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Recent applications of viscoelastic damping for noise control in automobiles and commercial airplanes

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Abstract

In this paper, the application of passive damping technology using viscoelastic materials to control noise and vibration in vehicles and commercial airplanes is described. Special damped laminates and spray paints suitable for mass production and capable of forming with conventional techniques are now manufactured in a continuous manner using advanced processes. These are widely used in the automotive and aerospace industry in a variety of applications to reduce noise and vibration and to improve interior sound quality. Many of these recent applications are not readily available for dissemination in academe and archival literature. It is hoped that the material presented in this paper will be useful for instruction and further research in developing new and innovative applications in other industries.

1. Introduction

Vibration and noise in a dynamic system can be reduced by a number of means. These can be broadly classified into active, passive, and semi-active methods. Active control involves the use of certain active elements such as speakers, actuators, and microprocessors to produce an “out-of-phase” signal to electronically cancel the disturbance. The traditional passive control methods for air-borne noise include the use of absorbers, barriers, mufflers, silencers, etc. For reducing structure-borne vibration and noise, several methods are available. Sometimes just changing the system’s stiffness or mass to alter the resonance frequencies can reduce the unwanted vibration as long as the excitation frequencies do not change. But in most cases, the vibrations need to be isolated or dissipated by using isolator or damping materials.

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In semi-active methods, active control is used to enhance the damping properties of passive elements. Examples include electro-rheological (ER), magneto-rheological (MR) fluids, and active constrained-layer damping (ACLD) in which the traditional constraining layer is replaced with a smart material. The full-scale implementation of active and semi-active control technology in vehicles and commercial airplanes has been slow because of high costs and the complexity of sound field in the cabin interior. Passive damping using viscoelastic materials is simpler to implement and more cost-effective than semi-active and active techniques. Damping can be added to a system by using special viscoelastic materials in a number of ways. This paper deals with the application of viscoelastic damping materials for passive vibration and noise control in automotive and aircraft structures.

Damping refers to the extraction of mechanical energy from a vibrating system usually by conversion into heat. Damping serves to control the steady state resonant response and to attenuate traveling waves in the structure. There are two types of damping: material damping and system damping. Material damping is the damping inherent in the material while system or structural damping includes the damping at the supports, boundaries, joints, and interfaces, etc. in addition to material damping. Various terms such as viscous damping, hysteretic damping, Coulomb damping, linear and proportional damping, etc. are used in the literature to represent vibration damping. It should be noted that these representations merely indicate the mathematical model used to represent the physical mechanism of damping that is still not clearly understood for many cases. A variety of nomenclature exists to denote damping as several disciplines are involved in damping research and it appears each profession has its own favorite nomenclature. These include, damping ratio (ζ), log decrement (δ), loss factor (η), loss angle (ϕ), $\tan\delta$, specific damping capacity (ψ), quality factor (Q), etc. It is beyond the scope of this paper to describe all of these models and mechanisms. However, readers should consult Refs. [1–3] for a review of the various mathematical models, physical mechanisms, and experimental measures of damping.

Passive damping as a technology has been dominant in the non-commercial aerospace industry since the early 1960s. Advances in the material technology along with newer and more efficient analytical and experimental tools for modelling the dynamical behavior of materials and structures have led to many applications such as inlet guide vanes of jet engines, helicopter cabins, exhaust stacks, satellite structures, equipment panels, antenna structures, truss systems, and space stations, etc.

The use of surface damping treatments in the automotive, commercial airplane, appliance and other industries has only been in recent years. The eventual application into these industries is made possible by the advancement in manufacturing processes which are cost-effective and are suitable for high volume production. Multilayer damped laminates consisting of two metal skins with a viscoelastic core can now be manufactured by a continuous process in coil form using existing equipment and technology rather than by the conventional laminating press procedure. Most of these applications and case studies have been confined to company brochures and are not readily available for dissemination in academe and archival literature. The purpose of this paper is to compile some of the recent applications of viscoelastic damping in automotive and commercial airplanes. It is hoped that the material presented in this paper will not only be useful for pedagogy but also will help as a spring-board for launching new and innovative applications in other industries.

First a brief discussion on the basic concepts of viscoelastic damping is provided, followed by the applications. No attempt is made to review the various theoretical models and analytical tools used in the design of passive damping treatments. The readers are referred to many excellent review articles and textbooks on this subject [4–8].

2. Basic viscoelastic concepts

Viscoelasticity may be defined as material response that exhibits characteristics of both a viscous fluid and an elastic solid. An elastic material such as a spring retracts to its original position when stretched and released, whereas a viscous fluid such as putty retains its extended shape when pulled. A viscoelastic material (VEM) combines these two properties—it returns to its original shape after being stressed, but does it slowly enough to oppose the next cycle of vibration. The degree to which a material behaves either viscously or elastically depends mainly on temperature and rate of loading (frequency). Many polymeric materials (plastics, rubbers, acrylics, silicones, vinyls, adhesives, urathanes, and epoxies, etc.) having long-chain molecules exhibit viscoelastic behavior. The dynamic properties (shear modulus, extensional modulus, etc.) of linear viscoelastic materials can be represented by the complex modulus approach. The introduction of complex modulus brings about a lot of convenience in studying the material properties of viscoelastic materials. The material properties of viscoelastic materials depend significantly on environmental conditions such as environmental temperature, vibration frequency, pre-load, dynamic load, environmental humidity and so on. Therefore, a good understanding of such effects, both separately and collectively, on the variation of the damping properties is necessary in order to tailor these materials for specific applications.

2.1. Effects of temperature

The temperature is perhaps the most important environmental factor affecting the dynamic properties of damping materials. This effect is shown in Fig. 1 for a typical polymeric material having four distinct regions. The first region is the glassy state where the material has very large storage modulus (dynamic stiffness) but very low damping. The storage modulus in this region

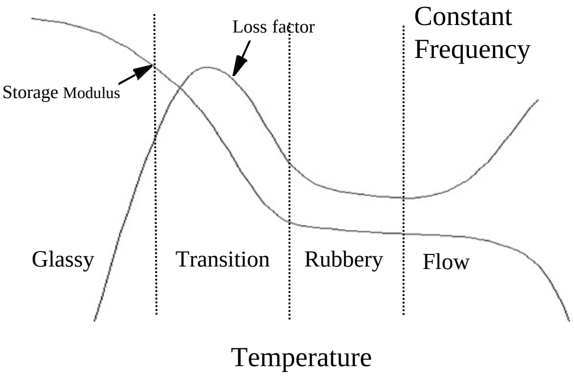

Fig. 1. Variation of storage modulus and loss factor of a viscoelastic material with temperature [5].

changes slowly with temperature, while the loss factor changes significantly with increasing temperature. In the transition region where the material changes from a glassy state to a rubbery state, the material modulus decreases rapidly with increasing temperature because of softening of the material that increases loss factor. The damping usually peaks at or around the glass transition temperature of the material. Some polymers can be made to have more than one transition region by changing the polymeric structure and composition to take advantage of the peak damping capacity in this region. In the rubbery state both modulus and loss factor take somewhat low values and vary very slowly with temperature. The flow region is typical for a few damping materials such as vitreous enamels and thermoplastics, where the material continue to soften as temperature increases while loss factor reaches very high values.

2.2. *Effects of frequency*

Experiments have shown that vibration frequency or the rate of loading has significant effect on the damping and dynamic modulus of viscoelastic materials. The variation of the modulus and loss factor of a typical high damping material with frequency over a range of three to five decades shows that for a material without the flow region, the effect of increasing temperature on the storage modulus is similar to the effect of reducing frequency. This behavior provides the basis for the temperature–frequency superposition principle that is used to transform material properties from the frequency domain to temperature domain, and vice versa [9].

3. Damping treatments

Viscoelastic materials have been used to enhance the damping in a structure in three different ways: free-layer damping treatment, constrained-layer or sandwich-layer damping treatment and tuned viscoelastic damper. Although these designs have been around for over 40 years, recent improvements in the understanding and application of the damping principles, together with advances in materials science and manufacturing have led to many successful applications. The key point in any design is to recognize that the damping material must be applied in such a way that it is significantly strained whenever the structure is deformed in the vibration mode under investigation.

3.1. *Free-layer damping (FLD)*

Fig. 2 illustrates a portion of a structure with a free-layer or sometimes called extensional type damping treatment. The damping material is either sprayed on the structure or bonded using a

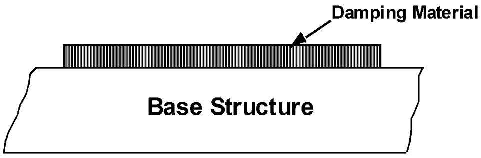

Fig. 2. Free layer damping.

pressure-sensitive adhesive. Examples include undercoating of an automobile and application of "mastics" to body and floor panels to provide damping. When the base structure is deflected in bending, the viscoelastic material deforms primarily in extension and compression in planes parallel to the base structure. The hysteresis loop of the cyclic stress and strain dissipates the energy. The degree of damping is limited by thickness and weight restrictions.

The vibration analysis of a beam with a viscoelastic layer was first conducted by Kerwin and colleagues [10,11]. The viscoelastic characteristic of the material was modelled using the complex modulus approach. The system loss factor in a free-layer system increases with the thickness, storage modulus, and loss factor of the viscoelastic layer. Another interesting feature of the free-layer treatment is that the damping performance is independent of the mode shape of vibration for full coverage by the viscoelastic layer. It is however, possible to optimize partial coverage for a particular mode or a limited number of modes [12,13].

3.2. Constrained-layer damping (CLD)

Fig. 3 shows an arrangement of a constrained-layer damping treatment. This consists of a sandwich of two outer elastic layers with a viscoelastic material as the core. When the base structure undergoes bending vibration, the viscoelastic material is forced to deform in shear because of the upper stiff layer. The constrained-layer damping is more effective than the free-layer design since more energy is consumed and dissipated into heat in the work done by the shearing mode within the viscoelastic layer. Damping tapes consisting of a thin metal foil covered with a viscoelastic adhesive and used on an existing structure is a constrained-layer type arrangement. The symmetric configuration in which the base and the constraining-layers have the same thickness and stiffness is by far the most effective design since it maximizes the shear deformation in the core layer. Many of the automotive applications described in the next section belong to this category. The constrained-layer design can be simply extended to include (1) stand-off damper in which a spacer is used in between the VEM and the base layer, and (2) multiple damping layers, which are very effective for obtaining damping over wider temperature and frequency ranges.

3.3. Tuned viscoelastic damper (TVD)

Fig. 4 is the design of a typical tuned viscoelastic damper. This is similar to a dynamic absorber, or sometimes referred to as tuned mass damper, except that a viscoelastic material is added to dissipate energy. The TVDs are generally applicable to reduce vibration/noise associated with a single frequency or a narrow band of frequencies. Properly tuned TVDs act to eliminate an unwanted resonance by splitting the original peak into two, one below and one above the

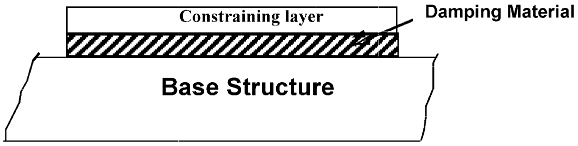

Fig. 3. Constrained-layer damping.

Fig. 4. Tuned viscoelastic damper.

resonance frequency of the original system. The addition of damping helps to reduce the overall displacement amplitudes as illustrated in Fig. 4.

Accurate "tuning" to match the natural frequency of the dynamic absorber with the frequency of the objectionable excitation is required to achieve desired results. The TVDs are effective when they are located at points of high displacements or anti-nodes. The viscoelastic material is used (either in extension or shear) as a lumped elastic element in combination with an appropriate mass.

Another controlling factor is the expected operating temperature range and the glass transition temperature of the viscoelastic material. It is well known that the stiffness and damping of viscoelastomers vary significantly with temperature. The TVD *should not* be designed to operate near the glass transition temperature of the viscoelastic material. The reason is simple. In the transition region, although the damping is high, the stiffness of the material changes rapidly with temperature. Any temperature change in the damping material caused by the internal heating due to energy dissipation is sufficient to alter the dynamic stiffness that may cause the TVD to detune itself. Therefore, elastomeric materials for TVDs must be used in the rubbery region where small changes in temperature do not have significant effect on the stiffness. Tuned mass dampers have been widely used in the automotive industry in the exhaust hangers, steering systems, engine frames and brackets, mirrors, etc. Several innovative concepts of TVDs using existing components such as airbag, spare tire, and battery as the tuning mass have been implemented.

4. Automotive applications

Reduction of interior noise and vibration in passenger vehicles is a major requirement for achieving world-class vehicle quality, performance and customer satisfaction. Noise, vibration and harshness (NVH) is being considered as a design parameter in the design of current and future generation of vehicles. Automotive interior noise usually arises from the transmission of vibration energy of different systems such as engine, power train, climate control systems and road inputs, etc., into the vehicle via various paths (engine mounts, suspensions, body panels, and floor panels, etc.). The vibration of these elements is responsible for about 90% of the harshness-related acoustical energy in the automotive interior.

4.1. Powertrain and body structures

Several families of CLD products consisting of metal outer skins sandwiched by a thin viscoelastic core material are commercially available (e.g., Quiet Steel®. Dynalam, LVDS, etc.) [14,15]. Viscoelastic core thicknesses are usually applied between 25 and 40 μm while the outer metal skins have thicknesses ranging from 0.25 to 5 mm. The peak damping loss factors of these laminates are usually greater than 0.07 and can reach a peak value of about 0.5 at varying temperature levels starting from room temperature to about 150°C (300 ^{0}F). These "laminate steels" supplied in the form of rolls, or panels can be formed into any desired shape by conventional processes like drawing, stamping, punching, etc. Furthermore, they can also be spot-welded or fastened by other special means with minimal negative effect on the damping performance. The following Table 1 and Fig. 5 show the current applications of these products in the automotive industry for reducing noise and vibration.

Fig. 6 shows the reduction in the overall sound pressure level at the driver's ear by replacing a regular oil pan with a laminate steel oil pan in a vehicle run- up. In addition to obtaining noise reductions up to 8 dB, a great improvement in the overall quality of sound has been observed using these new oil pans and valve covers. Since viscoelastic materials are non-conductive,

Table 1
Automotive applications

Engines and powertrains	Body structures	Brakes, and accessaries
Oil pans	Dash panels	Brake insulators
Valve covers	Door panels	Backing plates
Engine covers	Floor panels	Brake covers
Push rod covers	Wheelhouses	Steering brackets
Transmission covers	Cargo bays	Door latches
Timing belt covers	Roof panels	Window motors
Transfer case covers	Upper cowl	Exhaust shields

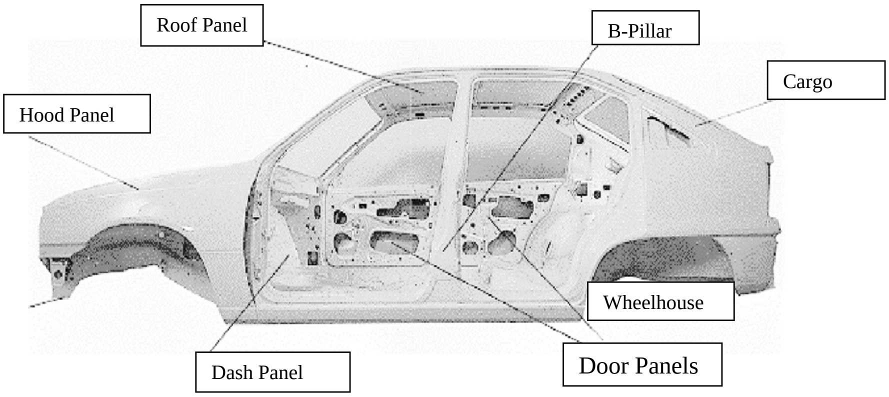

Fig. 5. Damping applications in automotive body structures.

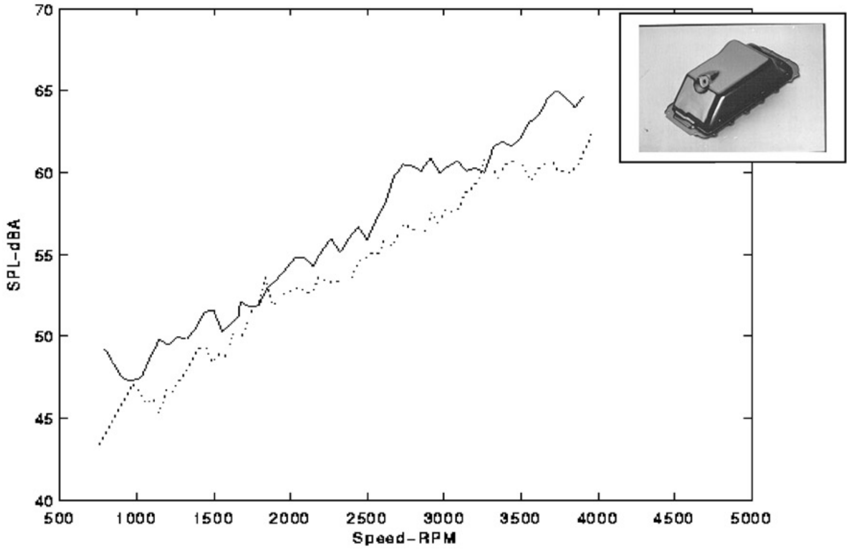

Fig. 6. Comparison of sound pressure level at the driver's ear for a car equipped with regular and damped oil pans: ——, galvanized steel; …., laminated steel.

weldability of these laminates is achieved by adding a conductive filler of special nature with particle size corresponding to the thickness of the damping layer [16].

Damping materials for automobile body, floor and dash panels have been undergoing rapid advancements in recent years. Expectations regarding damping materials are also increasing as the need for superior interior sound quality and weight reduction has increased. Most efforts to reduce acoustic sensitivity via body structural modifications have involved increasing body stiffness while damping treatments are often used to reduce the overall vibration and noise levels. It should be noted that mass, stiffness, and damping changes will affect different modes differently. Damping treatments usually help to reduce the vibration response at panel resonances. Currently many different materials are used to enhance damping in the body such as mastics, free and constrained layer viscoelastic materials, etc. The actual treatment implemented varies with vehicle platform and there is a need to develop a unified strategy to optimize the damping treatment.

The application methodology of the damping treatment has become very important because of increasing labor costs and material handling issues. Manually applied asphalt sheets tend to have high labor costs, seem to become brittle when stored for long periods of time or exposed to cold temperature environments. Constrained-layer damping treatments generally perform better than asphalt or spray dampers of the same weight, because of the additional damping provided by the shearing of the viscoelastic material. A careful design strategy needs to be implemented in order to select the locations, type, and thickness of damping and constraining-layer materials to optimize the performance over broader frequencies and temperatures with little or no weight and strength penalties. The adhesion of constrained-layer damping to complex contours such as ribs is also an issue which is somewhat overcome with conformal constrained layer (CCL) type damping treatments. The CCL is basically a constrained-layer damping tape that can be bent or shaped to conform to the contour of the base structure. A new class of extensional damping treatment in the form of “spray dampers” have emerged as attractive candidates for floor panels [17,18]. The sprayable type has a cost-advantage since it can be robotically applied thus allowing the placement of the material at selected locations. Sprayable dampers, however require significant up-front capital costs associated with pumping and robotic equipment.

Fig. 7(a) shows the application of a recent water-based spray damper made of acrylic elastomers for floor panel applications. These dampers, supplied in large cans, are robotically sprayed to floor panels and wheelhouses to thicknesses between 1 and 3 mm and cured in an oven. The data shown in Fig. 7(b) shows effectiveness of applying spray damper to a vehicle floor panel when compared to the same panel with no damping treatment.

Currently efforts are underway to use a new laminated vibration damped steel (LVDS) for dash panel application. These LVDS structures are being designed with the aid of computer aided engineering (CAE) to reduce both air- and structure-borne powertrain noise into the interior. This is basically a designed-in damping concept of replacing the original panel with new damping panel (instead of add-on treatments) similar to damped powertrain components shown in Table 1. Significant improvement in interior sound quality was noticed with these dash panels as evidenced by lower values of measured interior loudness and articulation index [19]. Fig. 8 shows one design of a dash panels using LVDS.

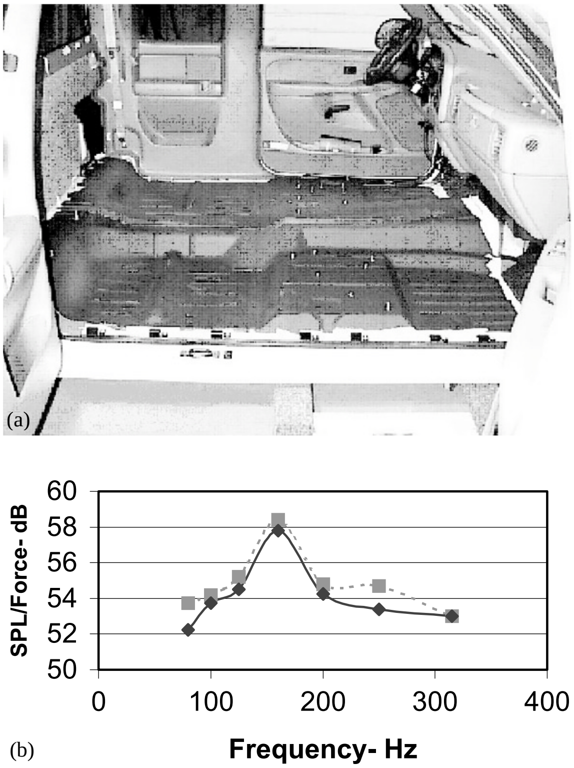

Fig. 7. (a) Application of spray damper to automotive floor panel. (b) comparison of acoustic sensitivity of floor panels: ▨, baseline; ◆, spray damper.

Fig. 8. Damped dash panels using VEM.

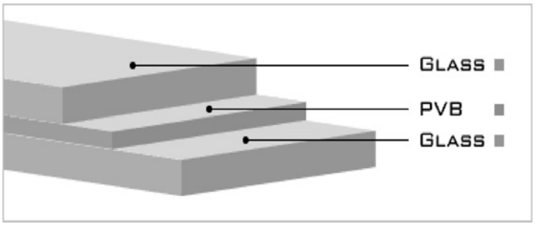

Fig. 9. Laminated glass for windows [20].

Body and floor panel damping is generally believed to be most effective in reducing structure-borne noise in the 100–500 Hz range. Damping treatment may also act in conjunction with sound package to increase the noise reduction (NR) of air-borne sound transmission paths. It should be emphasized that the following factors require careful attention in any damping treatment design: location, temperature, frequency, panel stiffness, thickness of the damping layer, and type (free layer, constrained-layer or combination) of damping design. The overall strategy is to obtain the required damping with the lowest cost and weight while maintaining panel stiffness and manufacturability.

4.2. *Laminated glass for windows*

A recent innovation to add damping into automotive side and rear windows is the use of a new "laminated" glass. This sandwich glass is made of a layer of polyvinyl butyral (PVB) bonded between two sheets of glass under heat and pressure as shown in Fig. 9 [20]. The polyvinyl butyral provides damping to reduce vibrations in the glass, resulting in a significant reduction in both road and wind noise in a vehicle. Fig. 10(a) shows a comparison of measured system loss factors from two similarly equipped side door of a vehicle—one with PVB glass and the other having standard tempered glass. These results were extracted using the power input method on frequency response data collected from the specimens using the set-up shown in Fig. 10(b) [21]. It can be seen that the laminated PVB glass has much higher damping than the regular tempered glass over the entire frequency range. At some frequencies, the damping of PVB glass is more than twice that of the regular glass.

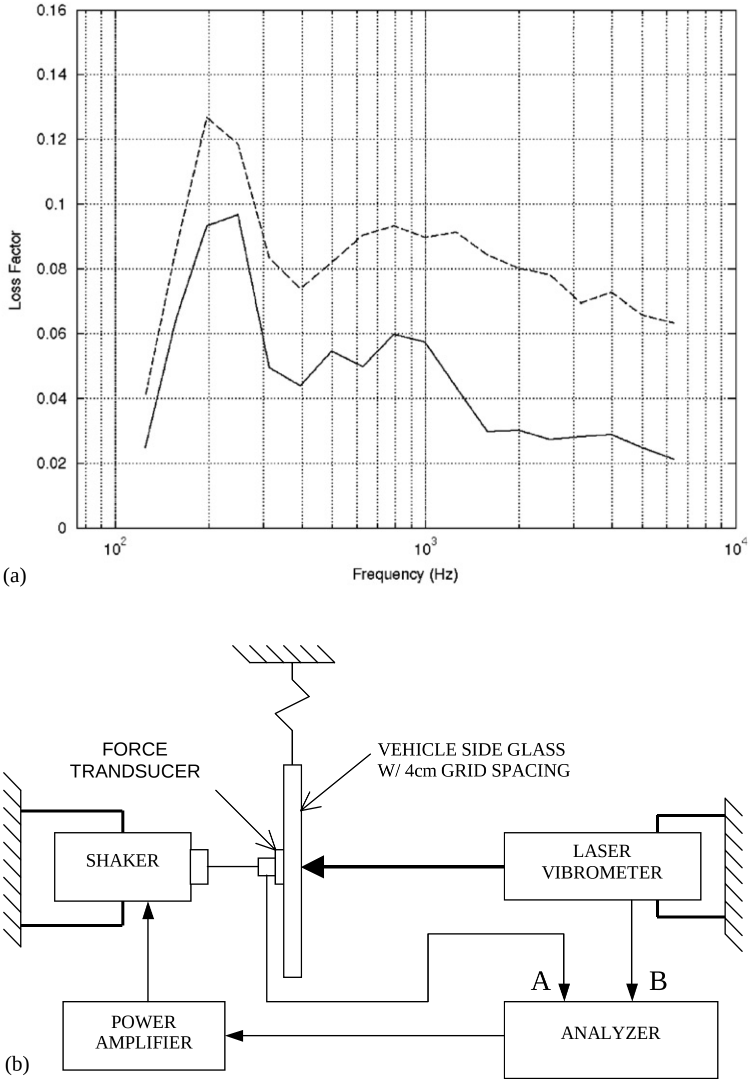

Fig. 10. (a). Frequency-averaged loss factor results. (b) experimental set-up: (——, tempered glass; - - -, laminated glass).

4.3. High-temperature laminates

Materials used in applications such as brake pad insulators are exposed to temperatures in the range 250–300°C. Families of multi-layer composite laminates have been developed to meet this requirement [22]. These materials are tailored to have peak damping properties at elevated temperatures in addition to having excellent thermal properties. This is achieved by using a multiple constraining layer construction using two different damping layers as shown in Fig. 11. Several high-temperature damping materials such as fluropolymers, and nitrile rubber phenols have been developed specially for brake application to reduce squealing noise.

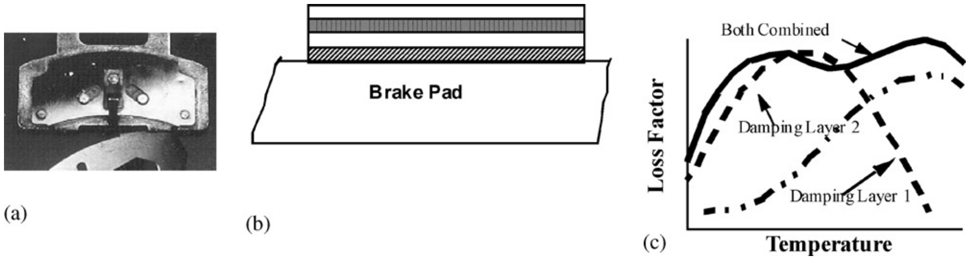

Fig. 11. Multiple damping laminates for brake application. (a) Brake pad. (b) layers: ▨, ■, damping layer; □, constraining-layers.

Furthermore, several prototype “Noise Deadeners” for very high-temperature applications (400–600°C) such as heat shields for exhaust systems and engine manifolds have been reported [23]. These laminates developed for noise and thermal control consist of thin metal sheets which are interlayered with core materials specially selected for their thermal properties. The outer skins of these systems are typically 0.25–0.75 mm thick and are stainless steel, aluminized steel or aluminum alloy. Typical core materials include graphite mat, glass cloth, alumina, and other refractory metal oxides having thicknesses from 0.1 to 0.5 mm. A salient feature of these laminates is that the metal/core interfaces contain very thin layers of air gaps deliberately introduced to provide damping. The damping comes from the “pumping” of air through these narrow gaps. The different layers are fastened together by special fastening devices.

5. Commercial aircraft applications

As mentioned before, the viscoelastic damping has been dominant in the military aircraft and spacecraft industries since the early 1960s. A number of applications have been reported in damping conferences sponsored by the Airforce Wright Aeronautical Laboratories during late 1980s and early 1990s. An effort was undertaken to develop a damping design guide for aerospace structures [24]. These events along with advances in material science have led to the development of many light-weight and cost-effective damping treatments described in this section for commercial airplanes.

The three main sources of continuous noise in an airplane cabin are, (1) boundary layer noise from air flowing around and over the airplane, (2) the environmental control system or the air-conditioning system noise, and (3) the jet noise from airplane’s engines. There are other transient sounds from airplane control mechanisms, landing gear operation, galley and lavoratory equipment, fuel and hydraulic pumps, etc. The continuous noise sources dominate the sound field inside the cabin, especially the noise due to the structural vibration of the fuselage side wall caused by the turbulent boundary layer. At the front of the airplane, where the air is just beginning to flow around the fuselage, the thickness of the boundary layer is small. The boundary layer thickness around the flight deck for most commercial airplanes is about 13 mm and grows to about 30 cm at the back of the plane. It has been observed that the boundary layer noise in the cabin will increase by about 2 dB for every 0.1 Mach increase in airspeed. The noise, however, decreases by the same amount for about every 1500 m increase in altitude [25]. Methods of reducing the cabin noise include blocking the sound by adding fiberglass acoustic insulation blankets, ceiling panels, stowbins, sidewall panels, and damping treatments to the airplane's fuselage.

Most of the applications of passive damping in commercial aircraft are confined to providing local damping treatment in the fuselage using add-on type damping to reduce the overall vibration amplitude. Because of weight restrictions, the treatments are designed to maximize damping with minimum weight increase, hence composite materials are the preferred choice for the constraining layer. Conventional CLD work by creating shear deformation in the adhesive when the structure bends. However, at lower order modes, when there is not much curvature, there is very little shear and hence very little damping in CLD. To overcome this, a stand-off treatment with a spacer as shown below in Fig. 12 is widely popular in the aerospace industry. The spacer material is supposed to ideally have infinite shear stiffness and zero bending stiffness.

The stand-off layer provides a greater separation between the neutral axis of the base structure and that of the overall system. The spacer acts as a kinematic amplifier to increase the shear deformation in the viscoelastic layer which significantly increases the damping capacity of the treatment. Additionally, the spacer layer can be slotted in order to reduce the bending rigidity and total mass of the treatment. Several light-weight/shear-stiff material made of polymeric compounds have been used for the stand-off layer and glass, graphite and kevlor fiber composites are used for the constraining layer.

Previous damping designs involved CLD damping tapes for skin, stringers and frames of fuselage sections shown in Fig. 13. These are slowly being replaced with stand-off dampers as shown in Fig. 14 for the skin pockets, Fig. 15 for stringers and Fig. 16 for frames. The stand-off dampers are also used in some crew-rest cabins, floor panels and bulk heads. Additionally, acoustic tile type dampers (Fig. 17) are used in some aircrafts for stingers. These tiles are lightweight compared to damping tape, however, they were designed for structures with hat section stringers and have not proven on structures with newer Z-section stringers. The stand-off damper offers a potential weight savings of 15% to 25% over damping tape and covers a significantly smaller area of the fuselage skin while providing equivalent damping. Skin and stringers are generally colder than frames. The reason is that the frame is not directly in contact with the exterior, most of the frame's surface is in contact with cabin air and the frame has greater thermal mass. Hence low-temperature damping materials are used in skin and stringer damping treatments, whereas, room temperature damping materials perform better in frames. The actual coverage of the damping treatment varies from plane to plane and some treatments are unique to a certain model.

Another innovative use of CLD in aircrafts is the I-beam damper used in the upper deck of some wide body planes [26]. This damper was designed to replace a rivetted stiffner used to reduce

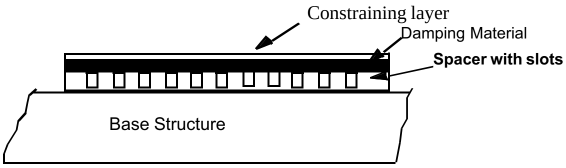

Fig. 12. Stand-off layer damping system.

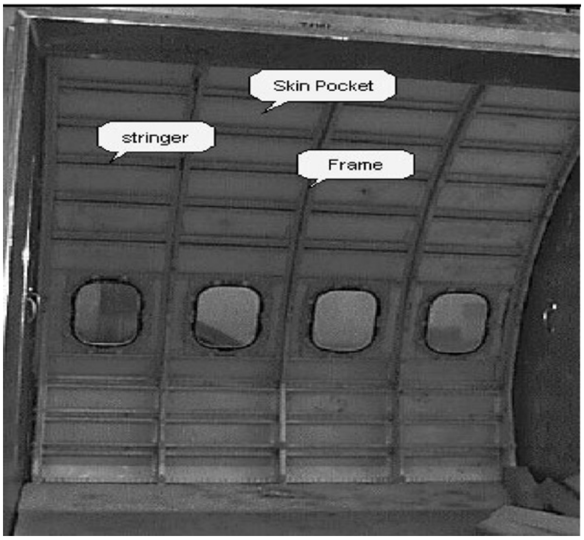

Fig. 13. A section of an aircraft fuselage.

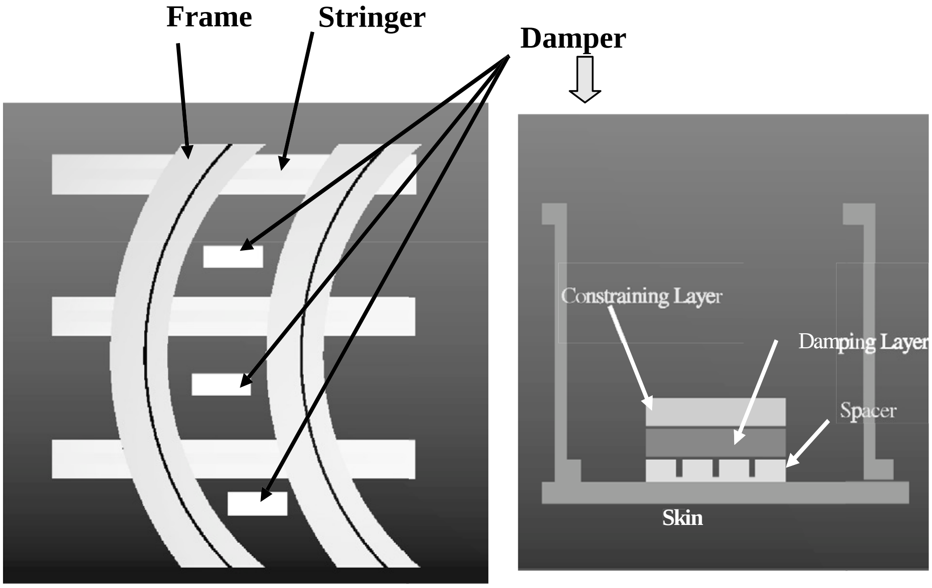

Fig. 14. Stand-off Dampers used in Fuselage Skin.

noise levels inside the cabin. In this design, a Kevlar I-beam was used as the constraining layer that is stiff in bending. Here, since VEM is thick and flexible, the constraining layer will cause thickness deformation in the adhesive along with shear. The I-beam damper is used in conjunction with stand-of dampers as illustrated in Fig. 18 in some airplanes.

The free-layer treatments including the spray damper and other designs used in vehicles are not suitable for airplanes because of weight constraints and safety issues. Additionally, any new

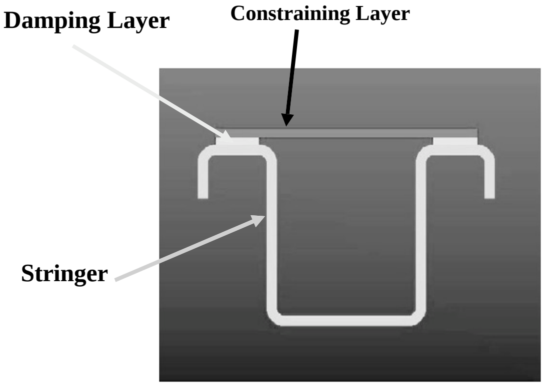

Fig. 15. Stringer damper.

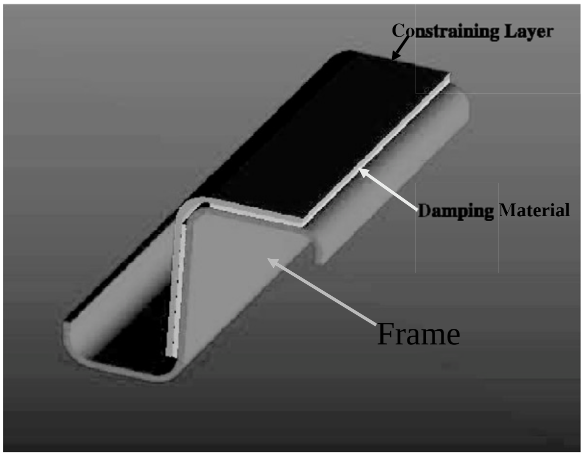

Fig. 16. Frame samper.

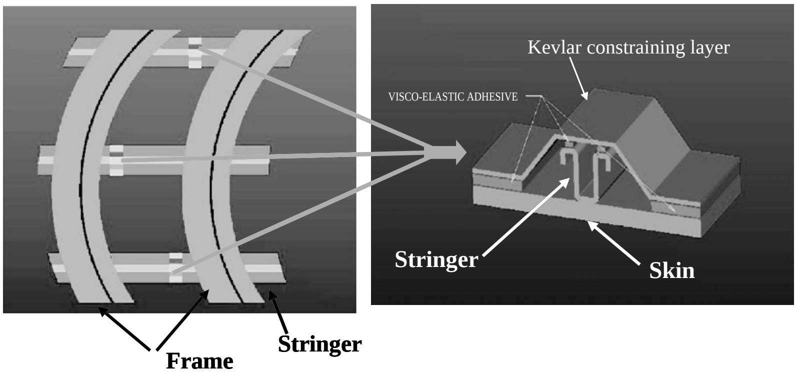

Fig. 17. Acoustic tile damper for stringers.

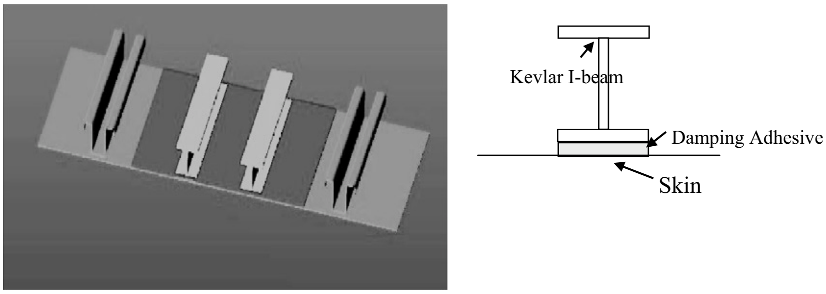

Fig. 18. I-Beam damper for the fuselage.

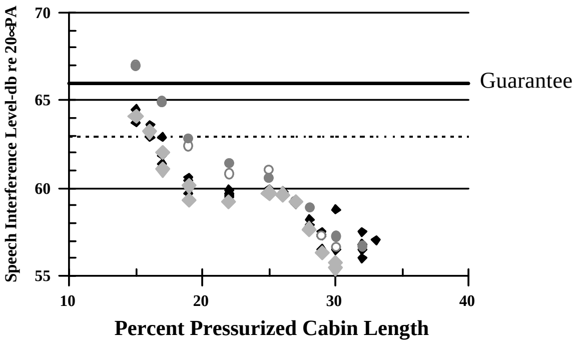

Fig. 19. Speech interference levels (SIL) inside an aircraft (from Boeing): ●, DTI stand-off with incorrect viscous damping; ◆, correct viscous damping; ◆, 3 M tape.

damping design in an airplane must undergo rigorous testing and certification process to address concerns with flammability, corrosion, durability, and ease of inspection in addition to safety.

One final note about the correct choice of the viscoelastic materials in the damping treatment design. Fig. 19 shows a comparison of measured speech interference levels (SIL) inside a commercial aircraft with two different stand-off dampers and a traditional damping tape installed in the fuselage. It shows that in one case with a wrong viscoelastic material, the damping treatment acts to increase the SIL by about 3 dB.

6. Other applications

The passive damping technologies described in this article, especially the CLD are used or being proposed in many other industries and applications. Examples include: (1) appliance industry—dishwashers, washers, dryers, refrigerators, de-humidifiers, air-conditioners and furnaces. Areas of usage are cabinets, wrappers, access panels, tubs, motors, fan housings, motor mounts, and bases. (2) Lawn and power equipment—usage in engine, blower housings and spindle covers of riding mowers, covers, panels of small engines, tractors, compressors, and generators. (3) Computer hardware industry—CLD have been used in head slider suspension systems, top covers, circuit board and substrate material for disk media and high speed disk drives, printers and copy machines; (4) machine tools, turbines, and ships—here several innovative designs including “particle dampers,” “impact dampers,” and “co-cured” composites have been proposed; and finally, (5) recreation and sports industry—several applications in yachts, skies, tennis rackets, golf clubs, baseball bats, and even in horseshoes!

7. Conclusions

The objective of this paper has been to describe some of the recent industrial applications of passive damping using viscoelastic materials. The three most common types of passive damping treatments described in this paper are: free-layer damping treatment, constrained-layer or sandwich-layer damping treatment and tuned viscoelastic damper. The symmetric configuration in which the base and the constraining layers have the same thickness and stiffness is by far the most effective design since it maximizes the shear deformation in the core layer. The use of damping treatment in the automotive and aerospace industries is made possible by the advancements in manufacturing processes that are cost-effective and are suitable for high volume production. A good understanding of the variation of the damping properties with temperature and frequency is very important in any damping treatment design. A final note about the use of passive damping technology—they are recommended for use in structural components that are not primary load carrying members. For load carrying members, the design should first satisfy the strength and stiffness requirements over damping benefits.

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