Dissipative Sound Package Systems

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This article discusses the importance of dissipative sound package systems in the automotive industry and how they work. Although this is not a new technique at this stage, it is still a challenge to meet subsystem target levels that were originally developed for parts based on the barrier-decoupler concept. We will review the typical construction of a dissipative system and then emphasize the importance of different layers of materials that are used in the construction, including what they can do and cannot do. We also also discuss the importance of proper manufacturing of a part.

The word "dissipative" is the adjective of the word dissipation, which means the result of an irreversible process where the energy is transformed from one form to another form and dispersed in various directions. In acoustics, the sound energy is transformed or dissipated to thermal energy, and thereby the noise is reduced.

With stringent fuel economy and emissions requirements all around the world, car companies are drastically looking into vehicle efficiency. One way to achieve this is to reduce the gross weight of the vehicle. This is being looked into in all areas of vehicles. This means reducing the weight of the body panels of the vehicles to the sound package materials that are used in the vehicle. The demand is of course to improve the fuel efficiency without affecting the safety of the vehicle or the acoustics inside or outside the vehicle.

Background

A lot of work has been done in the past 20 years to discuss the importance of lightweight sound systems that can substitute for the traditional barrier-decoupler systems.[1,2] Although, in a bench test, lightweight products may not perform well to attenuate the sound; as a system, these products have the potential to perform reasonably well. The lightweight product that is discussed here is the dissipative system that is generally a combination of two very different types of absorption materials that are working together to meet the acoustical needs in a vehicle. As has been already mentioned,[1,3,4] the dissipation system works on the principle that:

- The sound absorption property of the dissipative system is higher than the absorption material.
- The sound transmission loss property of the dissipative system is higher than that of the absorption material.
- As a system, the dissipative system performs similar to that of the barrier-decoupler system with significant noise reduction.

Figure 1 illustrates the situation where the curves on the top show the STL and absorption properties of a typical absorption material, a typical dissipative system, and a barrier-decoupler system. The vehicle on the bottom shows an example where typical acoustic rays after getting reflected at different trim surfaces reach the operator ear in the vehicle. Therefore, if the trim surfaces have a large amount of absorptive properties, less sound will reach the driver's ear.

Based on this understanding, the dissipative system is essentially a system made up of two layers of sound absorption materials, where the airflow resistance or surface impedance properties of these two layers of materials are very different. One of the layers is generally compressed and remains as the same thickness throughout the part. This is often called a hard, compressed, cap, or top layer. The other layer is generally called a soft layer or a loft layer, where in an application, this layer gets compressed to different thicknesses at different sections of the part.

The dissipative system is typically installed next to the sheet metal to block sound energy coming from outside to inside the vehicle. The compressed layer faces the vehicle interior and the soft layer stays next to the body panel. The two most common applications are dashmat and floor carpet systems. Of course, to meet the targets and acoustic expectations, a significant amount of tuning may have to be done, and additional layers may have to be used. An additional layer often is a flow-resistive material (commonly known as a scrim material) which is used to meet the impedance properties of the hard layer to meet the acoustic target.

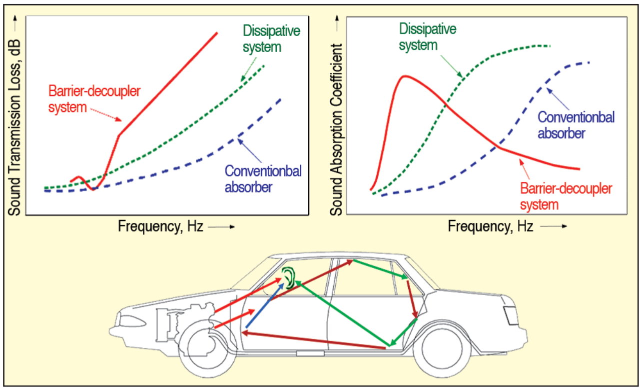

Figure 1. Typical acoustic performance of dissipative and barrier decoupler systems.

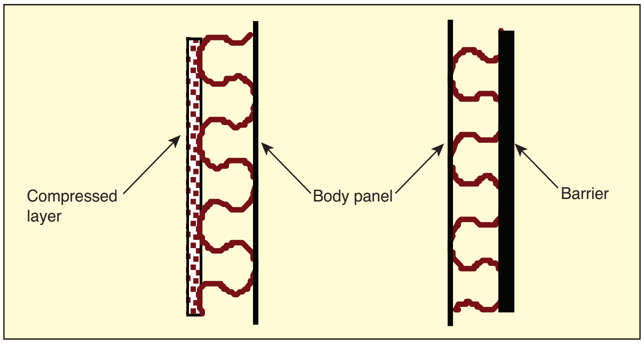

Figure 2. Schematic of dissipative and barrier decoupler system.

Note that in a barrier decoupler system, the barrier faces the vehicle interior and the decoupler is placed between the body panel and the barrier. In that sense, the soft layer and the decoupler perform similarly. However, the compressed layer and the barrier perform very differently. Figure 2 shows the schematic of a dissipative part and a barrier decoupler part.

It has been shown in the literature that the attenuation of sound that is obtained by placing a sound package material between two spaces is not only dependent on the sound transmission loss of the sound package material but also on the total absorption of the receiving space environment and the area covered by the sound package material.[3,5] Wentzel and VanBuskirk expressed that attenuation (expressed in terms of the noise reduction) provided by a part in an enclosure (this could be the vehicle interior or a receiving room) is related to sound transmission loss of the part and the total average absorption in the enclosure. This is expressed as:

$$\mathrm{NR} = \mathrm{STL} + 10\log\left(\frac{A}{S}\right) \tag{1}$$

where:

NR = Noise reduction or attenuation of sound, which is the difference in sound level outside and inside the enclosure, dB
STL = Sound transmission loss of the part, dB
A = Total absorption in the enclosure, m^2
S = Surface area of the part exposed to sound, m^2

Based on a paper presented at the SAE 2017 Noise and Vibration Conference, Grand Rapids, MI, June 2017

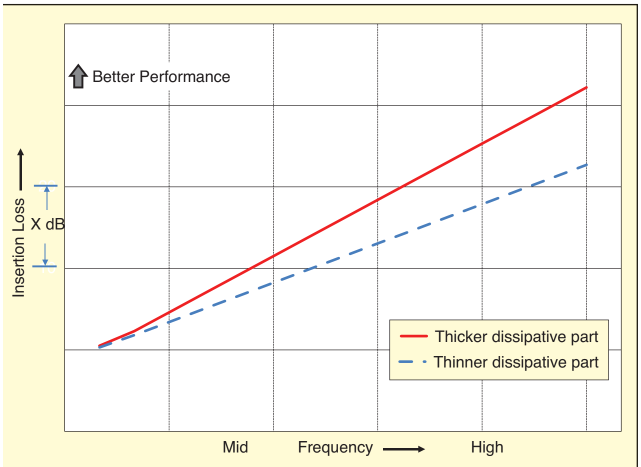

Figure 3. Typical absorption curve in specification for dissipative part.

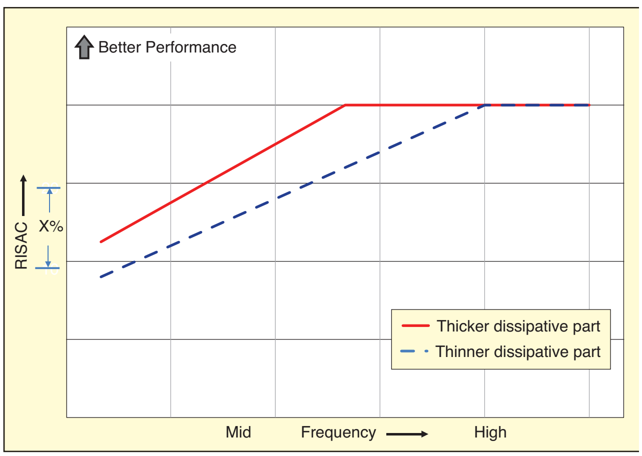

Figure 4. In-vehicle performance prediction using IL and absorption data.

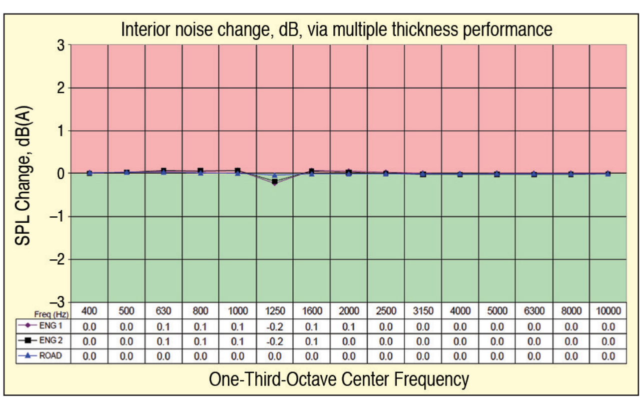

Figure 5. Typical IL curve in specification for dissipative part.

This alludes to the fact that a large amount of dissipation is available provided (A/S) in Equation 1 is large. This means the average absorption in the enclosure needs to be large compared to the surface area of the part where sound is incident. Then a balance could be achieved between the reactive and dissipative values, and one would be able to achieve high attenuation from a dissipative system. The corollary to this is that if the surfaces inside the vehicle that are exposed to sound could be made very absorptive, a dissipative system could provide acceptable attenuation of sound.[1]

Acoustical engineers in the auto companies have been marketing this understanding. They are predicting vehicle interior levels from statistical energy analysis (SEA) and other models. From this, the engineers are setting targets for dissipative systems that the parts need to possess to meet the vehicle interior target. The parts in this case are primarily the dashmat and the floor carpet systems that have the potential to block sound coming from outside to inside the vehicle. The acoustic properties of a given material are generally expressed in terms of insertion loss and random incidence sound absorption coefficient. Almost always the specification is designed for a flat sample to meet the specified values. However, the actual success of a part made from that material depends on many other factors such as pass-through designs.

The sound field inside a vehicle interior is not diffuse. It is made up of incident, diffracted, and reverberant waves, as it is in most other applications. There are a lot of assumptions that go in Equation 1 that will not hold true inside the vehicle. However, the equation shows that absorption in the enclosure plays a role on the sound transmission loss of the part. In that sense, this is a general equation and is used in many applications including sound transmission loss measurements in the field,[6] where the situations are less than ideal compared to measurements made in a laboratory.

Specifications

The acoustic target for a dissipative system is based on the combined effect of the absorptive and sound-blocking ability of the system. The two most common specifications for this system in the industry are:

- Explicit – Insertion loss and sound absorption coefficient values with frequency of 12-mm and 25-mm-thick flat samples.
- Interactive – Vehicle interior noise change from a target value versus frequency, with spreadsheet-based computing interface using insertion loss and absorption coefficient values of different thickness flat samples.[7]

The frequency range for most specifications covers from 315 or 400 Hz to 8000 or 10000 Hz. Insertion loss (IL) by definition is the difference in sound levels measured in the receiving room with and without the sound package material in place. Here, the sound package material is the dash system, and this will be placed next to the body panel as shown in Figure 2. Therefore, IL is the difference in sound levels of the body panel with the sound package material and of the body panel by itself. In the industry, however, insertion loss is measured from the difference of the STL values of the body panel with the sound package material and of the body panel by itself. Sometimes, this is also identified as the power-based insertion loss (PBIL), since the STL is a power-based property. The absorption data is based on random incidence sound absorption tests.

Explicit Discussion. This is a standard and very straightforward specification. A typical example of this is shown in Figures 3 and 4 for IL and absorption targets. The absorption targets are often expressed in terms of random incidence sound absorption coefficient (RISAC). These figures do not show any absolute values but only show the trend of acoustic performance with frequency for a typical thin and thick dissipative system. Of course, each original equipment manufacturer (OEM) is going to have different targets. Therefore, Figures 3 and 4 are to be used to visualize the trend and to start thinking what the dissipative system construction may need to be to meet this trend and eventually to meet the target for an OEM.

Interactive Discussion. Figure 5 shows the final presentation, where in-vehicle performance predictions are displayed in terms of sound level change. The suppliers put in the sound absorption coefficient and insertion loss data of flat samples of different thicknesses into a spreadsheet provided by the OEM for this study.[7] A macro programming is embedded in the spreadsheet that conducts internal computation and displays the sound level change in relationship to whether the acoustic performance of the flat samples meets the target. As mentioned in the reference, the zero or negative line in Figure 5 represents meeting the vehicle level interior noise target for the operating condition.

Supplier Parameters

Although, the two types of specifications mentioned here have some similarities, there are also many differences. The similarities are:

- Specifications are based on flat-sample acoustic data.
- The acoustic data are insertion loss and random incidence sound absorption coefficient.

The differences are:

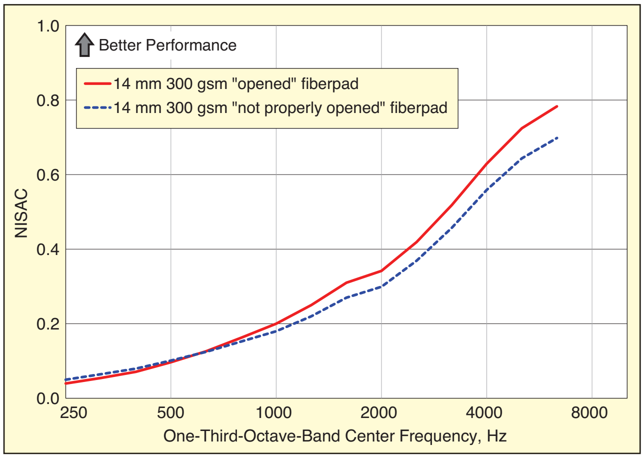

Figure 6. Impact of proper opening of fiber.

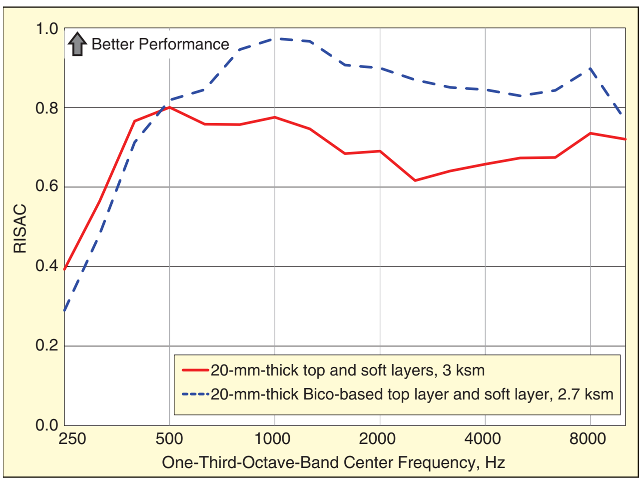

Figure 7. Effect of Bico on acoustic performance.

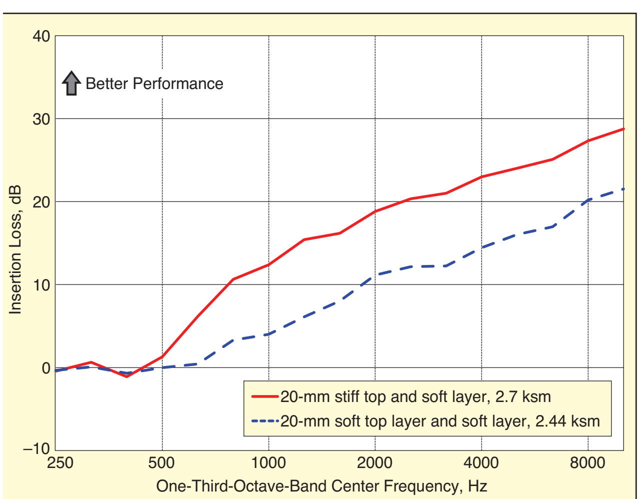

Figure 8. Impact of stiffness of compressed layer on insertion loss.

- For the explicit specification, it is simple to compare the measured acoustic values with the target values. If the measured data do not meet the target values, the supplier still has some understanding where the deficiencies are and has the potential to visualize easily what may have to be done to meet the target.
- For the interactive specification, if the performance does not meet the target, it is not so obvious where the problem may be.

Supplier Challenge. Light weight is becoming the norm in the sound package treatments today. The OEMs are developing specifications that will have the same acoustic targets as they used to be before with the barrier decoupler systems. However, these targets need to be met with sound package treatments of less weight. It is a challenge to meet the subsystem level targets that were originally developed for parts based on the barrier decoupler concept, unless the concept of the dissipative system is clear. Just two very different absorptive layers can only do so much. The compressed layer plays a very critical role in meeting the target. The performance depends not only on the type of fiber, or the fiber content, but also on how the product is made, including temperature, time, press tonnage, type of contact, and many other parameters. Often, a scrim layer with very specific airflow resistance characteristics needs to be used to meet the target.

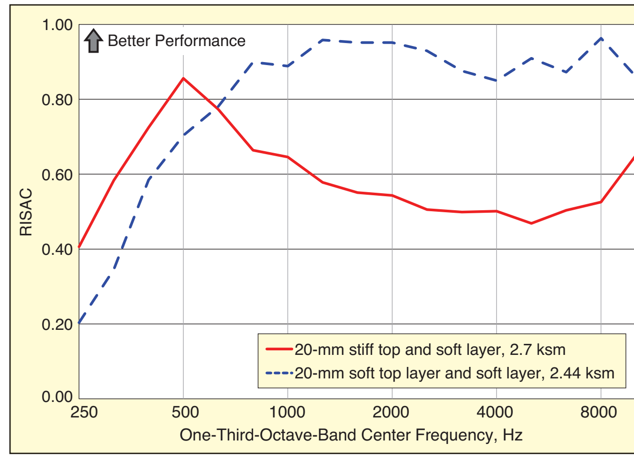

Figure 9. Impact of stiffness of compressed layer on absorption coefficient.

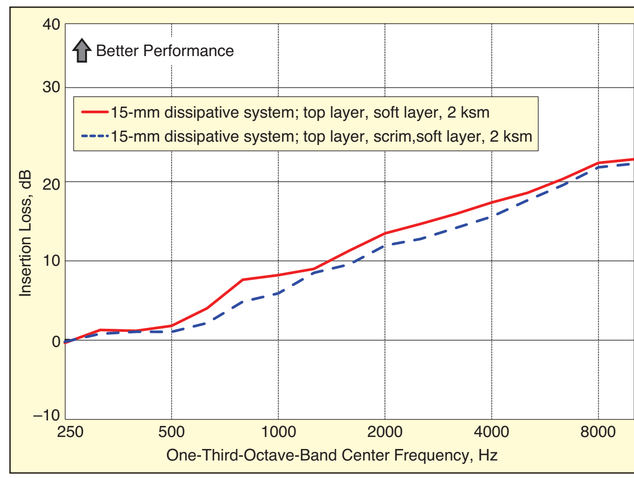

Figure 10. Effect of placement of scrim on insertion loss.

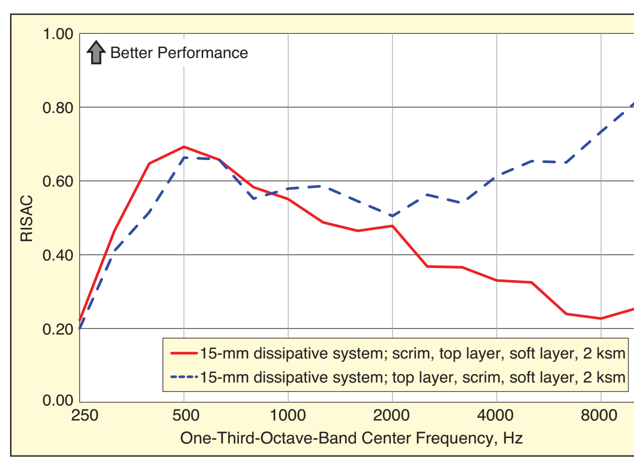

Figure 11. Effect of placement of scrim on sound absorption coefficient.

With various uncertainties at the initial stage, trial-and-error studies are conducted to get some confidence on the construction of the part. During this stage, different layers of the constructions are often studied separately and then studied as a prototype construction. The prototype constructions may consist of different compressed layers, for example, on top of a soft layer. These

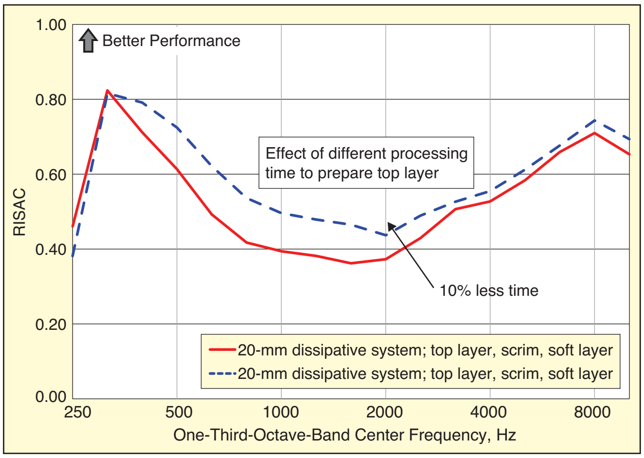

Figure 12. Impact of press time on absorption coefficient to make compressed layer.

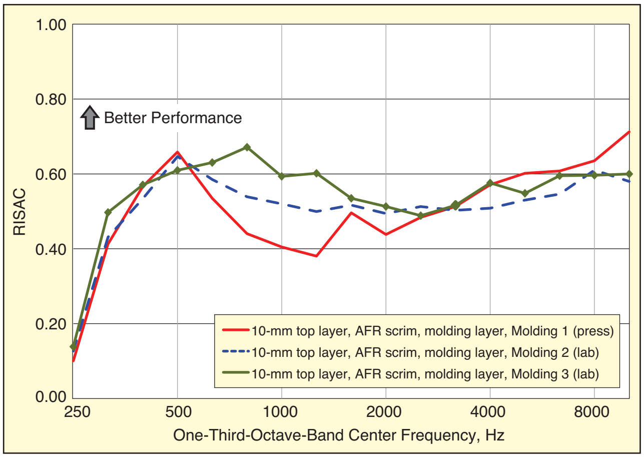

Figure 13. Efffect of adhesion and molding.

constructions are also evaluated with and without the scrim layer. The thought is that once a prototype construction meets the target, the part will be manufactured and validated again. Although this is a very valid approach and, perhaps at the initial stage, the only approach, eventually, may cause some issues. Even through predictive analyses work, these issues may not be addressed completely, since the analyses need input data and the data are not available in the initial stage.

Therefore, to properly manufacture the part, some of the following variables need to be understood and considered. These are discussed here and illustrated through examples in Figures 6 through 13.

Proper opening of the fiber is very critical. Opening is the preliminary operation in the processing of a staple fiber. This process separates compressed materials (large clumps or many flags) into loose tufts of fibers. This process opens up the fibers and provides higher sound absorption coefficient than improperly opened fibers (also called unopened fibers). Figure 6 shows the normal incidence sound absorption coefficient (NISAC) data of two sets of fiber-pad samples of the same thickness and surface density, but one is an opened sample and the other is an unopened sample. The opened sample performs higher than the unopened sample.

Almost all dissipative parts have a certain amount of reused fibers from other processed parts. However, a larger amount of reused parts degrades the dissipative properties of the new part and this affects performance.

The proportion of bi-component fibers (Bico) used to mold the part is critical, since it impacts the performance by affecting the airflow resistance of the fiber pad. Figure 7 shows the random incidence sound absorption coefficient (RISAC) of two fiber-pad samples, one with and the other one without the Bico fibers. There is an optimum amount of Bico usage. Using more will degrade the dissipative properties, although it will likely improve the IL properties. This may be beneficial up to a certain extent but may not be the best for meeting the acoustic targets in all cases.

The compressed layer impacts the overall performance of the dissipative part. Therefore, the type of press being used to prepare the compressed layer, the tonnage of the press, and the temperature and time the sample is compressed is important, including both the construction and the time on the press. These variables affect the stiffness of the sample, which in turn also affects the airflow resistance of the sample.

Figure 8 shows the effect of a stiff compressed layer and a soft compressed layer on insertion loss. The stiff compressed layer prepared using contact heat has higher insertion loss than the soft compressed layer that was prepared using convection heat. There is also a significant difference in RISAC performance for these two sets of samples shown in Figure 9.

Figure 9 also shows that the sample with the stiff compressed layer has a peak performance at a lower frequency, and then the performance drops off and eventually rises again after 5000 Hz due to some dissipation properties of the compressed layer. If the compressed layer was even stiffer, then at high frequencies, the performance would be even lower. Figure 9 shows that the soft compressed layer sample has high performance from 1000 to 8000 Hz.

Depending on the construction of the compressed layer, the position of the scrim is also critical, since the flow resistance characteristics of the compressed layer system will change. This is shown in Figures 10 and 11, where Figure 10 shows the insertion loss curves and Figure 11 shows the absorption curves (RISAC).

The press time needed to make the compressed layer is critical as well on the combined performance of the dissipative part. Figure 12 shows that samples prepared on the same press and using the same temperature, when 10% less time is used to prepare the compressed fiber pad, it provides a more absorptive dissipative part (RISAC).

Last but not the least critical item in making the dissipative part is the molding process. If the molding is done in the lab, the performance could be quite different than the molding done in a press. The proper adhesion of the two layers is very critical on the acoustic performance. Different layers bonded together using spray adhesive, web adhesive, or other process can also affect the performance. Figure 13 shows the effect of a different spray adhesion process applied and molded in the lab and in the press. Results show a significantly different performance between 630 and 1600 Hz.

Conclusions

The dissipative system that has been in application for about 20 years has a great deal of potential to provide performances similar to a barrier decoupler system and at a reduced weight. Prediction models have a significant role in developing acoustic targets for dissipative systems. However, there are several variables in the dissipative system that affect the acoustic performance and need to be understood thoroughly. Eventually, these need to be tuned to meet the acoustic targets.

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