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Absorption Materials Used In Muffler A Review

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Abstract: **This article is a bibliographical review of the muffler used in automobile industry. A muffler (or silencer in British English) is a device for reducing the amount of noise emitted by the exhaust of an internal combustion engine. This noise is reduced as the transmission loss (TL) inside the muffler increases. Different components are present in the muffler for transmission loss like perforated tubes, absorption materials etc. by which noise is reduced. This review depicts about transmission loss characteristics, different methods used in the design, calculation and construction of muffler both experimentally and in practical. Transmission loss using sound absorption material is the main feature in this review. Different sound absorption materials that are currently used for noise reduction are quoted and described.**

Keywords: **Muffler, Transmission loss, Absorption material.**

I. INTRODUCTION

Over the last decade and half the amount of vehicles are increasing and due to this the amount of noise emitted by the exhaust system of vehicles and emission requirements are also getting more and more. Muffler plays an important role in reducing the exhaust and intake system noise. So there has been a great deal of research and development in the design and performance of muffler. From designer's standpoint transmission loss (TL) or insertion loss (IL) is the main characteristic performance parameter of a muffler.

Transmission loss: Transmission loss is the difference in sound power between the incident wave entering and the transmitted wave exiting the muffler when the muffler termination is anechoic (no reflecting waves present in the muffler) (1). The **benefit of TL** is that it is a parameter of the muffler alone and the source or termination properties are not needed.

Insertion loss: The Insertion loss is the sound pressure level difference at a point usually outside the system, without and with the muffler present.

II. MUFFLER CLASSIFICATION

Typically mufflers are classified under two different categories, dissipative and reflective.

A **dissipative muffler** consists of ducts and chambers which is lined with acoustic absorbing materials which absorb the acoustic energy and convert it into heat. These mufflers are useful for broad frequency band at high frequencies. The benefit of this muffler is that the pressure drop across the system is relatively low as the flow path is not significantly altered by flow reversals, twists and turns inside the muffler.(2)

The downside of dissipative muffler is that they are insufficient at low frequencies as the wavelength is much too large to be attenuated. But it could be overcome by using an absolute thickness of absorbing material.

The second type of muffler is **reflective muffler**. Reactive mufflers generally composed of several chambers of different volumes and shapes connected together with of pipes. They reflect the sound energy back to the source and are essentially sound filters. They are useful for noise reduction at fixed frequencies or in hot, dirty and high-speed gas flow system. . They contain several chambers, flow reversals and end resonators.

Advantage: They are quiet inexpensive and requires little maintenance (3, 12).

Disadvantage: The downside of this type is that there are some areas in the frequency range of interest where there is little attenuation of the exhaust sound pressure.

III. MEASUREMENT OR CALCULATION OF TRANSMISSION LOSS (TL)

According to the definition of transmission loss (TL), the equation of transmission loss is expressed as

$$\mathrm{TL} = 10\log\frac{(\text{incident energy})}{(\text{transmitted energy})}$$

$$\mathrm{TL} = 20\mathrm{Log}\left(\left|\frac{p_{inc.}}{p_{trans.}}\right|\right) + 10\,\mathrm{Log}\left(\frac{S_o}{S_i}\right) = 20\mathrm{Log}\left(\left|\frac{p_1+\rho c v_1}{2p_2}\right|\right) + 10\,\mathrm{Log}\left(\frac{S_o}{S_i}\right) \quad \text{.......................Equation 1}$$

The transmission loss can be calculated in a variety of ways by using different methods such as the decomposition method, the two load method and the two source method (4).

Decomposition method: In this method two microphones are placed at the inlet section of the pipe for the decomposition of the progressive and reflective waves and at the outlet a single microphone is placed from where only transmitted waves exist (2).

Two load method: The two load method is another method for transmission loss. This method consists of four microphones. Two microphones are placed at the inlet and two are placed at the outlet pipe for calculating the progressive and reflective waves. This technique is used for deriving the 4 pole parameters of a muffler. After knowing the four parameters it is placed in the below equation and transmission loss is determined. It can be calculated by

$$\mathrm{TL} = 20\mathrm{Log}_{10}\left(\left|\frac{1}{2}\left[A + \frac{B}{\rho_o c} + (\rho_o c)C + D\right]\right|\right) + 10\mathrm{Log}_{10}\left(\frac{S_o}{S_i}\right) \quad \text{..Equation 2}$$

The derivation of 4 pole parameters is described in the works of Tao et al. (5).The different equations used in 4-pole parameters are used in works of Tyler W. Le Roy.(2). This method of TL testing is adequate in the frequency range given by equation 4.

$$f > \frac{1.841}{\pi D} C_o \quad \text{...Equation 3}$$

Two source- location method: In the source location method the source is moved from the inlet to the outlet location. This method is based on the transfer matrix approach in which the acoustical element is modeled by its 4 pole parameters. To minimize the noise an absorptive material is used at the end of the inletand outlet. As this is a stable method Tyler W Le Roy (2) has used this method for the measurement of transmission loss.

IV. RESEARCH MOTIVE

This paper reveals the variation of transmission loss in muffler by using different absorption materials as the main component for reduction of noise in muffler.

Absorption materials: The use of sound absorption material in an exhaust system dissipates the energy of the acoustic waves into heat and also store heat energy from the exhaust stream. Using an absorptive material can greatly increase the transmission loss of an exhaust system in the mid to high frequency ranges. If the sound absorption materials are measured experimentally then it is done with the two cavity method. As an absorption material is placed inside the muffler the effective expansion area reduces and this sound absorption material absorbs the pressure waves and reflects very little. Some of the absorption materials are fibers, glass wool, woven glass fiber etc (2).

$$\frac{\bar{Z}}{Z_o} = 1.0 + 0.0954\left(\frac{\rho_o f}{\sigma}\right)^{-0.754} - j0.085\left(\frac{\rho_o f}{\sigma}\right)^{-0.732} \quad \text{...Equation 4}$$

$$\frac{\bar{k}}{k_o} = 1.0 + 0.16\left(\frac{\rho_o f}{\sigma}\right)^{-0.577} - j0.189\left(\frac{\rho_o f}{\sigma}\right)^{-0.595} \quad \text{.. Equation 5}$$

According to Lord et al. all glass fiber materials have the same flow resistivity values relative to their density. Therefore, he demonstrated that flow resistivity can be estimated for glass fiber materials regardless and produce accurate results (6). Later Tyler W Le Roy demonstrated that by varying the flow resistivity properties of glass fibers there is an insignificant differences in transmission loss (TL)(2).

V. RESEARCH REVIEWS OF THE SOUND ABSORPTION MATERIALS

According to Jorge P. Arenas and Malcolm J Crocker sound absorbing materials absorb most of the sound energy striking them, making them very useful for the control of noise. A wide range of sound-absorbing materials exist. In the 1970s, public health concerns helped change the main constituents of sound-absorbing materials from asbestos-based materials to new synthetic fibers. Although, these new fibers are much safer for human health, more recently, issues related to global warming may increase the use of natural fibers instead of synthetic ones.(6). The production of synthetic materials contributes to the emission of carbon dioxide (mostly from power plants and transportation), methane, and nitrous oxide which is very harmful for human purpose. Fiber materials and different foams are proposed to use as the absorption material. This materials are light weight and very effective although it will help in fuel consumption (6). Jorge and Crocker also comment that recent advances in material science, chemistry and nanotechnologies are improving the design and performance of the absorption materials used in our components. These advances include the use of natural fibers, bio-based polymers, recycled and surplus materials and porous metals (6).

Porous Absorbing Materials

Sound-absorbing materials absorb most of the sound energy striking them and reflect very little. Therefore, sound-absorbing materials have been found to be very useful for the control of noise. They are used in a variety of locations: close to sources of noise (close to sources in electric motors, for example), in various paths (above barriers), and sometimes close to a receiver (inside earmuffs). A wide range of sound-absorbing materials exist; they provide absorption properties dependent upon frequency, composition, thickness, surface finish, and method of mounting. However, materials that have a high value of sound absorption coefficient are usually porous (6). A porous absorbing material is a solid that contains cavities, channels or interstices so that sound waves are able to enter through them. Porous absorbing materials can be classified as cellular, fibrous, or granular; on the basis of their microscopic configurations. These materials consist of small holes or openings through which sound waves enters. Open-celled polyurethane and foams are examples of cellular materials. Fibrous materials generally consist of natural and synthetic fibers such as glass fibers and minerals and they also can be sometimes granular. Granular absorbing materials include some kinds of asphalt, porous concrete, granular clays, sands, gravel, and soils (7).

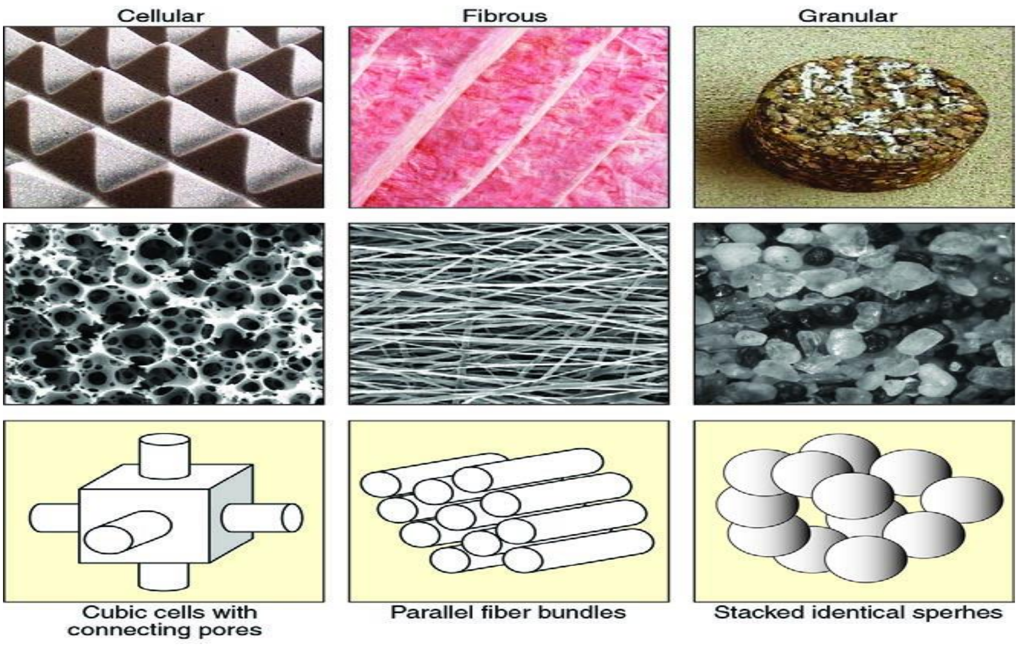


Figure 1: The three main types of porous absorbing materials.

Various models were proposed to interpret the acoustical behavior of porous absorbing materials. Such models generally aim at deriving the characteristic propagation constant, *G*, and the characteristic wave impedance, *Z*, of a plane wave in the absorbing material as functions of non-acoustical properties such as porosity, air flow resistance and tortuosity(6).

Various structures of porous materials are shown in Figure 2.

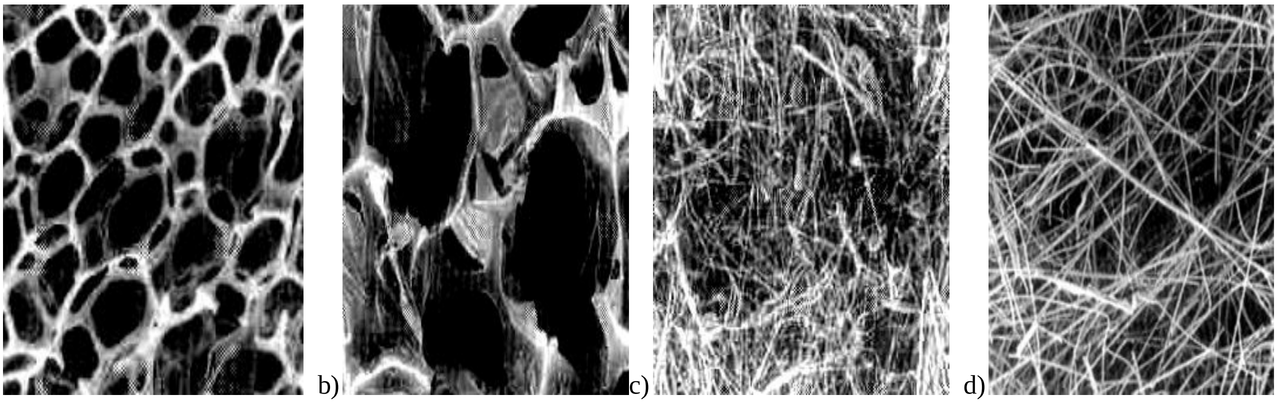
a) 

Figure 2: Structures of different porous materials:

a) Reticulated foam. b) Partially reticulated foam. c) Mineral wool. d) Fiber glass. (Fahy, 2001).

Porous Fibrous Materials

Most of the porous sound-absorbing materials available are fibrous. The Fibrous material composed of a set of continuous filaments which trap air between them. They are produced in rolls or slabs with different thermal, acoustical, and mechanical properties. Fibers can also be classified as natural or synthetic (artificial). Natural fibers can be vegetable (cotton, kenaf, hemp, flax, wood, etc.), animal (wool, fur felt) or mineral (asbestos). Synthetic fibers can be cellulose (bamboo fiber, for example), mineral (fiberglass, mineral wool, glass wool, graphite, ceramic, etc.), or polymer (polyester, polypropylene, Kevlar, etc.)(6).

Synthetic fibrous materials were made from minerals and polymers and were mostly used for sound absorption and thermal isolation. As these were made from high-temperature extrusion and industrial processes based on synthetic chemicals and are often from petrochemical sources their carbon footprints are also quite significant. Now a day the use of natural fibers in manufacturing sound absorbing materials are getting more and more environment friendly and useful. These properties can also be modified by pre-treatments such as drying, carbonizing, impregnation, and mineralization (6).

Hemp (*cannabis sativa*) is one of the most important natural fibers. A hemp crop requires virtually no chemicals in their production, as they are naturally resistant to most pests. Also cotton accounts for approximately 50% of all pesticides and herbicides used in U.S. agriculture today. Further hemp produces significantly more fiber per square meter than cotton or flax and uses less water to grow.

Kenaf (*hibiscus cannabinus*) is a different plant and that is cultivated in the U.S. and is related to cotton. Its fibers were used to strengthen concrete and other composite materials for construction applications and for materials used in the automotive industry.

Materials for thermal isolation and acoustic absorption were made of a mixture of natural kenaf fibers, polyester fibers for strengthening, and a natural fireproof product, were currently available commercially.

Apparently sound absorbing materials were made of natural fibers such as hemp and kenaf and can be recycled easily, and their production includes a low carbon footprint and no CFC emissions, so that they could be classified as ecologically green building materials. Therefore, they provide an alternative to chemical building materials, polymers, and other artificial no sustainable materials.

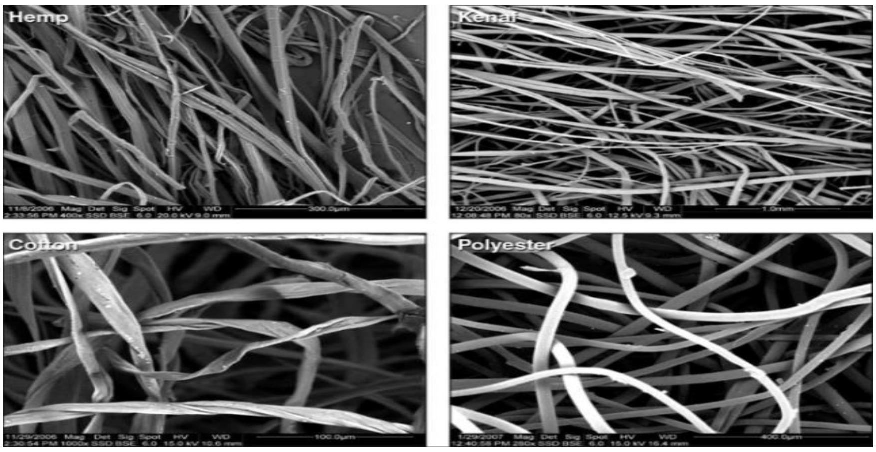


Figure 3: Scanning electron microscope images of samples of hemp, kenaf, cotton and polyester fibers. Courtesy of Dr. J. Alba (Polytechnic Univ. of Valencia)

Advanced Metal, Ceramic and Gel Foams

Metal foams are becoming much useful because of its lightweight structures. Aluminum, nickel, steel, titanium and copper are some of this type. In this aluminum is the most effective.

Metal foams are having high stiffness, low weight, fire resistance and low moisture absorption. Metal foams are also usually expensive and they can also be recycled.

Depending on the manufacturing method used, metal foams could be either mostly open celled or closed celled. Open-celled metal foams could be manufactured using polyurethane foams as a matrix base. The resulting metal foam has values of porosity between 75-95%. Open-celled metal foams with cell sizes from 0.2-0.5 mm were commercially available for high-temperature applications (6).Closed-celled metal foams had a large number of small closed pores (typical pore size is 1-8 mm) filled with air, and these materials were usually employed as impact absorbers and as cores in sandwich panels. They were commonly made by injecting a gas (air, nitrogen, argon, carbon dioxide or carbon monoxide) or adding a foaming agent (titanium hydride or calcium carbonate) into molten metal. Closed celled metal foams don't absorb sound well, so these types of materials were not used in mufflers.

These metals foams could also use for shock and vibration control because of its ability to absorb sound energy at almost constant pressure and also had the ability to absorb impact at constant crushing load (9).

Ceramic foams are having porosities from 80-90% and could be used at temperatures over 1,500° C. New ceramic foams were made of aluminum oxide and could have porosity values over 94%. This type of foam absorbs sound in great amount. Currently, ceramic foams were used extensively in aerospace and industrial applications such as rocket nozzle components, composite panels, heat shield elements, and acoustical liners in aircraft mufflers. Ceramic foams were silicon, zirconium, titanium and boron based (8).

Aerogels were another form of micro porous materials used in some complicated applications. Aerogels were the best thermal insulators which could absorb sound to great amount. This material is 40 times better than common fiber glass material as these materials are extremely lightweight, highly porous, and translucent material in which most of its volume is filled with air. Its structure is composed of small spherical silicon dioxide clusters from 3-4 nm in diameter that were linked to each other forming chains that in turn form a spatial grid with air-filled pores.(6) The typical average sizes of the pore is 30 to 40 nm. The typical porosity of an aerogel is greater than 75%, and its melting point is 1,200° C. However aerogels were still very expensive and these materials had been used primarily in high-tech aerospace missions by NASA

Recent studies aimed at mitigating climate changes caused by automobiles and by the steel and aluminum industries have shown that a 10% weight reduction results in fuel savings in the range of 4.5 to 6% for vehicles with internal combustion engines(6).

Other materials

Apart from these materials other materials such as megasorber, k-foam, and kinetic fiberglass are some of the materials which can resist temperature up to 550^{o}C. These materials are lightweight, corrosion resistant, fireproof and cost effective.

VI. SOUND ABSORPTION MATERIAL USING IN FUTURE

Day by day our environment is getting more and more polluted and it is getting noisier. So to get adapted with this harsh environment we need that type of absorption material which is adaptive with this environment and can be used in our vehicles to reduce the amount of noise produce by it. One such type of absorptive material is **Refractory Open-Cell Foams.**

Refractory Open-Cell Foams

Refractory foams which is a type of absorption material are ideal for reducing noise in harsh environment because they can easily resist high temperature oxidizing environment. They also have excellent attenuation characteristics.

They are low cost and have excellent sound attenuation properties when the sound waves are propagating perpendicularly through the foam.

In the laboratory testing the foam achieved noise reduction of about 44 dB at 250 Hz and 64 dB at 1000 Hz (11, 12).

The matrix of cells and ligaments of silicon carbide foam is completely repeatable, regular, and uniform throughout the entirety of the material. It is a rigid, highly porous and permeable structure and has a controlled density of metal per unit volume.

Characteristics of silicon carbide foam:

- Low density
- High strength to weight ratio
- High surface area to volume ratio
- Isotropic load response
- Controlled stress-strain characteristics
- It has high porosity and mechanical and chemical stability.
- Excellent resistance to thermal attack and corrosion from molten iron liquid.
- It can effectively remove inclusions; reduce trapped gases from liquid metal.

Specification:-

Porosity: 80~90

Compression Strength =1.0 MPa

Bulk Density =0.5g/cm3

Thermal Resistance =1300°C~R.T. 5 times.

VII. CONCLUSION

A comfortable environment free from unwanted noises is always dream of every person. One of the sources of unwanted noises is the sound emitted by vehicle. Porous sound-absorbing materials have evolved into more advanced materials over the years. Compared with the older absorbing materials produced in the 1960s, the new materials have become safer, lighter and more technologically optimized. The concept of environmentally friendly, sustainable, recycled, and green building materials will soon have an important role in the marketing of sound-absorbing materials. The production of metal foams, ceramic foams, and aerogels can contribute to greenhouse gas emissions, their practical use in transportation will help in reducing other emissions and help in reducing fuel consumption. Since these materials possess high structural strength and reduced structural weight simultaneously, their use in the aerospace and automotive industries has the potential to reduce fuel consumption and save energy.

This paper has concentrated on noise attenuation consideration of absorption materials. It was concluded (from the review) that studying on noise eliminations by innovative material such as refractory foam in experimental and practical approach becomes a new area of study.

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