Silentex® glass fiber noise control solution for vehicle exhausts

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SILENTEX® GLASS FIBER SOLUTIONS

DESIGN GUIDE

1. INTRODUCTION

Silentex®[1] system technology is a process for separating a roving strand into individual filaments (known as texturizing) so that they can efficiently dissipate acoustic energy. Texturized material produced by this process can be directly injected into a silencer chamber, into a bag, into a box, or into a mold to produce a preform. Boxed texturized material can be utilized in filament winding or hand stuffing operations.

Fiberglass roving is made of continuous fibers. For example, a single 20 kg doff (bobbin) of ST2070 material contains one strand consisting of 5800 filaments, each of which is 2.86 km (1.77 miles) long. The Silentex® process maintains the continuity of the fibers. As a result, these continuous fibers are typically more resistant to strand and to short fiber blow out from the silencer than short fiber (e.g. chopped) materials.

Owens Corning offers Advantex®[2] glass as a standard for the Silentex® system. This glass can operate at a continuous glass temperature of up to ~740ºC and is suited for the vast majority of muffler applications. For other glass chemistries please contact your local Owens Corning representative. In determining suitable use temperatures, it needs to be kept in mind that the actual glass temperatures are often 20-50ºC lower than the maximum measured exhaust gas temperature at the silencer inlet. The temperature differential between the maximum glass and maximum exhaust temperatures is highly dependent upon the design of the exhaust system.

As with any exhaust system development program, it is best to consider Silentex® system technology early in the design phase. This allows the advantages of acoustic materials to be fully utilized while creating designs that can be filled in the most efficient manner that optimizes the cost/performance/weight opportunities.

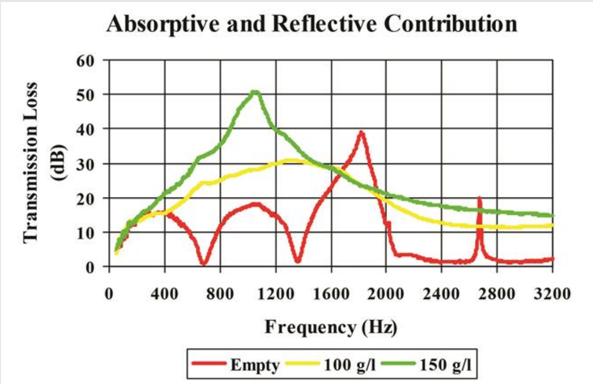
2. ACOUSTICS

As shown in FIGURE 1, the Silentex® system technology does an excellent job of absorbing sound over a broad frequency range, except for the lowest frequencies. This provides a quality low frequency "performance sound" when desired.

Low frequency attenuation can be addressed in a coupled reflective/absorptive system design when desired.

The best acoustic performance is normally seen with fill densities in the 100 to 150 kg/m³ (gm/liter) range but a specific fill density should be determined for each design. However, optimum filling densities outside the 100-150 kg/m³ range are possible depending upon the actual silencer design (e.g., motorcycles). Filling densities in the range of 95 kg/m³ and lower can result in the material shifting during use in an automobile muffler. Depending upon the muffler design and gas velocities, the shifting material can result in voids next to a perf tube. These voids can result in flow noise being generated at the void areas. (No flow transmission loss data indicates that voids away from perf tubes have no significant impact upon noise attenuation.)

FIGURE 1: Acoustic transmission loss of a simple expansion chamber approximately 16 cm. in diameter and 25 cm. long containing a 5 cm diameter perforated tube with 8% porosity.



Voids in the filling resulting from low densities can have an impact upon the thermal insulating value of the filling as well as the resistance of the muffler shell to corrosion due to heat tinting of the shell. Voids could also have a negative impact upon resistance to particulate blowout due to motion of the wool pack within the muffler cavity. Good texturization of the fill material is important.

[1] Silentex® is a registered trademark of Owens Corning
[2] Advantex® is a registered trademark of Owens Corning

Higher frequencies, often generated by high velocity exhaust gases, are typically well attenuated by absorptive materials.
The absorptive materials are most effective in reducing flow-generated noise when the absorptive component is placed at the rear of the exhaust system. Furthermore, in many cases, shell ring is reduced in silencers with acoustic absorption materials such that single layer shell construction can be employed.
The Silentex® filling material process distributes the glass fibers in a random manner in a silencer, bag, or preform mold. Thus, there are variations in the glass filling density over volumes of a few cubic centimeters. It has been shown[3] that these density variations have no impact upon acoustic performance as long as a void is not located adjacent to the opening in a perforated tube.

[3] N. T. Huff "The Impact of Fiber Filling Density Variation on the Acoustic Performance of Silencers", SAE Noise and Vibration Conference and Exposition, May 16-18, SAE Paper 2005-01-2367

3. METHODS OF EXPOSING GAS FLOW TO ROVING

There are three methods of exposing roving to the gas flow, namely: perforations, louvers, and slots. However, in no case should absorption materials be placed in the system such that gas may flow unrestricted directly into or through the absorption material.

3.1 PERFORATED TUBES

Good performance has been obtained with perforated holes of 3-5 mm in diameter. There is some indication that larger holes perform a little better acoustically, especially when the exhaust gases are flowing at a high velocity. Normally, 20-30% open area in the perforated tube will have better overall acoustic performance than a perforated tube with only a few percent open area. (The open area, or porosity, is defined as the sum total area of the openings divided by the total surface area of the tube including openings.)

FIGURE 2: Perforations

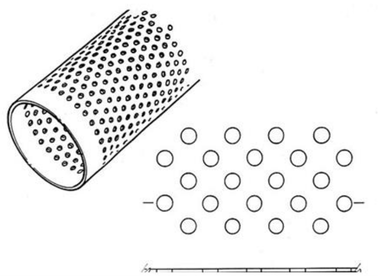


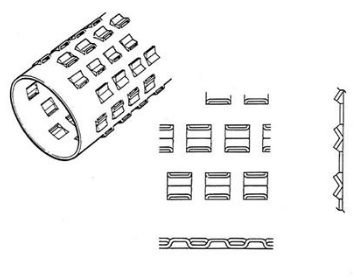
TABLE 1: Typical North American Perforation Patterns

Hole Ø (mm)	**Hole Center Spacing** (mm)	**% Open Area**	**IPA Number**
3.175	5.55625	29	114
3.175	6.35	23	115
4.7625	7.9375	33	119

3.2 LOUVERS

Louvers can interfere with the ease of the filling operation for direct filling, bag filling, and preform filling. It is possible that louvers tend to reduce the amount of acoustic communication between the exhaust gases and the absorptive material. This could result in lower acoustic performance of the absorptive material.

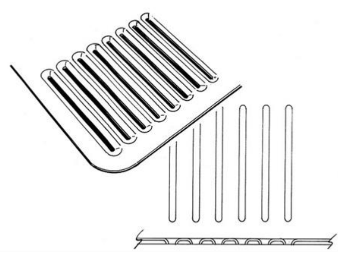
FIGURE 3: Louvers



3.3 SLOTS

While slots are able to contain well texturized roving, they must be carefully designed. Depending on the location and orientation of the slots in the silencer design, wider and longer slots can be more susceptible to strand blowout in the silencer, especially if they are aligned parallel to the exhaust gas flow. However, there are indications that aligning the slots parallel to the gas flow does tend to improve the acoustic communication between the gas flow through the perf tube and the glass fibers.

FIGURE 4: Slots



SILENTEX® GLASS FIBER SOLUTIONS

DESIGN GUIDE

4. DESIGN FOR DIRECT FILL

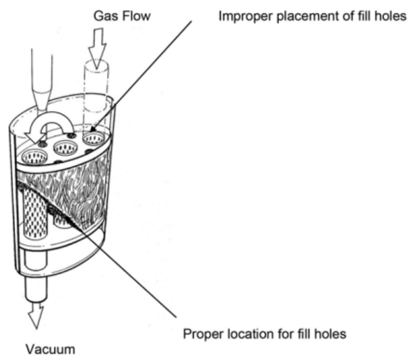
4.1 WHY DIRECT FILL

Inserting texturized roving directly from a texturization nozzle into a muffler cavity provides the lowest cost per kilogram for glass used in sound control. Moreover, multiple examples from the field show that directly filled, well texturized glass leads to more even density distribution and lower tendency to sag. Under long term exposure to vibration the compression of the fibers contributes to level out fill density throughout the cavity. However, this requires an investment in capital equipment which must be compatible with the muffler production line. In addition, depending upon the design of the muffler and the glass-filled cavity, one may not be able to observe how uniformly the glass is inserted into the muffler chamber, especially around perf tubes. Thus, the use of a highly automated machine is recommended to ensure consistent filling quality of the muffler cavity, rather than a manual machine.

4.2 ROUND/OVAL SILENCERS

Direct filling of silencer chambers is normally possible regardless of chamber location. To obtain the best filling results when a muffler is being filled directly, a vacuum is usually applied from the end opposite the end through which filling is taking place. This method helps to pull the glass into the silencer thereby ensuring better texturization and more even filling. When direct filling (for either interior or exterior chambers) a minimum spacing of 15 mm between silencer components (i.e. tube to tube and tube to shell distances) is recommended in order to obtain optimal roving texturization and filling without voids. If this spacing cannot be respected, then the tubes should have no perforation in the narrow areas to avoid risk of flow noise where not covered by fiber.
When filling end chambers the chamber depth should be at least 100mm to prevent the roving from spilling out. The intermediate baffle should be perforated to allow sufficient vacuum, especially for shallow end chambers and high fill density. Inner tubes should be centered and perforated if possible.

FIGURE 5: Placement of fill holes for direct fill of round and oval silencers



If an inner chamber is filled, fill holes in baffles/partitions between the chambers are required. Care must be taken in the placement of holes in the baffle with relation to the gas stream such that the gas flow will tend to push the roving inside the fill hole (see FIGURE 5) rather than pull against it and drag it out. In doing this, the design is de-sensitized with respect to strand blowout, which may be caused by an improperly trimmed tail of roving left hanging out of the fill hole during filling. To allow for proper filling of inner silencer chambers, the minimum recommended clearance hole for the filling nozzle is 15 mm diameter.
When the muffler consists in a single cavity, the inner tube should be perforated and press fitted to one of the end caps for optimal processing.
For direct filling, there should be no rough projections inside the silencer which would interfere with the roving completely filling the cavity. Examples of possible protrusions are louvers, spot welds, or burrs on silencer components or stainless steel wool wrapped around a perf tube. Furthermore, heavy oil deposits can also impact the filling process

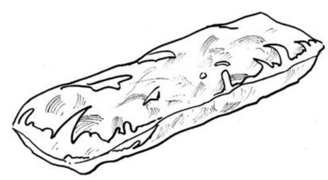
4.3 STAMPED SILENCERS

Owens Corning has designed special machines and can assist in implementing filling methods for the direct filling of stamped silencers.
Factors to be considered when filling stamped silencers include production line rate, optimal filling density, fill-tooling design, and individual machine rates. Owens Corning develops direct fill tooling for each application as part of its range of services. If direct fill cannot be economically applied, then bag fill or pre-forms are recommended.

5. DESIGN FOR FILLING WITH BAGS

Using bags filled with texturized materials (FIGURE 6) is the second lowest glass cost method for inserting texturized roving into muffler cavities. Bags are utilized to contain the glass until it is inserted into the muffler cavity, which removes the need for significant capital cost. However, the insertion of bags may lead to more improper chamber filling than other methods of inserting texturized glass into mufflers. In addition, depending upon the design of the bag and muffler cavity, a significant amount of time (30-60 seconds) may be required to insert the bag into the muffler chamber in the proper manner.

FIGURE 6: Typical Bag Configuration



5.1 PLASTIC BAGS

The most common bag material is made from short chain aliphatic hydrocarbons (e.g. polyethylene and polypropylene).
These bags typically have perforations in them to allow the texturization air to exit the bag during the filling process. The perforations also aid in providing maximum acoustic performance from initial startup of the engine, instead of having to wait until the polymer bags have melted around the perf tube or have decomposed. To minimize odors which might be noticeable in enclosed areas the first time hot gases flow through the silencer, a spun bond polypropylene material is recommended. This material will melt near 150ºC and will completely decompose below 400ºC with sufficient oxygen present. The primary decomposition products of the polyethylene and polypropylene materials are CO_2 and H_2O.

5.2 FIBERGLASS BAGS

Fiberglass mesh bags are also available but at a higher cost. Fiberglass bags are typically made of glass fiber and sewn together with a cotton or polymer thread. Fiberglass bags can also be produced using a knitting process. Thus, minimal decomposition products are produced when fiberglass bags are first heated. The knitted bags are typically produced in a tube or sock type configuration, which might not always conveniently fill the muffler cavity. Depending on the type of glass used to make the bags and the silencer operating temperatures, the fiberglass mesh may remain essentially intact over the life of the silencer.
With both the polymer and glass bag materials, the actual design of the bag for a given chamber can be specified with Owens Corning technical assistance. Proper bag design plays a major role in the ease of insertion of the bag into the silencer and upon good texturization of the roving as the bag is being filled.

6. DESIGN FOR FILLING WITH PREFORMS

6.1 WHY PREFORMS

Preforms are made by introducing texturized fibers into a mold after they have been coated with a binder. The inner dimensions of the mold are typically slightly smaller than the cavity in a muffler into which texturized glass fibers are to be inserted. The binder (generally a phenolic-based material) is cured by heating the coated texturized fibers in the mold. The resulting part is called a preform (some companies refer to the preforms as bricks). Preforms are designed to make it possible to insert them into a muffler cavity very rapidly (e.g., less than 5 seconds). Typically, they will fit into the cavity only one way which virtually eliminates improper filling. This is normally much faster than a bag can be inserted into a muffler depending upon the complexity of the cavity. Because all surfaces of the preform can be visually examined when it is removed from the mold, it provides better assurance that the texturized roving will be well distributed throughout the muffler cavity, especially next to perf tubes. The potential for higher quality, less labor intensive, and low capital requirements means that even though preforms provide the most expensive source of texturized roving, by the time the muffler is produced, it can be a very cost competitive solution.

6.2 CAVITY DESIGN

Molds have the same issues involved with direct fill mentioned above. That is, it is difficult to fill gaps between tubes and/or between tubes and shells smaller than about 20 mm. When one notes that the preform mold will normally have interior dimensions smaller than the cavity to make insertion of the mold easier, it is obvious that many preforms will have tube-to-tube or tube-to-shell distances of less than 20 mm. This situation of small distances between tubes, etc. is made more difficult by designs where the small space is more than about 100 mm in height. However, by increasing the complexity of the molds, it is possible in many situations, to produce acceptable preforms with wall thicknesses as low as 6-7 mm. Again, if there are questions about the practicality of filling cavity designs, Owens Corning personnel should be able to assist in determining filling feasibility.

7. DESIGN FOR FILAMENT WINDING

7.1 WHY FILAMENT WINDING

When the clearance between a long central perf tube and the shell is less than about 20 mm, filament winding can be a good option for placing texturized roving in a muffler. In this situation, the texturized roving is wound around a perf tube. The perf tube with the roving on it is then inserted into the muffler.
Filament winding can also be used for placing texturized roving around stainless steel wool. The winding process removes the sticking issues associated with blowing (direct fill) or sliding texturized roving (a preform) across the surface of stainless steel wool. This method is sometimes employed for wrapping well texturized roving onto stainless steel wool in thicknesses of 50 mm or more. Low and high degrees of texturization can be produced during the texturization process for any filament winding operation.

7.2 USING THE ROVING

Typically filament winding is employed when there is a convenient source of texturized roving (e.g., a single strand of texturized roving placed in a box, which can then be pulled out of the box without knots and tangles). The texturized strand is wrapped around a perf tube rotating on a lathe. The tension applied to the texturized roving needs to be controlled in order to maintain the required degree of texturization of the roving on the perf tube. Machines have been constructed which will pull roving from a doff, texturize it, and then wind it on a perf tube in one operation.

8. FAILURE MODES

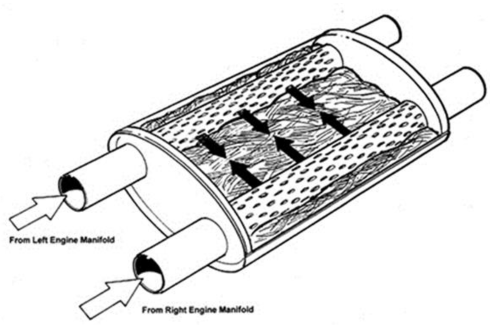
The two types of failure modes are particulate blow out and strand blow out.

8.1 PARTICULATE BLOWOUT

Particulate blow out occurs when the glass filaments are broken into small pieces. These small pieces of glass fiber can then be drawn into the exhaust gas stream and blown out the tail pipe of the exhaust system. Particulate blow out typically occurs when the glass is exposed to temperatures above its time/temperature use limit. If exhaust gas temperatures entering the silencer are in excess of 740ºC most of the time the engine is in operation, then measurements should be made of the actual temperatures achieved by the glass. Typically, the temperature achieved by the glass is significantly (as much as 20-50ºC) below the maximum measured exhaust gas temperature.

In a properly designed silencer, the Advantex® glass should not have significant blowout if the continuous operating temperature of the glass remains below 740ºC. However, if there is direct impingement of the gas flow into the fibers, blowout may occur at glass temperatures lower than 740ºC.
For example, in FIGURE 7, locating the roving between two down-pipes in the front part of the system where high temperatures and high instantaneous pressure pulses are encountered, particulate blow out may result. Under this combination of high temperatures and high gas flows, the fibers may break up below 740ºC. Of note, when gas flows through the roving, much of the thermal insulating value of the roving to the outer shell is lost. This can be prevented with a design having no significant gas flow through the roving.

FIGURE 7: Particulate blowout from gas flow through the roving.



Advantex® fibers can maintain mechanical integrity for temperatures above their continuous operating temperature limit (740ºC) for varying periods of time. To determine whether blowout might occur for particular time/temperature operating conditions, it is recommended that direct contact be made with Owens Corning for technical assistance.

8.2 STRAND BLOWOUT

This phenomenon occurs when an entire strand is caught in an exhaust stream and pulled out of the silencer. This can occur if the end of a “long” strand is left hanging out of a fill hole, especially if the fill hole is oriented toward the downstream end of the silencer. Figure 5 shows a configuration where a loose strand could be dragged out of the muffler by the flow of exhaust gases through the end chamber and out the exhaust pipe. Alternatively, if the openings in the perforations/slots are large, under some conditions a poorly texturized strand end can be caught in the exhaust stream and pulled into the gas stream. Following this guideline can largely eliminate this blowout mechanism.
In addition, strand blowout may occur when there is not a good seal between the ends of the chamber filled with fiberglass and the silencer shell. For example, in Figure 5, if there is a gap present and if there is sufficient pressure differential between the chambers on each end of the filled chamber, air flowing between the ends of the filled chamber and the silencer shell may be sufficient to pull fiber strands out of the filled chamber and into the exhaust gas stream. Taking into proper consideration these examples can virtually eliminate strand blowout.

9. THERMAL INSULATING CHARACTERISTICS

Advantex® glass used between the perforated tube and the silencer shell reduces shell temperatures. The temperature decrease near the perforated tube toward the shell is often on the order of 90ºC/cm of glass material thickness if there is not significant flow of exhaust gases through the glass and the filling density is on the order of 100 g/l. Thus, the use of Silentex® material can result in the shell temperature being significantly lower than the exhaust gas temperature.

However, if there is significant exhaust gas flow through the Silentex® material or if the filling density of the Silentex® material is significantly less than 100 g/l, then the thermal insulating characteristics of the Silentex® material can be severely compromised.

9.1 THERMAL MANAGEMENT DESIGN CONSIDERATIONS

Exhaust gas temperatures – Since less heat is lost from the walls of a silencer where Silentex® material is present, the result is that more heat will be carried out through the exhaust gas. This will result in somewhat higher exhaust gas temperatures coming out of the tailpipe. Although the increased exhaust gas temperature is not normally an issue, it needs to be considered during the exhaust system design phase.

Maintenance of thermal insulation properties throughout the life of the silencer – In some applications, the thermal insulation properties of Silentex® materials are required to be maintained throughout the life of the silencer. An example would be the elimination of a heat shield to protect underbody components. In such cases, special attention must be given to ensure that the required thermal insulation properties of the Silentex® material will be maintained for the lifetime of the silencer. Among the items that must be considered (this is not meant to be an exhaustive list) are 1: the average filling density of the Silentex® material, 2: the variability of the filling density, and 3: seams between two-piece preforms.

With respect to the average filling density, typically, if there is no direct gas flow through the filling material, a filling density of 100 g/l will sufficiently fill a chamber such that the glass will not migrate in a significant manner during normal use. In addition, there will not normally be significant gas flow through the filling material at this filling density unless very high pressure differences are encountered. If the average filling density is significantly less than 100 g/l, then after the silencer is put into operation on a vehicle, there may be some movement of the material in the chamber which could produce void or near void conditions in the filling material. These voids or near voids can also be found immediately after the muffler is filled whether direct fill, bags, or preforms are used to fill the muffler cavity if the average fill density is too low. This might allow exhaust gases a nearly unrestricted path to the shell. This could then result in unacceptable heating of the shell in the area of the void. As long as a void is not adjacent to a perf tube, the impact upon the acoustic performance of the silencer due to the glass shifting during use will be negligible (see footnote 3 in section 2 above).

With proper filling techniques, the probability of there being a significant low flow resistance path from the perf tube to the silencer shell is minimized for direct fill and preforms. However, if improper filling techniques are utilized while direct filling a silencer or in the filling of a preform mold without good visual quality control of the parts produced, voids or low filling density regions can be produced. These areas could provide low flow resistance paths to the silencer shell which could result in unacceptable heating of the shell in some areas.

For silencers filled with bags, even if proper techniques are followed in filling the bags, care must be taken in the installation of the bags in the silencer. If the bags are placed in the silencer cavity in such a manner as to leave a void or very low filling density in a region, then again, this could allow exhaust gases to easily access the silencer shell and thus cause a relative hot spot on the silencer shell. The possible movement of bags after their insertion in the silencer must also be taken into account. This is especially true if glass mesh bags are present because these types of bags typically remain partially intact for extended periods during typical vehicle operations.

In any application where the thermal insulation properties of Silentex® materials are relied upon to keep the shell below a given temperature, sufficient testing on actual silencers needs to be carried out to ensure that the required shell surface temperatures are attained. The tests should be carried out not only on freshly filled silencers but also on silencers that have been installed on test vehicles driven under conditions simulating the lifetime of the silencer. If “hot spots” are detected on the silencer after testing and improvements to filling techniques/methods cannot ensure the absence of “hot spots”, then other methods of controlling the shell temperatures (e.g., dual wrap shells, providing an insulation material between the dual wraps, placing heat shields between the muffler shell and temperature critical areas) must be considered.

10. CORROSION CHARACTERISTICS

The thermal insulating properties of the texturized roving keep the silencer shell cooler than silencers not using absorptive materials. This reduces the heat tint of the shell and thus its susceptibility to corrosion of both the inside and outside of the shell.

In addition, field studies have indicated that shells of Silentex® system filled silencers are protected on the inside from corrosive acids and salts in the areas adjacent to the glass filling. Exhaust gas condensates are largely trapped on the glass, thus reducing the amount of condensate contacting the silencer shell (which is the primary cause of interior shell corrosion). The behavior of the relatively large diameter Silentex® materials is just the opposite of the behavior of systems filled with small diameter materials such as basalt wool or needle felt.

Capillary action in the small diameter densely packed fiber materials encourages the corrosive condensates to contact the silencer shell. Under some operating conditions, this will actually accelerate the corrosion of the silencer shells from the inside out. Thus, the corrosion characteristics of small fiber diameter basalt and needle felt filled silencers will be different than the corrosion characteristics of large fiber diameter texturized roving filled silencers. Advantex® glass and HTS® glasses themselves are chemically very resistant to exhaust gas condensates.

11. GENERAL REFERENCES:

Physical Properties of Inorganic Fibrous Materials Used for Noise Absorption: Norman T. Huff; Inter-Noise 2002
Acoustic Characteristics of Perforated Dissipative and Hybrid Silencers: Ph. D. Dissertation of Iljae Lee, The Ohio State University, 2005
Corrosion Analysis of Eight Owens-Corning Fiberglass-Filled Stamped Mufflers from Canadian Field Exposure: Richard Strait, AK Steel Corporation, August 23, 1999

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