. So, for the fibrous medium this becomes the volume of the total material.

So, here how have we got this expression; this is simply see volume occupied by the total material minus the volume occupied by the fiber. This will give you what is the; the difference between the two will give you what is the volume of the pores divided by the volume of the material, so V material minus V fibers by V material. So, what we get is E can be written as 1 minus the volume occupied by the fibers divided by the volume occupied by the material and this is found as. So, the volume occupied by fibers is simply the mass by the volume of the sample.

So, this is the volume occupied by the fiber sorry. So, the volume occupied by the fiber becomes this particular quantity here. So, volume occupied by the fiber becomes the mass of the sample by the density of the fiber will give you the total volume of the fibers and this is the volume of the material. So, overall this is the expression we are getting. So, derivation is; obviously, not within the course; but it is good to know how this expression came about.

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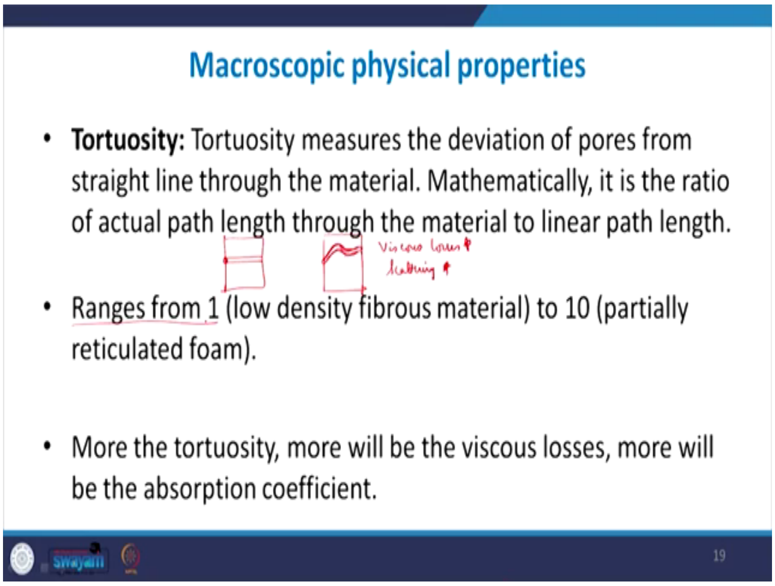

So, porosity is defined and again as the porosity improves, the materials absorption value is going to improve; but just like in flow resistivity, there will be obviously some mid range value.

Too low a porosity means that the material is almost solid. So, it would not be a good absorber, it will rather be a good reflector; but to higher porosity means that, now the structure is too weak and cannot be even used. And obviously a porosity equals to 1 means; there it is no solid medium, it is just air. So, it has to be a mid range value; but usually higher value, so porosity are preferred. So, typical acceptable porosities are be up to 0.85 or more; and as in general as E increases, alpha also increases in general. So, high velocity high value of porosity is desired ok.

The third property here is tortuosity which means that, what is the deviation of the pores from a linear path. So, we can have a material here and this can be a pore or an opening with the straight path or we can have a material here and the same pore is all twisted and goes through a very sharp turns. So, as you know that the more is a tortuosity which means that, first of all the sound wave has go to go through larger length compared to the material thickness. So, as the tortuosity increases you see here; this length, this path length for the sound wave is going to increase.

So, which means that, and the viscous resistance is dependent upon the length that the fluid has to cover. So, as the length is increasing, the viscosity will obviously increase. So, viscous losses will be more; the longer the path it has to travel, the more will be the viscous losses. So, viscous losses are going to increase and scattering will also increase, because of the sharp bends and turns. So, overall as you increase the tortuosity, there is going to be more dissipation and therefore, alpha value is going to be high; the typical range of tortuosity is from 1 to 10.

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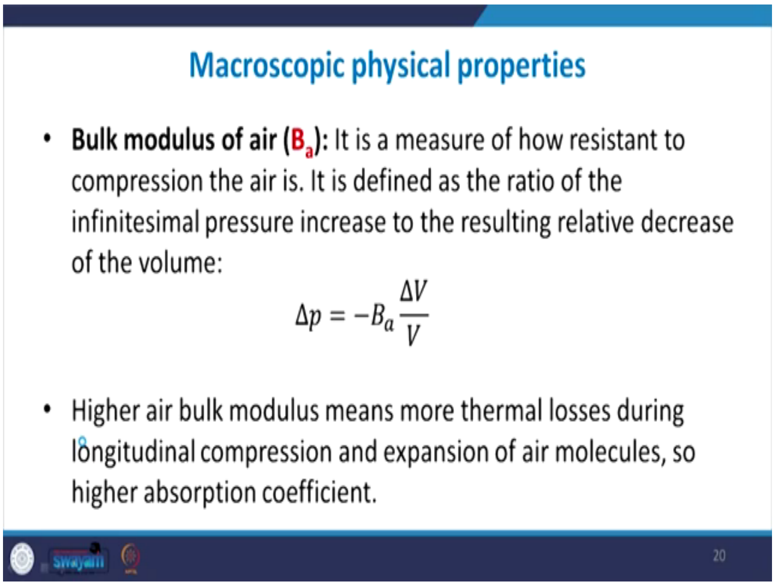

So, then we have the last two parameters are bulk modulus of air, which is the resistance to the compression of the air and the bulk modulus of the material which is the resistance to the compression of the solid frame.

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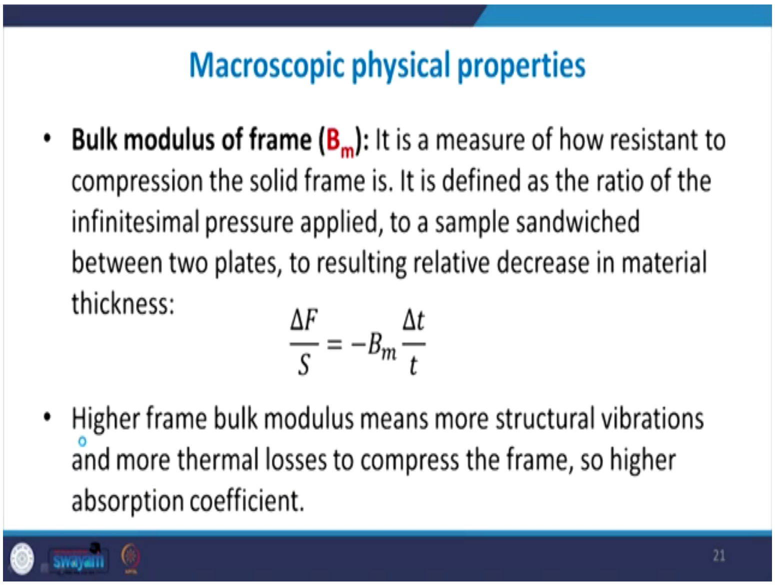

And these are the expressions for that; resistance to compression for the air and the frame. So, we are going to study their properties together.

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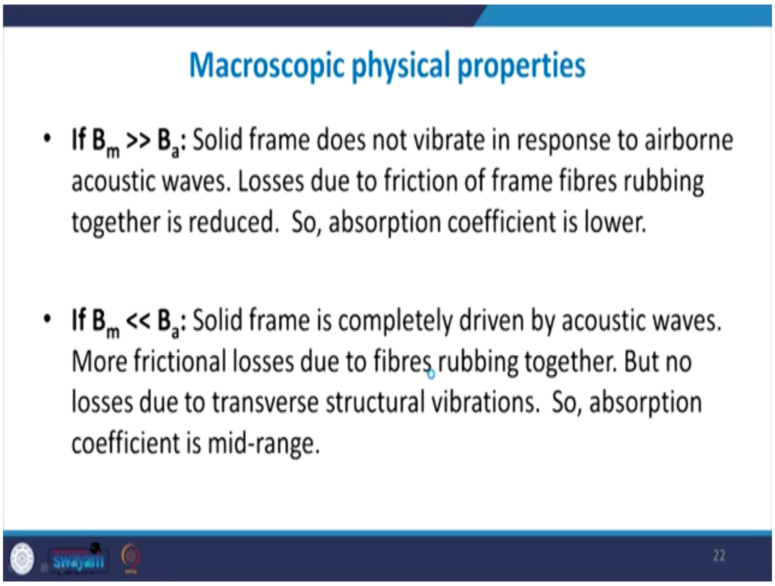

So, if suppose the bulk modulus of the material is much greater than the bulk modulus of the air medium.

So, in that case what it means is that; in that it means that when the air is passing through, then the material will be almost very stiff, it would not vibrate, it would not compress or expand. There will be no response to the acoustic waves flowing through. And because the material will not respond to it which means that; the losses due to friction of the fibers rubbing together will not happened. So, there will be no loss due to friction, there will also be no loss due to any other compression and expansion of the material.

But if the, so in that case absorption coefficient is going to be low; because where would not be any fictional losses. If the bulk modulus of material becomes very small compared to the air; so now, it is offering no resistance at all. So, the way the sound waves are flowing, it is following the same pattern. So, it is a effectively it is the acoustic waves; so the sound waves flowing through the air medium which are which is also driving the material. Therefore, in that case, the loss frictional losses will be more.

Because now as the sound vibrates to and fro, so as well as the sound vibrates to and fro while passing through the material; the material will also vibrate to and fro, then the fibers can rub against each other, and lots of friction loss will take place. But because it does not offer any resistance to compression or expansion; so there would not be any structural vibration loss. So, in this case alpha will increase, but alpha will be a mid range value.

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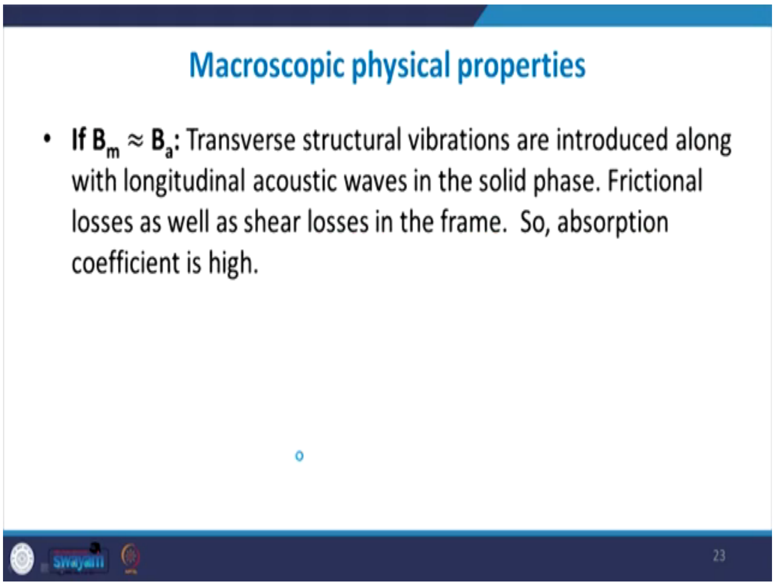

However when both are of the same order in that case both happens; both the frictional losses take place as well as we have the material is resistant enough to compression and expansion.

So, it resists this and this loss due to structural vibration is then introduced. So, we have both frictional and vibrational losses due to the structure, and alpha value in this case is very high.

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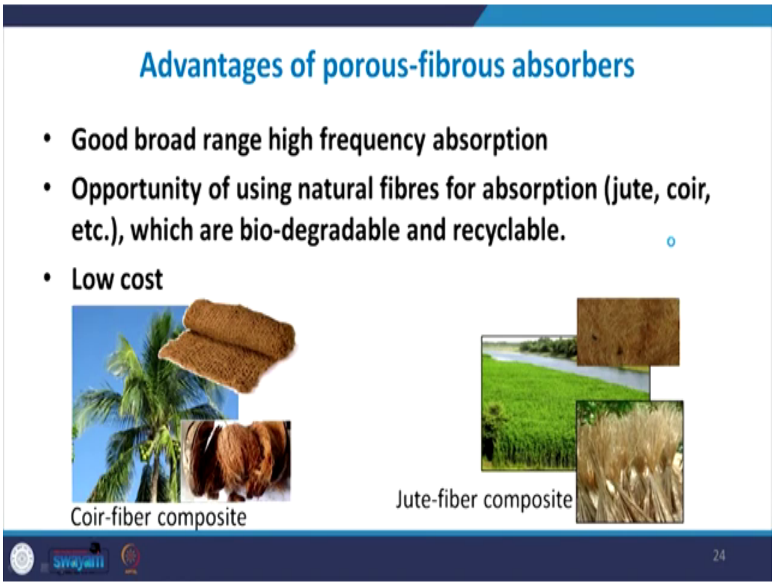

So, this is how the different macroscopic properties they determined; how the overall material will behave as an absorber. So, let us quickly glass to what are the advantages and limitations of a porous fibrous absorber. So, first of all it offers us a broad range of high frequency absorption. As you have seen from all the graphs beyond a certain limit, where 500 to 1000 beyond that every almost every absorber the value reaches more than 0.8. So, it is usually a very good absorber at a wide range of high frequencies.

And then we also have the opportunity of using some natural fiber materials. For example, we can use materials like derived from coir so we can have a coir fiber, derived from jute we can have some jute fibers. So, natural biodegradable materials can also be used for such absorption. So, biodegradability or the eco friendliness is an option and then low cost. All the materials that we have discussed here they are not very high and they are easily found in nature or can be easily manufactured and therefore, it is a low cost solution.

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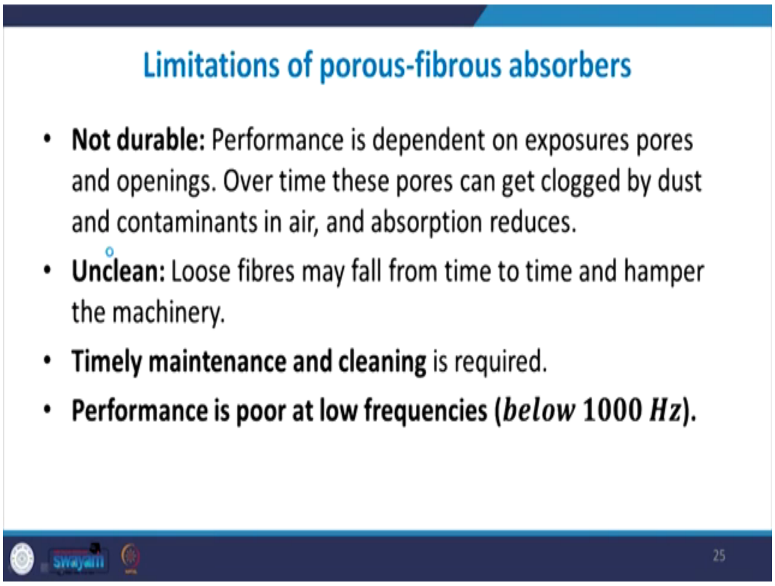

But the limitations here is that, these solutions are not durable; which means that, here the performance is dependent on the. We know that the performance is dependent on how many pores are exposed; but with the long term usage these pores can get clogged by dust and contaminants and therefore, the absorption can reduce. Therefore, it is very unclean solution. So, first of all it is not durable and therefore, it needs timely maintenance and cleaning. And more over if you are using such fibrous medium; so loose fibers can always, there is always a chance that some fibers can fall out.

So, if it is used in some complicated part of the machinery, then these fibers that are falling out over a long term usage can contaminate or block that machinery. So, it is not a clean solution and most importantly their performance is usually very poor at low frequencies typically below 1000 hertz. So, these are a few limitations. So, the next set of sound absorbers that we will study, which is a Helmholtz resonator or a panel resonator. All of that they will try to overcome the limitation of this porous fibrous medium. So, with that we would end this particular lecture and see you for the next lecture.

Thank you.