New Frontiers for Fiber-Based Noise Control Solutions

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Recycled fiber products that add improved noise control, weight reduction, durability, and design versatility to the toolbox of the noise control engineer are now available. The performance envelope of fiber materials has been expanded using engineered fiber constructions. Thermoplastic fiber formulations allow these materials to be molded to three-dimensional shapes of variable thickness for noise control. Specialty scrims and films can be used with fiber materials to tune the sound absorption and transmission loss. Finally, fiber decouplers can be used with heavy barriers, mastic layers, lightweight barriers, or dissipative systems. New developments in highly durable non-woven fiber constructions allow these materials to be used in exterior applications. Also, thermoplastic binder fibers with improved heat resistance can now be used to provide high-temperature dimensional stability of molded fiber parts. The multiple uses of recycled fiber products are presented to show how they are moving out of their traditional role as sound absorbers and into new applications and new markets.

Fiber-based acoustical products have historically been selected as cost-effective sound absorbers for industrial noise control and for architectural acoustics applications.[1] In the automotive market, fiber products are widely used in a vehicle's noise control package to improve sound absorption and transmission loss.[2] Over the last several years, the use of recycled fibers in acoustical products has grown for economic reasons. Accordingly, fiber manufacturers have redesigned their products with engineered fibers and have optimized their manufacturing processes to extend the usefulness of these low-cost materials in a range of noise control applications.

Our purpose here is to present new frontiers in the performance of fiber-based noise control solutions. These frontiers include product designs that improve sound absorption and transmission loss through unique constructions. Engineered fiber formulations and robust manufacturing processes can also improve durability and temperature stability of these products for highly demanding applications. These results show why fiber-based products are increasingly used in next generation noise and vibration packages in the automotive industry.[3] These same products offer noise control opportunities in related transportation and marine applications as well as for general noise control applications.

Fiber Content and Processes

Both natural fibers and synthetic fibers are used in manufacturing fiber-based acoustical products. The sources of natural fibers include cotton, jute, flax, sisal, wood, kenaf, or other materials. Synthetic fibers can be made from polyester, polypropylene, acrylic, nylon, rayon, glass, mineral wool, or other materials. In cases where recycled fibers provide a cost-effective alternative to virgin fibers, recycling operations have been set up to capture these materials from the waste stream and to condition and prepare the fibers for further use.

Several types of manufacturing operations are used to convert virgin or recycled fibers into acoustical products.[4] The most common operations include needling, carding, and air lay.[5] These operations are aligned more with the desired end product than with the input stream of recycled or virgin fiber. In fact, most manufacturing processes can function equally well with recycled or virgin fibers. Each process produces a unique product based on the fiber formulations used.

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Postprocessing operations can add further value to fiber products. Laminating and layering are used to add unique acoustical properties to the product. Molding operations can transform a two-dimensional material into a three-dimensional shape for specialized applications. But in this article, the acoustical performance of typical fiber products is compared rather than the manufacturing operations themselves.

Product Properties

At first glance, it would seem that the most critical property of a fiber product used in a noise control application would be its acoustical performance. This property could be either its sound absorption or transmission loss. This is partially true. Other critical properties are its physical characteristics related to its ease of processing and handling. The physical properties are also important when considering its durability under a range of environmental conditions such as temperature and moisture. Each of the acoustical and physical properties is reviewed to demonstrate the new frontiers that are being opened with fiber materials.

Sound Absorption

Most fiber materials have a porous, homogeneous structure with a density from 8 to 80 kg/m^3. The product's density is a result of the type of fiber and the manufacturing process selected. The porosity of these materials makes them inherently good absorbers of sound, and their sound-absorbing properties are controlled by their thickness, fiber content, and weight (or density).

Studies of fiber products have shown that sound absorption can be improved by increasing the thickness or by increasing the percent of finer fiber.[5] At a given thickness, the maximum sound absorption is limited by the blend of fibers and weight. If a lightweight sound absorber is required, then fine fibers must be used to achieve high sound absorption. If fine fibers are too costly or cannot be used in the manufacturing process, then the surface weight must be increased to deliver the required performance.

Comparisons of current products can be made to validate these trends. All sound absorption measurements were made using a small reverberation chamber. The size of the room restricts measurements below 400 Hz but comparison in critical speech frequency bands can be made. Figure 1 shows the sound absorption for two 19-mm-thick materials, one at 1200 grams per square meter (gsm) with standard fiber and the other at 470 gsm with a higher amount of fine fiber. The lighter material with fine fiber uses 60% less fiber by weight, while having only 10% less absorption at mid frequencies. Additional fine fiber could be added to make this lighter-weight product comparable to the heavier product, but the lighter-weight material was developed to suit a particular customer requirement. The improvement in sound absorption from finer fiber is evident.

Another means to improve sound absorption is to apply an acoustical scrim with a controlled airflow resistance on the surface. This is useful when higher sound absorption is needed, but the thickness cannot be increased. This also creates an economic opportunity when a lower-cost fiber blend can be used with a high-performance acoustical scrim.

Figure 2 shows the sound absorption for identical 13-mm, 400-gsm materials with standard fibers both with and without an acoustical scrim. The improvement in sound absorption by adding the scrim is seen throughout the frequency range. Included in Figure 2 are the data for the 19-mm fine fiber sample from Figure 1. It is significant that the 13-mm, 400-gsm standard fiber material with scrim performed better than the 19-mm, 470-gsm material with

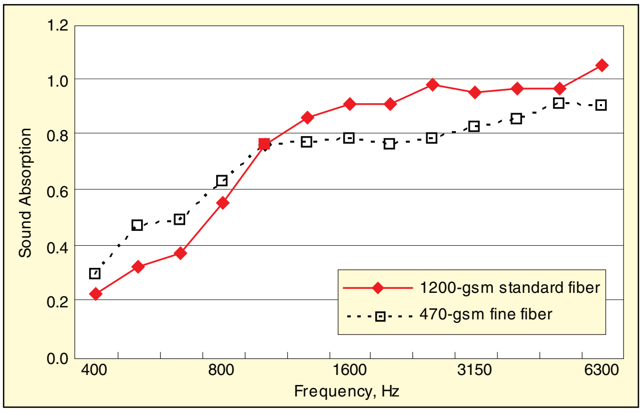

Figure 1. Sound absorption improved by fine fiber.

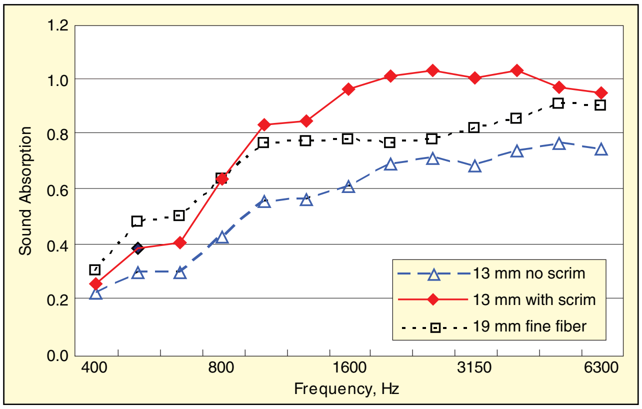

Figure 2. Sound absorption improved by acoustical scrim.

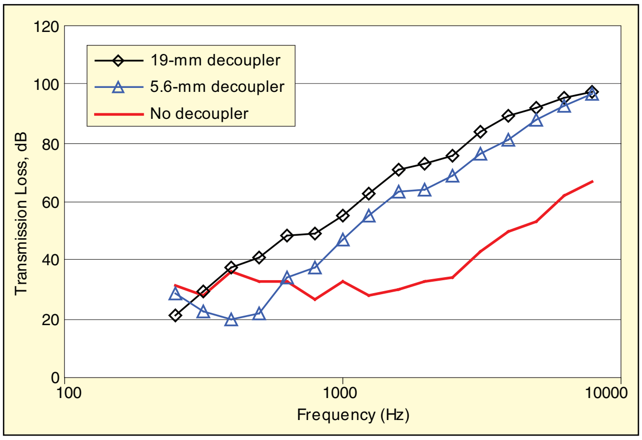

Figure 3. Transmission loss (TL) for a mass barrier system with decouplers.

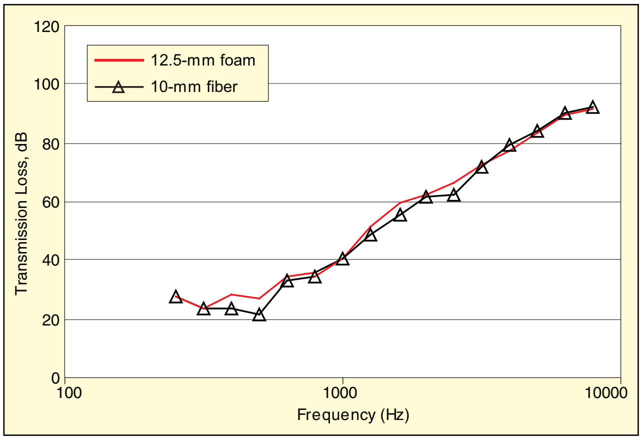

Figure 4. TL for a mass barrier system with fiber and foam.

fine fiber. This shows how acoustical scrims can add performance to make thinner materials comparable to thicker materials. These properties open new frontiers for tuned sound absorption and for cost reduction of fiber blends in noise control applications within multiple industries.

Transmission Loss

Most materials used for transmission loss (TL) employ a heavy barrier sheet that blocks sound. Low-cost mass layers typically include sheets of ethylene vinyl acetate (EVA) or mastic, a blend of asphalt. Due to the porosity of fiber materials, they perform better as sound absorbers than as sound barriers. However, a fiber material placed next to the mass layer as a decoupler significantly improves the efficiency of the mass barrier in blocking sound. This fiber and mass system then behaves as a double-wall barrier that delivers greater performance than can be achieved with a single mass layer whose performance is controlled by mass law.[1] In these double-wall applications using fiber, the fiber behaves as an isolator between the two impervious layers.

Transmission loss measurements were made using a small two-room chamber with the test sample separating the source and receiver room. When TL results are reported with sheet metal, the metal is a 20-gage flat panel. Figure 3 shows the TL of a carpet mass layer tested with sheet metal. The surface weight of the carpet is 3.43 kg/m^2, which is typical of weights used in automotive floor systems. The baseline condition is represented by the mass layer placed directly against the sheet metal with no decoupler. When a fiber decoupler with a surface weight of 1.15 kg/m^2 is used with the mass layer, the TL improves over the baseline. Increasing the thickness of the decoupler improves the TL even more. Clearly the fiber decoupler improves the TL in the upgrade from a single- to double-wall barrier system. Additional comparisons and recommendations for double-wall systems using fiber in automotive applications[6] can be extended to noise control solutions in transportation, marine, and general industrial applications.

Knowing the value of a decoupler on TL for a barrier system, comparisons were made between a fiber and foam decoupler. Figure 4 shows the TL for a mass layer of 2.74 kg/m^2 with decouplers of both fiber (870 gsm) and foam (550 gsm) placed against sheet metal. The TL is nearly identical throughout the frequency range. This shows that fiber can be used in place of foam in barrier systems without compromising TL performance. This again shows the value of a decoupler in a double-wall barrier system and refutes a common myth that fiber does not perform as well as foam as an acoustical decoupler.

The importance of an impervious mass layer in a barrier system for TL was demonstrated in the previous figures. Attempts to create a hybrid mass layer from fiber were made by compressing a recycled fiber blend containing thermoplastic fibers under heat. TL tests were conducted on single layers of material without sheet metal to isolate any double-wall effects and thereby focus only the barrier properties of the material.

Figure 5 shows the TL for a fiber composite having a nominal weight of 1.7 kg/m^2 made with a 25-mm recycled fiber layer and a decorative nonwoven face. The fiber layer was compressed to 15 mm and to 3.8 mm and compared to an equal weight EVA barrier. As expected, the 15 mm fiber layer has low TL due to its porosity. The higher density 3.8-mm fiber layer shows an improvement in TL, but it still is not closed enough to perform like an impervious layer. Even at the same weight as the EVA, it does not have the same TL. When a fiber material is compressed to a thin, high-density layer, its porosity decreases, but it does not turn into an impervious barrier. Since the 3.8-mm fiber layer could not be compressed further to reduce porosity, alternate approaches were investigated to create a fiber barrier.

A barrier-like material was created for the fiber layers by adding an impervious film between the decorative surface and the fiber. Composites with film were made at 15.7 mm and 4.7 mm thickness and compared to the composites without film and to the EVA layer. Figure 6 shows the improvement in TL with a film added to the 15-mm layer, but it still does not match the TL for an equal weight EVA layer. The thinner construction shows more favorable results.

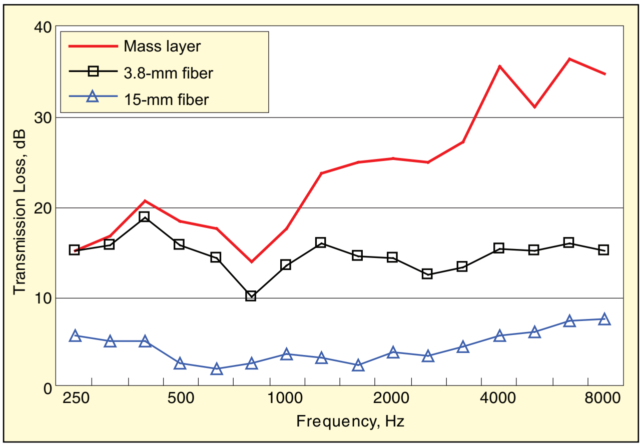

Figure 5. TL for single layers of equal surface weight.

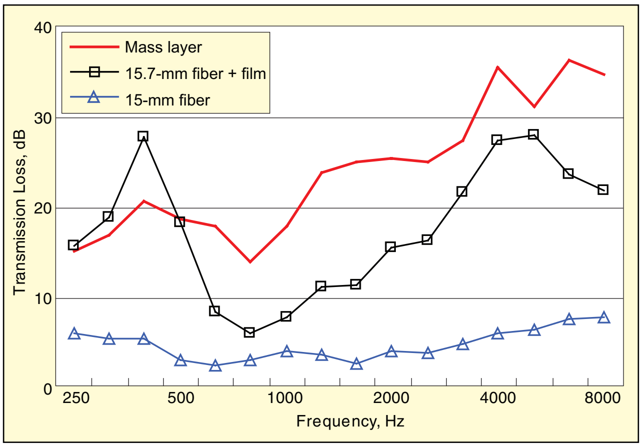

Figure 6. TL for single layers of equal weight with film.

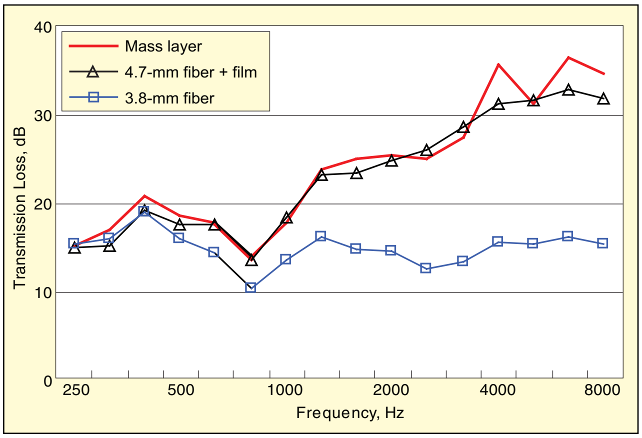

Figure 7. TL for single layers of equal weight with film.

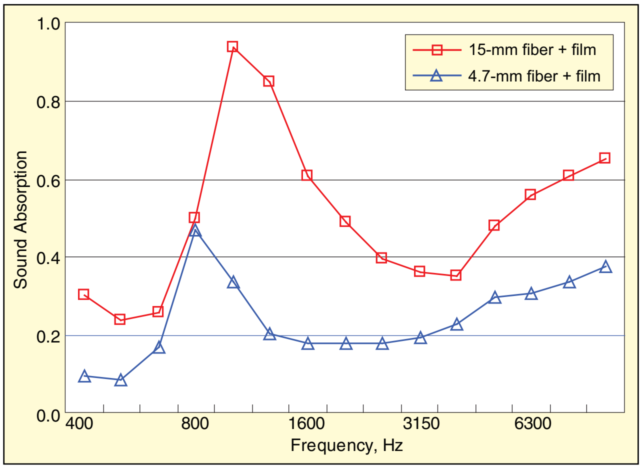

Figure 8. Sound absorption for equal weight layers with film.

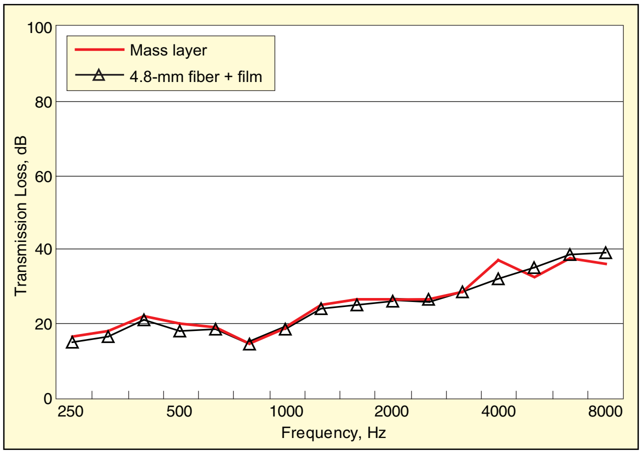

Figure 9. TL for single layers at 2.0 kgsm.

Figure 7 shows that the TL for the 4.7-mm layer with film has matched the TL performance of a single mass layer of the same weight. A critical part of this TL performance with fiber and film is the necessity to compress the fiber to a thin enough layer so that it behaves as a loaded film barrier. It is not sufficient to simply add a film barrier to a fiber layer without compression (see Figure 5).

When molded fiber constructions are used in the trunk of a passenger vehicle, these results show how the TL of the trunk can be improved with a fiber layer, film, and decorative surface. The advantage of this fiber construction is that it provides additional sound absorption over an impervious barrier with no absorption.

Figure 8 shows the sound absorption for each of the fiber constructions with film at nominal 15- and 4-mm thickness. Even with the impervious film near the surface, the fiber construction adds sound absorption.

The high sound absorption for the 15-mm sample in Figure 8 corresponds with lower TL for the 15-mm sample from Figure 6. The peak in absorption in Figure 8 at 800 and 1000 Hz needs further study, but it does correspond to the drop in TL at 800 Hz seen in Figures 6 and 7. The ability to tune sound absorption and TL based on thickness provides a trade-off in the design of a part or allows varying properties across the surface of a part based on its molded thickness.

These tests were repeated with a second sample of fiber, film, and decorative facing to see if the behavior was true at even higher weights. This composite construction at 2.0 kg/m^2 was compared with an equal weight EVA sample in a single-layer test and then in a double-layer test with sheet metal. The single-layer test focused on material characteristics; the double layer test examined system effects. Both of the following figures for these tests will use the same scale for the y-axis for TL to show comparisons between single- and double-wall performance.

Figure 9 shows the TL for both samples as single layers. The performance is equal, and the same notch in TL at 800 Hz is seen as noted previously. The 6-dB-per-octave slope of the TL versus frequency data follows single-layer mass law, so the compressed fiber with film again behaves as a hybrid mass layer.

Figure 10 shows the TL of the samples in a double-layer system with sheet metal. This shows a significant improvement over the single-layer data from Figure 9. In addition, the fiber layer with film shows superior performance over the mass barrier above 1000 Hz. Even though both the fiber composite and the EVA were placed directly against the sheet metal and both had the same surface weight, the improved performance with the fiber composite indicates that a better barrier system has been created. The 18-dB-per-octave slope of the TL versus frequency data show the performance of a double-wall system. This may indicate a need to add a thin fiber backing on all mass layers placed directly against sheet metal to take advantage of the benefits from a thin fiber decoupler. This improvement in TL avoids using higher-weight mass layers to make up this difference in performance.

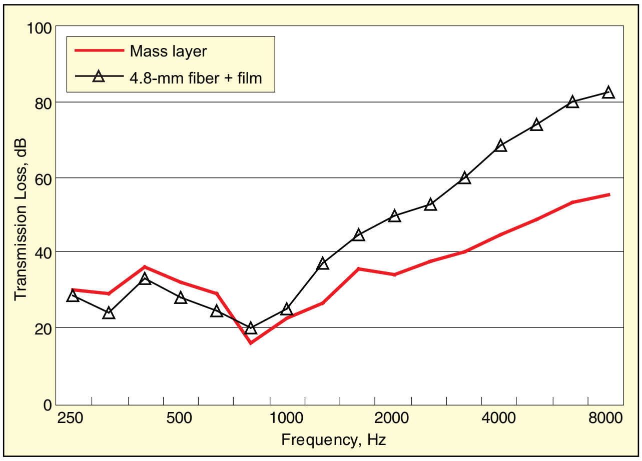

Figure 10. TL for layers at 2.0 kgsm and sheet metal.

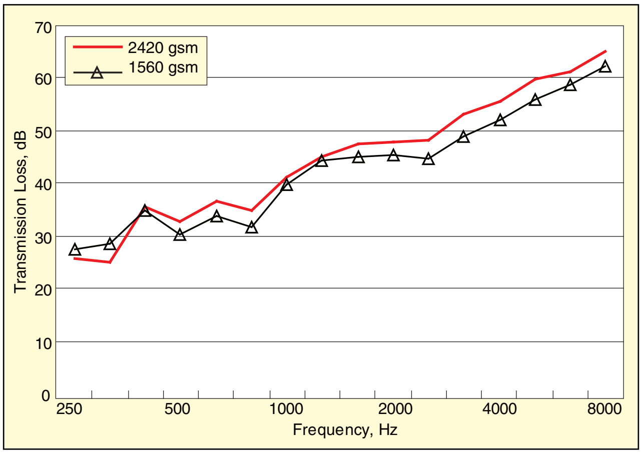

Figure 11. TL for dissipative fiber systems at 25 mm.

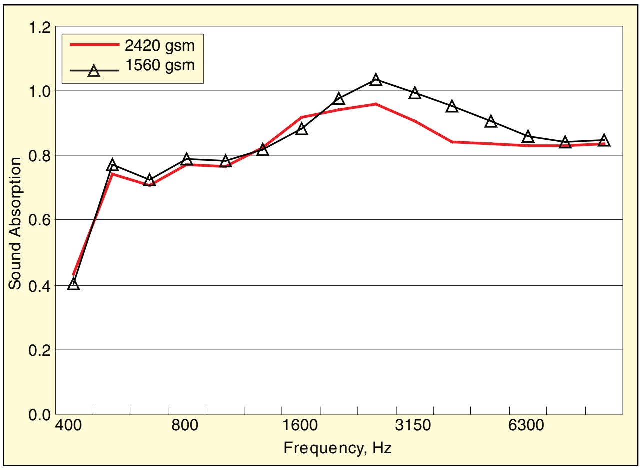

Figure 12. Absorption for dissipative systems at 25 mm.

While noise problems in vehicles are often solved by using barrier strategies for the dash insulator, floor, or trunk, this approach adds weight to the vehicle. Vehicle systems today are searching for acoustically efficient, lightweight alternatives to heavy barrier systems to improve fuel economy.[3] Hybrid fiber systems to meet this need have been developed using a dense fiber top layer, an acoustical scrim, and a lightweight fiber decoupler. These systems fill a performance gap between barriers having high TL but poor sound absorption and porous absorbers having high absorption but poor TL. These dissipative systems can be designed to strike a balance between sound absorption and transmission loss.

Figure 11 shows the TL for 25-mm-thick dissipative fiber systems with weights of 2420 gsm and 1560 gsm when tested with sheet metal. The higher-weight, dissipative fiber system has better TL. Compared to the TL for double-wall barrier systems in Figure 3 and 4, these dissipative systems have lower TL than barriers but also come with a large amount of sound absorption. This additional sound absorption becomes extremely important when the TL of a barrier is compromised by edge leaks or penetrations for mechanical equipment.[1] If this happens, the full value of the heavy mass layer is not realized.

Figure 12 shows the sound absorption for the same dissipative fiber systems at 25 mm with the dense top layers exposed to sound. The lighter-weight, dissipative fiber material has better sound absorption. This is largely due to the higher weight of the dense top layer on the heavier sample, which has slightly better barrier characteristics (see Figure 11).

These dissipative fiber systems can be modified to tune the NVH performance required in a vehicle. They are being used in more vehicles each year to meet demands for quieter and lighter-weight vehicles. Dissipative fiber products for the dash insulator and the floor have replaced barrier systems in vehicles and saved 40% to 60% in weight of each part. Nearly all Japanese vehicles follow an all fiber NVH strategy.

Physical Properties

Fiber acoustical products are used as two-dimensional, die-cut parts and as three-dimensional molded parts in noise control applications. Regardless of the shape, the fiber material must have sufficient durability and integrity to be processed, installed, and perform in the environment for which it is intended.

Molded Products. Secondary molding operations are frequently used to convert flat, two-dimensional fiber materials into three-dimensional parts. Thermoplastic fibers added to the fiber blend allow complex molded shapes with variable thickness to be achieved in the molded part. The production part will then have the exact shape to fit the application. Improved high-temperature binder fibers are now in use so that molded parts remain stable under extremes in temperature and humidity.

Durability. Durability of a fiber acoustical product is important for processing and handling and for longevity of the part in the intended application. All but the lightest density fiber products have sufficient product integrity to be handled without tearing and even the lightest-density products often will add a reinforcing scrim to improve integrity.[5]

Unlike natural fibers, synthetic fibers are not biodegradable. When synthetic fibers are exposed to the environment, they will not degrade over their life. For this reason, they are commonly selected for automotive applications. They also have the benefit that they can be recycled with similar thermoplastic parts at the end of a vehicle's life.

Needled-fiber products with a high surface density are extremely durable and have high resistance to abrasion, puncture, tearing, and impact. A multilayer, needled product made from an engineered blend of fibers is currently in production as an exterior sound-absorbing liner for automotive tire systems.[7] A water-repellant treatment improves the hydrophobic properties of the synthetic fibers in this product. In this exterior location, it has demonstrated high durability against puncture, abrasion, water, and ice with no failures.

Temperature Stability. The maximum service temperature of a fiber acoustical product is determined by the maximum temperature of the fiber used in the product. For recycled fiber blends of natural fiber, the maximum service temperature is about 375°F. Products made from PET (polyethylene terephthalate) fibers can extend this range to 400° F. These products will satisfy a large majority of automotive, transportation, marine, and general noise control applications. In addition, high-temperature binder systems can be used for molded parts exposed to these higher temperatures to stabilize the shape and to eliminate delaminating or warping with temperature extremes.

The temperature resistance of fiber parts can be extended using heat-resistant thermal patches placed at high-temperature locations in contact with the acoustical part. Thermal foils that dissipate heat can also be applied. The highest-temperature applications will require materials with fiber having the highest temperature resistance such as glass or mineral wool. Flame-retardant additives are also used to minimize flame spread and combustion for these materials.

The properties of fiber materials that allow them to be good sound absorbers also allow them to be good thermal insulators. This is a result of their porous structure and their ability to retard heat flow with a low thermal conductivity. While the thermal properties of acoustical materials are usually less important then their acoustical properties, these materials can often serve multiple functions as acoustical and thermal products. This adds another value for fiber-based acoustical products used in solving industrial or appliance noise control problems.

Conclusions

The conclusions from this study are:

- Advances in fiber formulations and manufacturing processes have extended the acoustical and physical properties of fiber products for use in multiple noise control applications.
- Recycled fibers represent a large part of the fiber stream for acoustical products and provide economic incentives for considering fiber products.
- Sound absorption of fiber materials can be improved with fine fibers, with acoustical scrims, and by modifying the fiber blend, thickness, or weight.
- Fiber decouplers improve the TL of mass barrier systems and show comparable TL performance to foam decouplers.
- Hybrid fiber constructions compressed to thin layers with film provide single-wall TL comparable to equal weight barrier layers.
- Hybrid fiber constructions compressed to thin layers with film provide better TL than barrier layers used directly on sheet metal (without a decoupler).
- Dissipative fiber systems with acoustical scrims bridge a gap between individual materials for TL and sound absorption while also delivering significant weight reduction.
- Durability and temperature resistance of fiber products can be achieved with engineered fiber formulations and manufacturing processes.

In summary, the acoustical and physical performance envelope of fiber products has been expanded using engineered-fiber formulations with advanced manufacturing processes. These products provide NVH performance, weight reduction, and durability in each application. Fiber products have been successfully used to solve noise problems in the automotive industry for several years. Their use can be easily extended to the transportation, marine, appliance, and industrial markets to solve noise problems. The low cost of recycled fibers and the many combinations of design and performance rating make these products attractive options for the toolbox of the NVH engineer.

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