Acoustic Materials and Metamaterials
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Lecture – 11
Acoustic Materials

Welcome to the third week of a series on Acoustic Materials and Metamaterials. So, in the first 2 weeks, we studied about some fundamentals of acoustics and the fundamentals of noise control. Now we will begin with the discussion on Acoustic Materials. So, today is a lecture on an introduction to Acoustic Materials.

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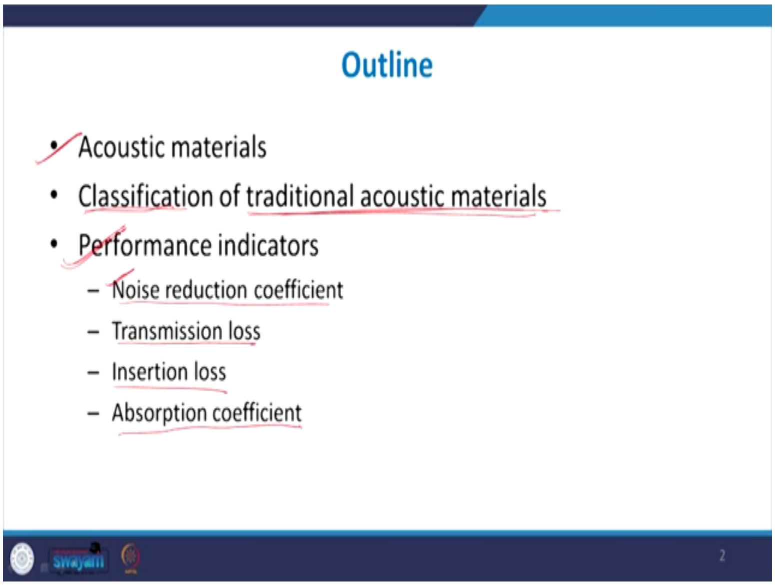

So, the outline for the courses we will first start with a discussion of what is meant by acoustic materials and what are the general principles of reducing, how do this acoustic materials try to reduce the noise . So, what is the basic principle behind these acoustic materials, then a classification of some traditional acoustic materials. So, in this in the next 2 weeks over the next 2 weeks what we will study is some standard acoustic materials which are being widely used since a lot of time now.

So, these are the traditional acoustic materials and then after that from the fifth week onwards we will discuss about what are the limitations of acoustic materials and we will delve into a new type of material called as the metamaterial. So, today here we will do the classification of the traditional acoustic materials and then how is the performance of these materials measured. So, we have different way of measuring the performance, one is called is the noise reduction coefficient or rather noise reduction, then we have transmission loss, insertion loss and absorption coefficient.

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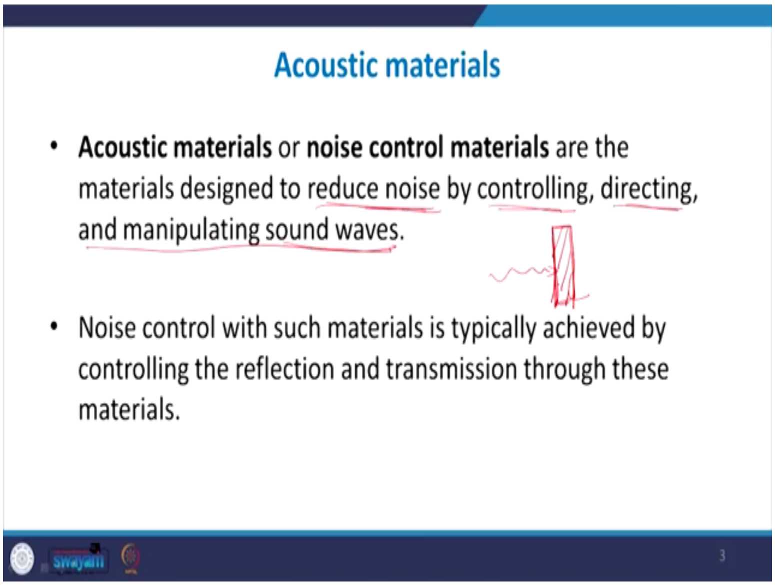

So, what is meant by acoustic materials, they are typically acoustic materials you can call them or you can also call them noise control materials. So, they are the materials specifically designed to control the propagation of sound waves and how do they do it? They reduce the noise by either controlling, directing or manipulating the sound waves as it passes through the materials. So, the main principle is that now you know that whenever a sound wave is propagating. So, it is propagating in some fluid medium one and suddenly it encounter some boundary.

So, here the boundary can be a layer of material and the sound wave is propagating. Then whenever it encounters the boundary then a part of energy is reflected some part gets transmitted and when there is a material then some part of it also will be dissipated.

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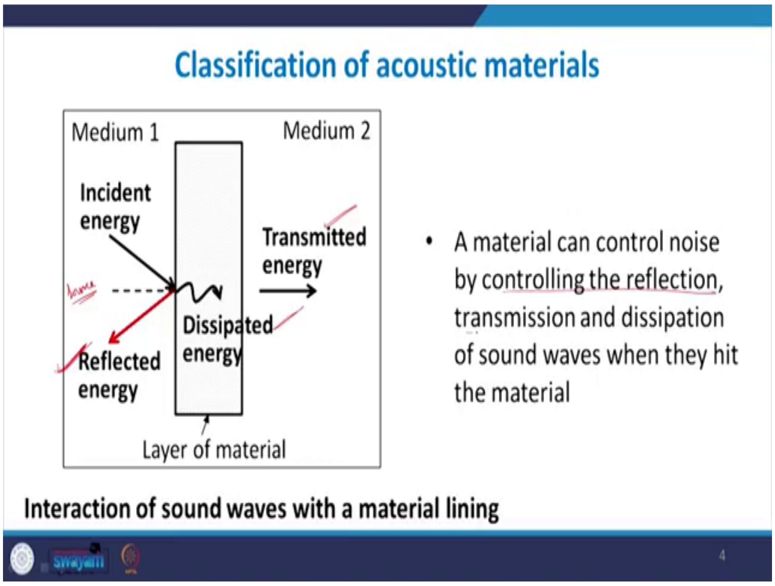

So, to give you a semantic here suppose we have place the layer of material and this is where this is where the source is. So, the source is generating the sound wave and we have placed a material in between.

So, how do these waves interact? They will some part of the energy is reflected some part is transmitted and some part of it is lost or dissipated when it passes through the materials. So, it be it can depend upon the structure of the material. So, the material can offer some resistance to flow and that is why some of the sound wave energy gets converted into heat and due to the friction faced while passing through the layer of material. So, all this happens and by manipulating this phenomena either by controlling reflection, dissipation and transmission the different materials they control the sound they control the noise by manipulating these things so, by controlling reflection, transmission and dissipation.

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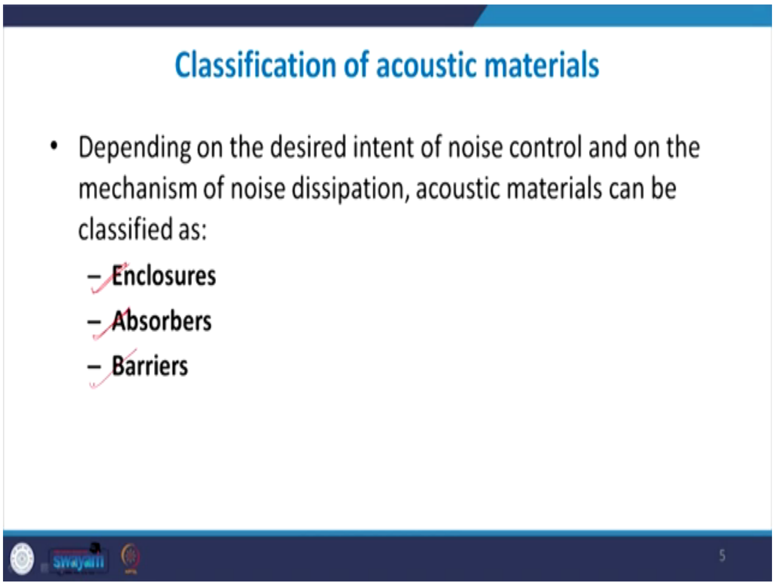

So, depending upon what is the intent of noise control and what is the mechanism through which this noise is being dissipated or being controlled, the materials are generally classified as enclosures, absorbers and barriers. So, what is the basic difference between these three?

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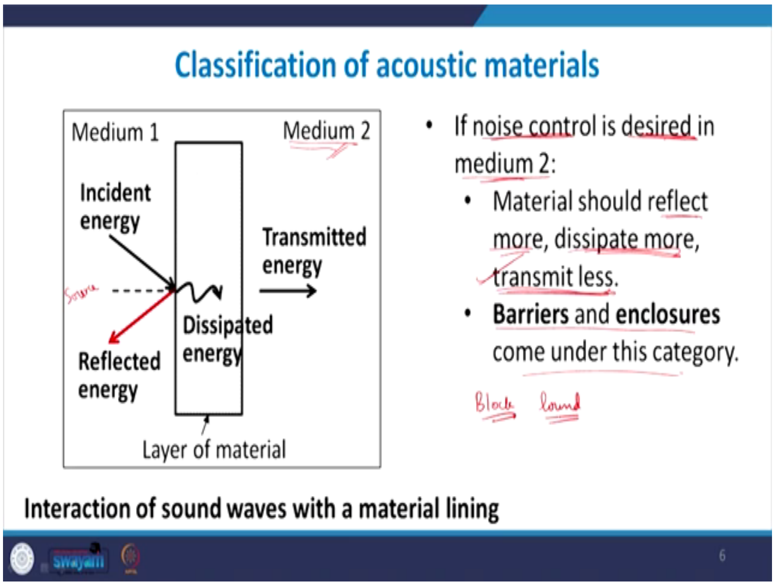

So, let us say we again refer to the same diagram this is how the interaction takes place in the material. Now suppose this is the medium where the source is being source is generating the noise and we want to reduce the noise and the medium 2. So, here noise control is being desired in the second medium. So, the main purpose here is that we want a material. So, we have some source. we place the material so that it does not allow the sound waves to pass through it. So, the other end of that material could be controlled so, the noise can be controlled in the other end.

So, here to achieve this, the material should be able to it can the main purpose is that here it should transmit less. So, as less amount of energy should be transmitted so that this medium could be quite end. So, for that either you should reflect more or dissipate more, but transmit less so that becomes the principal and the materials which are barriers and enclosures they come under this category.

So, what is that they do? They block sound. So, if you have to talk in general term so, whenever these materials are placed whatever sound is heating them the main purpose of this is that they want to reduce they do want to reduce the flow of sound waves through the material. So, as much less energy is transmitted through the material. So, they are sort of blocking the sound.

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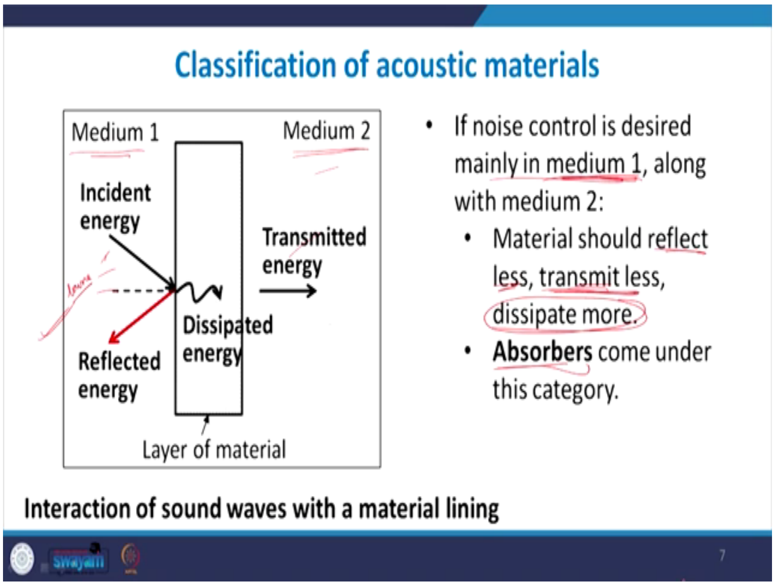

The second type of control can be let us say now that in the same thing same situation, we want to control the medium the noise in the medium 1 itself. So, here this is the medium where there is source is there, the noise is being generated and we want to control the noise primarily at the medium 1, but also at the medium 2. So, both ways we want to control noise.

So, in that case just a blocking material may not be sufficient because here the blocking material will block it. So, when it blocks it, then this medium 2 will be quite end, but all the sound will be reflected back and this medium suddenly the sound pressure level will increase. So, this is what we do not want, if you want to control both mediums so, in that case what we want is that the material should be able to transmit less. It should also be able to reflect less. So, this reflection is also reduced transmission is also reduced so which means that almost all them energy is getting dissipated while passing through the material. So, that is how we can control both the mediums and the absorbers they come under this category, where both mediums can be controlled. So, this is the basic principle of both.

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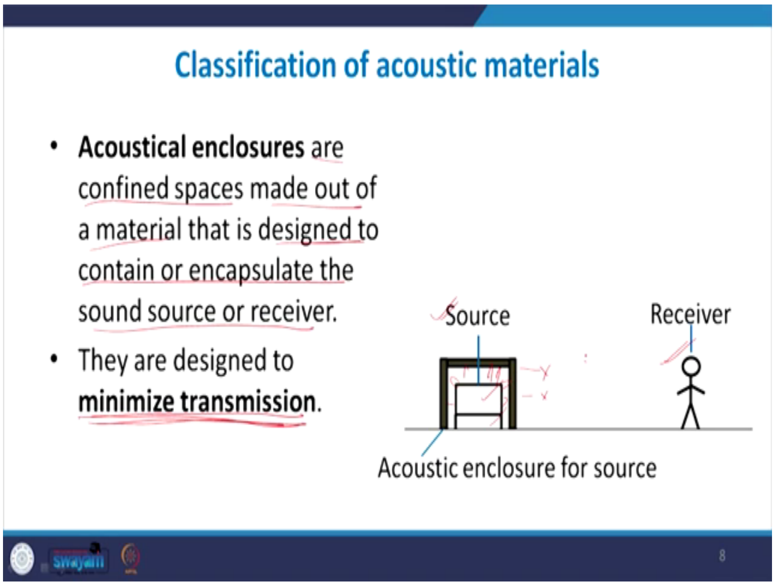

Now, let us study let us study these one by one. So, we will briefly study what are enclosures barriers and absorbers and then in the subsequent lectures, we will go deep into these materials. So, acoustic enclosures are confined spaces. So, these are usually confined spaces that are made out of a material to that is so designed to contain or encapsulate the sound source or the receiver.

So, the basic criteria here is that, they should minimize the transmission through the material so, as we have studied. So, let us say there is a machinery here a machinery or a source is here and we have some receiver. So, what do the enclosures do, it enclosure as the name suggest is that we can either enclose the entire machinery or the entire receiver we can close this with some thick walls, then whatever sound is being generated it is reflecting back or this material is simply blocking the sound nothing is going outside or almost nothing is going outside. So, this was the main purpose and you can do this, you can have enclosures both at the source.

So, either at the source you fully covered this source with such material that no sound, sound only remains confined within the space and nothing goes outside so, the speaker is protected or you can simply protect the speaker by enclosing him or her.

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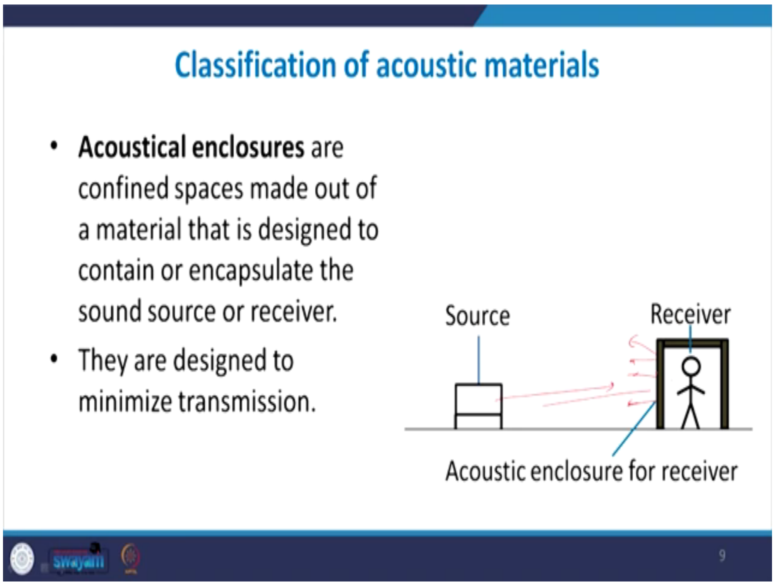

So, the machinery is generating the sound, but nothing of that is entering this medium everything is getting reflected or blocked. So, again this medium is quite end. So, in both cases the transmission is minimized, here also nothing goes outside and here nothing enters inside or you can have enclosures both for the source and the receiver.

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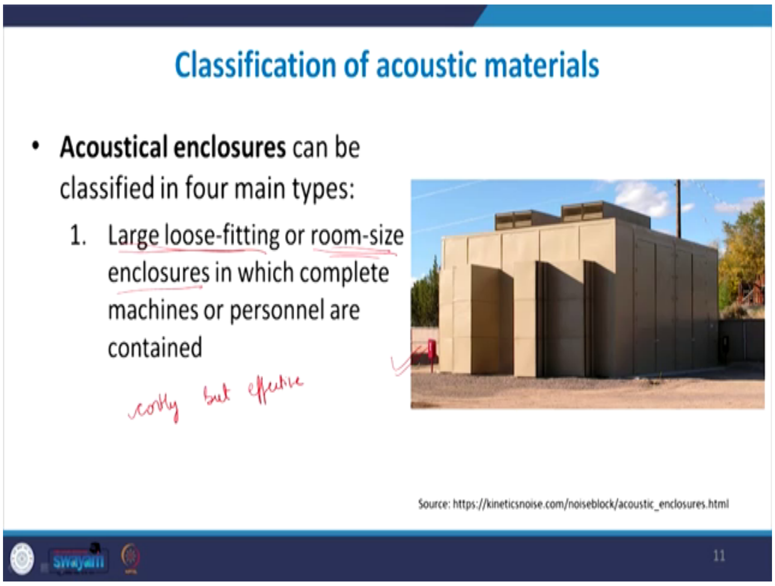

Now, there are various types of acoustic enclosures that are usually encountered in an industry, the first type is if you see this figure it is a large loose - fitting or room size enclosure. So, let us say we have some industry where we have lots of machines so and the entire machinery setup. So, sometimes you see that the entire machinery is being isolated. So, there is no worker which works near the machinery. So, the entire machinery and it is components they isolated and they kept inside a big large room, which can be called as the plant room.

So, it is an isolated plant room or an isolated machinery room and such rooms are only opened when something goes wrong with the machinery or it need some replacement or maintenance, otherwise it is always isolated and closed behind thick walled thick walled rooms and therefore all the noise is contained within the machinery unit and none of the noise enters outside into the environment. So, such large rooms can be used and they are the best way to protect everyone within the industry, but as you see it requires large amount of construction, more amount of materials so, it more costly. So, this is costly, but it is more effective as it can protect the entire personnel from noise control.

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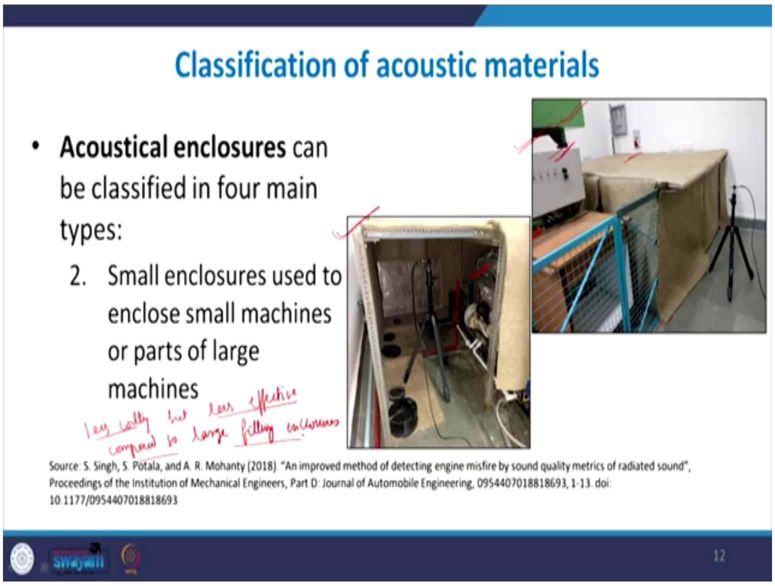

Acoustic and then the second type could be when only a small portion of the machinery is being enclosed; this is usually done when we have some budget constant we cannot afford to buildup such large structures for the entire plant. So, why not just build small structures and only enclosed or encapsulate that particular component which is making the most noise.

So, here I have shown you in the figures of an enclosure which I used for my own experiment. So, I was conducting some experiments here and we had a big setup of an IC engine simulator. So, it had many components, it had a dynamometer, it had of control board, it had a fuel pump etcetera, but the most noisiest part was the engine. So, because of the lack of budget cost, because of the budget constraint etcetera so, due to these reasons we only enclose the enclosure and we took the noise signals measurement inside the enclosures.

So, we used jute composite and ply wood, lined enclosures. So, the noisiest portion of the machine is being enclosed here and the remaining non noisy parts they are outside. So, this is smaller in size so, this is slightly less costly, but also less effective not very less effective, but compared to large fitting, fitting enclosures. So, only small part is and so, this is usually for less costly, if you go further down even less costlier approaches even less costlier approaches.

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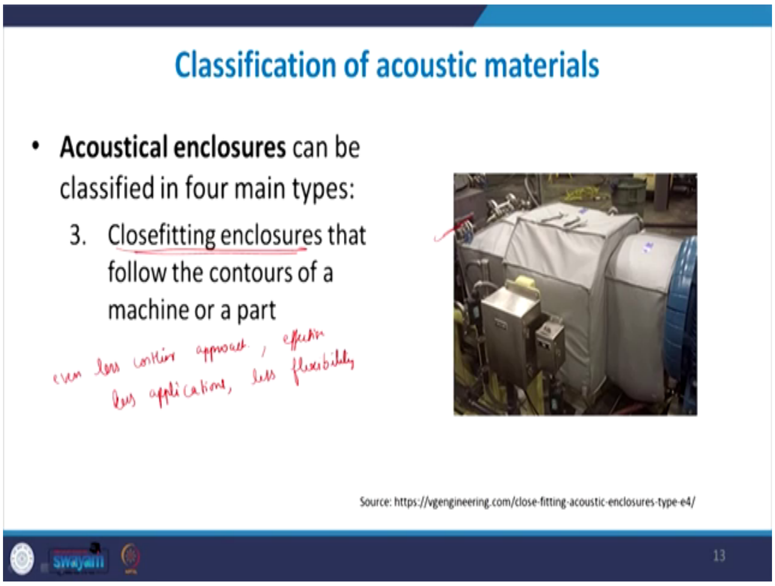

So, what you do here is that you have close fitting enclosures. So, here whatever is the shape of the machinery so, the machinery shape in this figure is this kind and exactly close fitting enclosure that follows the continuous of the machine is made.

So, making that the installation can be difficult because you will have to make individual one particular enclosure can only be used for a specific machine now, because it is build customized for a particular component. So, it has less applications and less flexibility, but it is less costly as well and you can achieve effective an effective, noise control, but it is not flexible; it is more customized approach.

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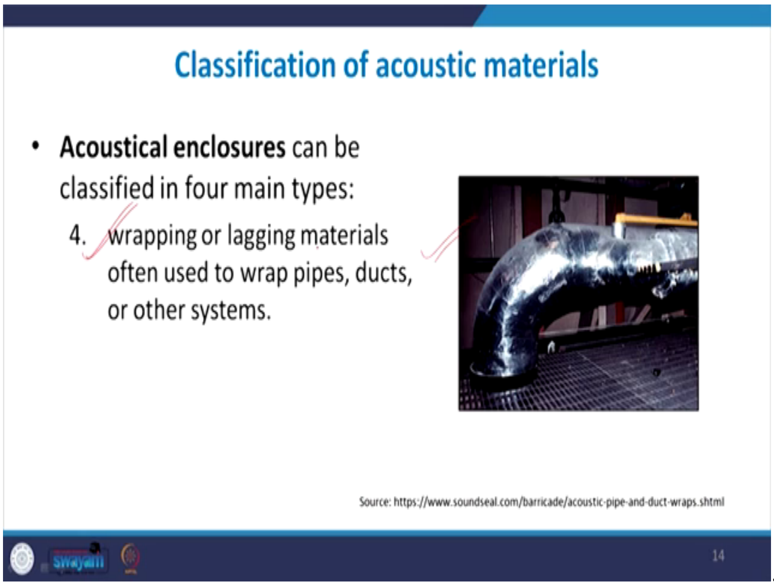

Then some times in many of the industries the pipes or the ducts they are also very important source of noise. So, usually these pipes can be lined with some absorbing materials or lagging materials and noise can be controlled. So, this is also a form of enclosure.

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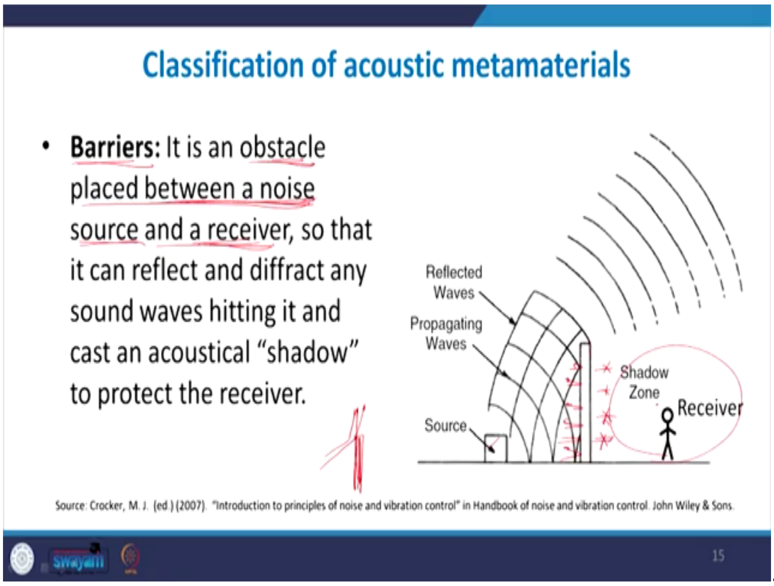

So, when we have we have seen the different types of enclosures that I usually found then what is a barrier? The barrier is as a name suggests is simply defined as an obstacle that is placed between a noise and a source. So, the sorry that is placed between a noise source and a receiver.

So, suppose we have a source here that is generating all the noise we have a receiver I here, we place a big wall or some blocking material in between. So, what will happen? First of all the transmission here will be reduced. So, the waves will be reflected back, the waves are getting reflected back and the transmission is being reduced and even at the and at the edges of these barriers the wave is getting diffracted so, it is turning away. So, just like how the light waves undergo diffraction when they hit here then they go diffraction and their direction changes.

So, a small zone is created where they sound waves are almost less no sound wave is reaching which is called as an acoustic shadow and the receiver can be placed here. So, barriers and enclosures they both have similar kind of materials because they both want to minimize transmission and they want to block the sound, but barrier are more like they are not full enclosures, but they are rather obstacles placed.

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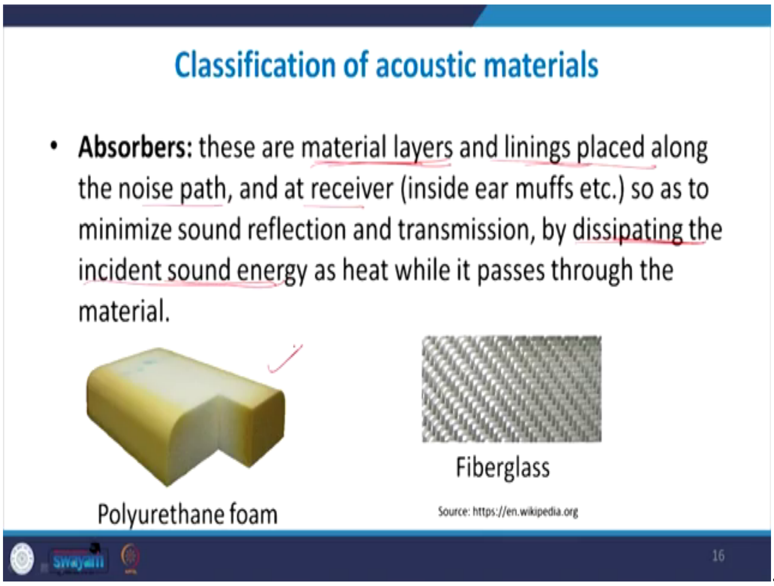

The third type of material is the absorber, now this is usually in the form of material layer. So, linings that are placed along the noise path and the receiver for example, some absorption material can be added to the headphones or the ear mufflers of the receiver and then along the noise path, the walls can be lined with noise absorbing material and the purpose is that it dissipates the sound energy. So, it reduces the reflection as well as the transmission.

Some common absorbing materials are you must have seen a typical sponge that you use in household. So, that sponge is a commercial name for polyurethane foam. So, this polyurethane foam or sponge as you call it is a good noise absorbing material. In fact, you can try it you can use some sponge pieces you inserted in your ears and something is playing you will see that the sound reduces it is absorbing the sound waves.

Then another common material is a fiberglass. So, we will study about these individual materials in the subsequent lectures, now after getting a brief overview of the common noise control materials that is enclosures, absorbers and barriers. Let us see how the performance of these materials is measured.

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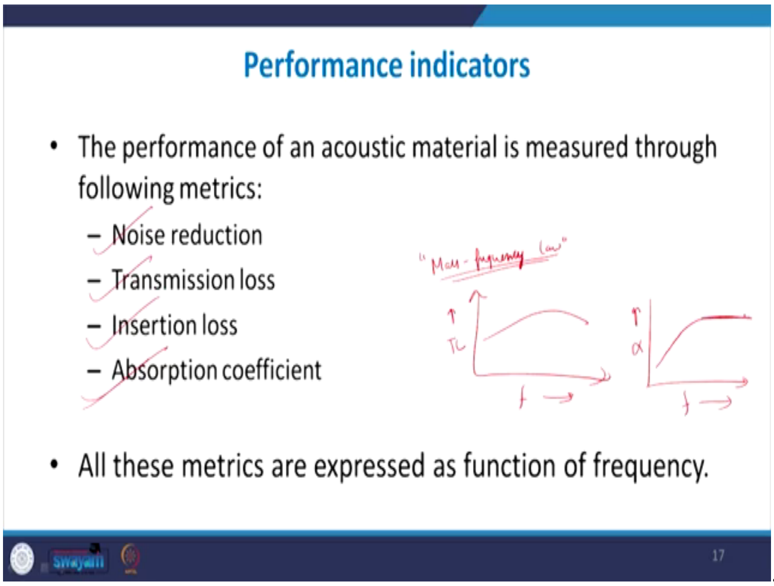

So, we have some standard metrics, noise reduction, transmission loss, insertion loss and absorption coefficient and all these metrics. So, what happens again in a subsequent lecture you will know about something called as a mass frequency law which I will teach you in the week 5. So, week 5; I will teach you this mass frequency law.

But what it says is that for every material the transmission and the absorption it is highly dependent on the frequency. So, it is easier for a material to reduce to dissipate a sound of high frequency. So, usually when high frequency sounds are incident the transmission loss will be heavy, because it is easier to dissipate such sounds, but low frequency controlling low frequency is the challenging problem low frequency is the absorption and the transmission for the same material is less. So, usually the transmission loss as well as the absorption they are given as a function of frequency. So, let us say this is some material we have a fixed material and this can be like a graph of it is transmission loss.

Similarly, we have some fixed absorber and this can be the graph of it is absorption coefficient with frequency, this is a typical graph. So, usually we absorption is low at low frequency and then it becomes high and reaches a limiting value. So, all these performance matrix they are dependent on the frequency of the incident sound wave and that is why they are represented not as a single value, but as a number as a set of values which are a function of frequency.

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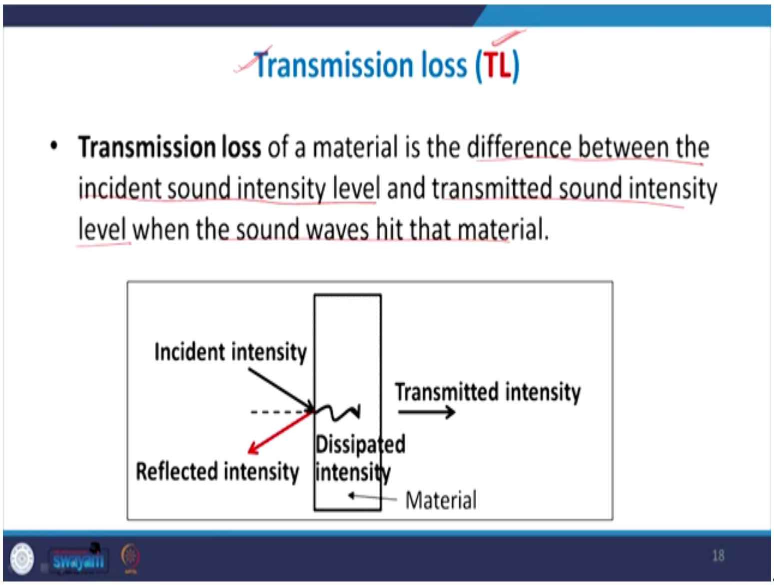

So, let us start with the first performance matrix that is most commonly used which is transmission loss or TL. So, how is the transmission loss of a material defined, it is the difference between incidence sound intensity level and transmitted sound intensity level when the sound waves hit that material. So, the difference between the sound intensity level that is incident and that sound intensity level that is being transmitted. So, this is the material given to us.

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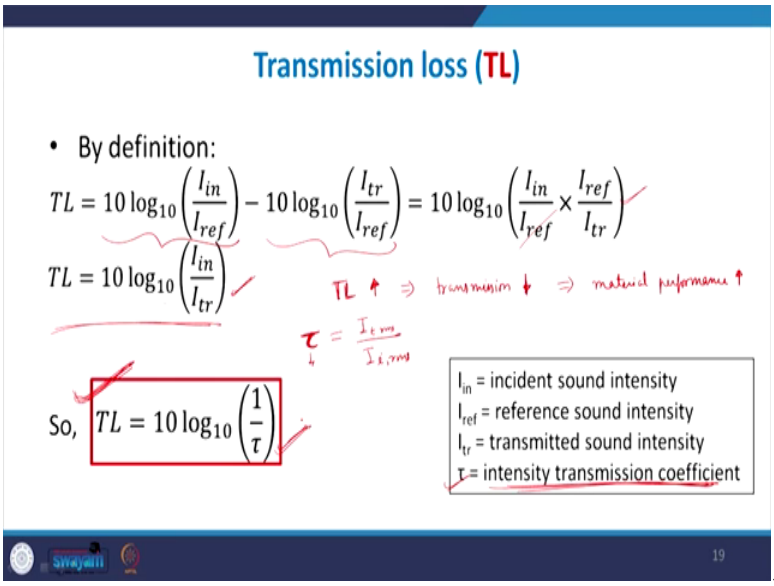

So, by definition this is the sound intensity level of the incident wave and this is the sound intensity level of the transmitted wave and the difference between the two will be transmission loss.

So, as you see from this definition if TL is high TL is high which means that transmission is low. So, the lower the transmission the more the material is blocking the sound the higher will be it is transmission loss so, material performance is better. So, it directly relates to the material performance of a barrier and the enclosure. So, if a barrier or enclosure has got high TL values which means that it is almost stopping all the transmission, so it is a better performing material. So, this is a measurement matrix I transmission loss.

So, this expression we obtained this is intensity level of incident wave minus the intensity level of transmitted waves if you use the log property then this becomes 10 log 10 you combine the

2 terms. So, it is minus so, this divides. So, I in by I reference multiplied by I reference by I reference by I transmission. So, this is what you get, this cancels out. So, what you left with is 10 log 10 of I reference by I transmission. So, this is the expression which we get for transmission loss.

Now, we have already studied a matrix called as transmission intensity, intensity transmission coefficient tau, we studied this when we are discussing about sound wave propagation at medium boundaries. So, we studied about absorption coefficient reflection coefficient and transmission coefficient and I told you that this tau is very important parameter and this was defined as the ratio of the transmitted sound intensity by the incident sound intensity this was the definition of tau. So, if you use that definition here so, this becomes 1 by tau. So, this is a important equation for calculating the transmission loss in terms of the transmission coefficient of the material 10 log 10 of 1 by tau.

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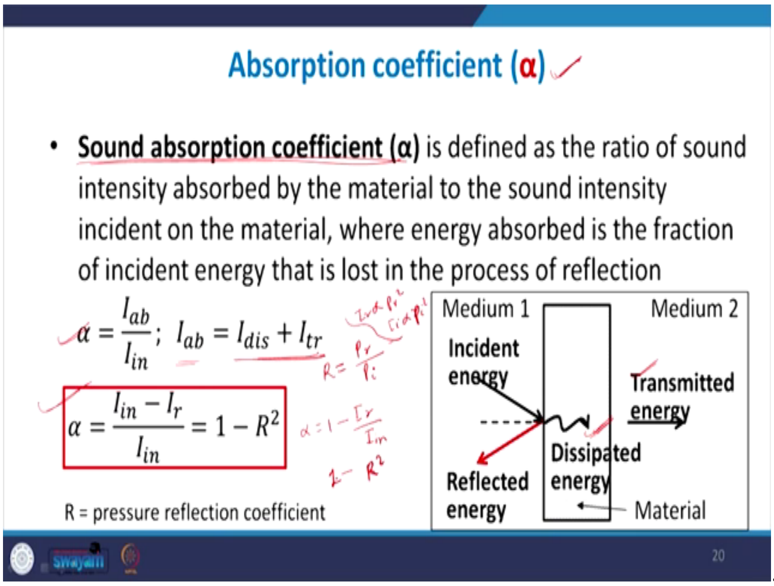

Now, this next performance metric is an absorption co efficient or alpha sound absorption coefficient we have already described this metric before. So, it is defined as the ratio of sound intensity that is absorbed to the sound intensity that was incident and this total absorption is what it is whatever value was dissipated total absorption means whatever is being dissipated plus transmitted this constitutes the total absorption.

So, basically what this coefficient measures that what is the fraction of energy what is the fraction of the incident energy that is lost in the process of reflection. So, here is the definition. So, it is I absorbed by I incident an I absorbed I is anything that is dissipated plus transmitted. So, or we can write it as simply the intensity of the incident wave minus the intensity of the reflected waves divided by the intensity of the incident wave.

And we know that the pressure reflection coefficient R is given by pressure of the incident wave, pressure of the reflected wave by pressure of the incident wave and. So, this alpha is what it is 1 minus I r of I in which is going to be and we know that I r is directly proportional to P r square and I, I is directly proportional to P i square. So, this will be R square. So, you have I am not going to the derivation for this because we have already covered this derivation in our first lecture on the sound medium sound propagation and I medium boundaries.

So, this is alpha which is 1 minus R square, where R is the pressure reflection coefficient ok, now suppose now we have studied these 2 matrix. Now we studied about transmission loss and alpha. Now let us say if we have a particular layer of material so, we have a boundary surface and it is composed of different patches of different materials.

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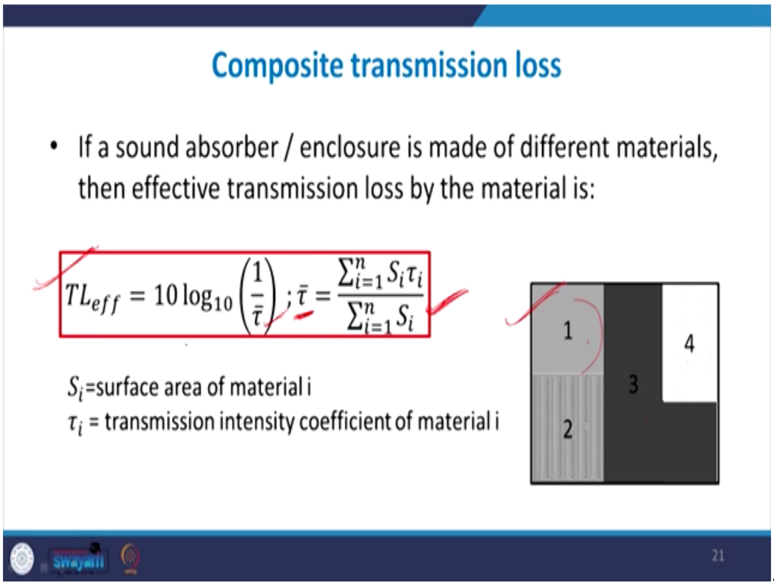

So, let us see we have a composite material. So, this is the entire block of the material which contain some individual material 1 2 3 4 that have their own transmission coefficient. Then the total effective transmission loss for this will be 10 log 10 of 1 by tau bar which is the average transmission coefficient and the average transmission coefficient is obtained as you multiply this surface area of 1 with the tau of 1 plus tau of 2 with surface area of 2 way tau of 2 and so on. So, you multiply the surface area with a respective transmission coefficient and you sum this quantity over for all the materials and you divided it with the total surface area.

So, this is how you can get. So, if a material is composed of different patches. So, one particular block is composed of different patches with different transmission co efficient than the then the net transmission coefficient tau average can be obtained using this formula which can then be put to get the total transmission loss.

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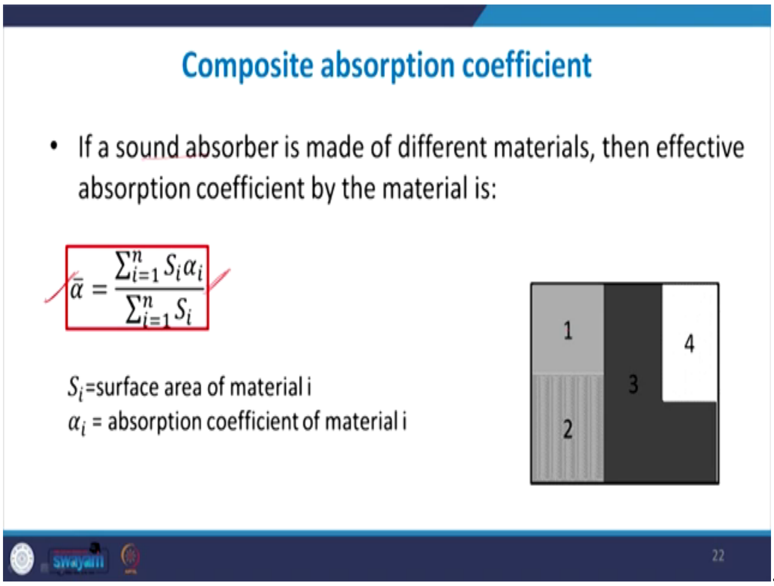

Similarly, if you have the same kind of material with different patches of absorbing material then the average absorption through this entire block you can be given by the same kind of formula. So, we are multiplying this surface area with the respective trans. The surface area is being multiplied with their respective absorption co efficient and they summed over divided by the total surface area.

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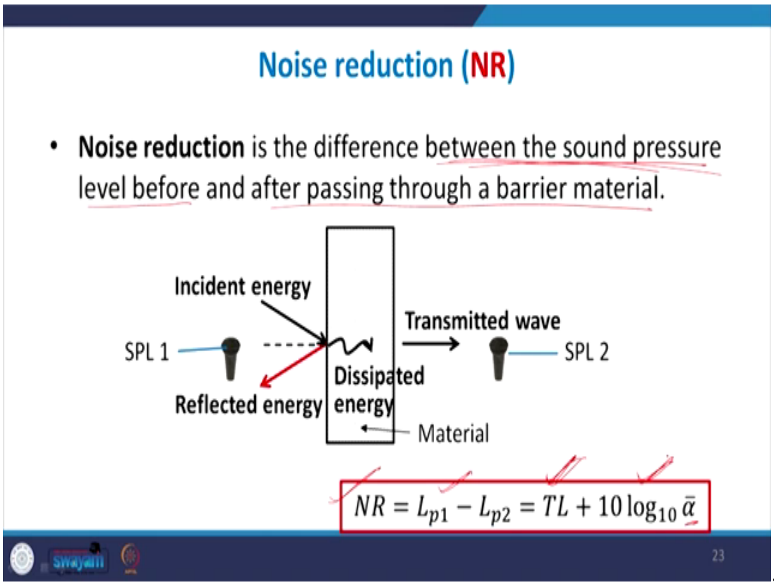

So, let us now briefly describe what is a noise reduction this is another performance metric, it is the difference between the sound pressure level before and after passing through a barrier material.

So, here the distance between the 2 is almost kept the measurement point is almost approximately equal to like one meter or so, that is the standard used and then we measure this was the SPL just before entering the material and this is the SPL just after the entering the material and the value of this comes out to be. So, this will be the L p at 1 minus L p at 2 that is the definition, which in terms of the transmission loss is TL plus 10 log alpha bar where alpha bar is the alpha of the layer of materials, the average absorption co efficient of the layer of material. The derivation again is not within the scope of this particular course, but you can always go to the reference materials for further reading.

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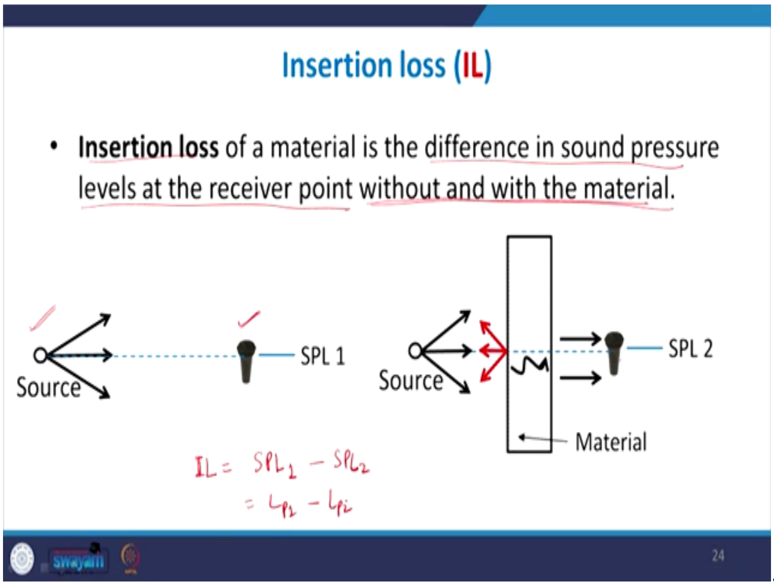

Then the insertion loss this is the last performance metric and how it is defined? It is defined as the difference in the sound pressure levels at the receiver point with and with without and with the material.

So, let say we had some source and no material was placed an at a particular point we measured this was the SPL at this particular point and then the same source is there the now we place another the blocking meant the layer of material in between and at the same point we take the measurement again. So, the insertion loss comes out to be here SPL 1 minus SPL 2 now simply L p 1 minus L p 2. So, this is the difference the actual difference is noise level when there is no material to when there is material ok.

So, we will continue with our discussions I in the next lecture where we will study the individual acoustic materials one by one.

So, thank you for listening for to this lecture.