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ACOUSTICAL PROPERTIES OF ELECTROSPUN NANOFIBERS FOR AIRCRAFT INTERIOR NOISE REDUCTION

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ABSTRACT

Electrospun micro and nanofibers produced via electrospinning method were used for the sound absorption purposes. Polymers were initially dissolved in dimethylformamide (DMF) or ethanol with a ratio of 80:20 and electrospun at 20 kV, 20 cm separation distance and 3 ml/hrs pump speed. The two-microphone transfer function method of the B&K impedance tube was used to determine the acoustical properties of the manufactured nanofibers at various frequencies. The test results showed that the absorption coefficients of nanofibers (~500 nm) drastically increased. The reason behind this phenomenon may be attributed to the higher surface area of nanofibers and their interactions with more sound waves/air molecules. This result may open up new possibilities for the sound absorption problems in many fields, such as aircrafts, other transportation vehicles and infrastructures.

INTRODUCTION

Aircraft interior noise is produced by aircrafts including propeller and jet driven engines during the run-up, taxiing, take off, over-flying or landing [1,2]. Interior noise studies on general aviation aircraft show that the noise level varies based on the types of aircrafts and engines. Noise mitigation is a set of strategies to reduce unwanted noise/sound inside aircrafts. It is known that any material that allows air to pass through will act as a sound/noise absorber. The friction of a sound energy moving through the absorber reduces sound by transferring it into heat energy. Thicker materials usually offer greater resistance to air molecules because of the greater porosity and

surface areas, so they are more efficient in absorbing sound. However, thicker absorbers will increase the overall weight of the aircraft and reduce fuel efficiency [2-7].

It is known that noise interferes with the crews' and passenger flight ability and health (e.g., hearing disorder, higher blood pressure, dizziness, headache, etc.), and threatens flight performance and safety in the long term. Therefore, a multidisciplinary research approach is needed to achieve the acceptable noise levels in aircrafts, and other transportation vehicles [3-5].

Some of the noise absorbers used to control the aircraft interior noise are porous, membrane, cavity, perforated panel and composite absorbers in the forms of open cell foam, fiberglass, mineral fiber wool, acoustic ceiling tiles and wood fibers. The porous absorbers include mineral wool, fiberboard, plastic foams, textiles, fleece, carpets, cotton and special acoustic plaster. Kevlar is a very strong porous fiber in the forms of ropes or sheets of fabric, and can either be used as-is, or in the construction of composite components for puncture resistant panels, cloths, and bullet proof vests. Nomex is also in both fiber (50-100 μm) and sheet forms, and is used as a fabric (i.e., overframe blanket) wherever heat and flame resistances are required. Both of these aramides are considered for noise absorptions for the aircrafts [1,2].

Absorptive membranes directly influence the reverb time and the reflected sounds, and are more effective at low frequencies. Cavity absorbers are simply air containers with a narrow neck. This can be broadened slightly by placing a porous material lining inside the cavity. Perforated panel absorbers are combination of porous, absorptive membranes and cavity absorbers. Finally, composite materials are commonly used acoustic absorbers due to their wide range of

applications and good acoustical properties. These composites are typically fire retardant polyether foam absorbers with mass loaded polyvinyl chloride (PVC) or similar barriers. The performance of porous absorbers (and thus any other absorption methods which use microfibers) to minimize the sound absorption can be increased significantly by utilizing nanofibers since nanofibers have larger surface area and porosity (100-10000 times higher than that of the micro-fibers).

Electrospinning is a unique method to produce nano/micro size (3 nm – 30 μm) polymeric wires/fibers that consist of higher surface area, porosity and flexibility, which in turn can enhance the absorption rate of the noise more than conventional micro-fibers (50-100 μm). Electrospinning uses an electrical charge to form a mat of micro and nanosize polymeric fibers (Figure 1). The polymer solutions dissolved in appropriate solvents are placed in a plastic syringe, and then attached to a syringe pump, generating a constant pressure and flow of the fluid through the tip of the syringe. The driving force is provided by an electric potential source through a platinum wire immersed in the polymer solution. When the intensity of the electric field is increased, the hemispherical surface of the fluid at the tip of the capillary tube elongates to form a conical shape, called the Taylor cone [12]. The repulsive electrostatic force overcomes the surface tension and a charged jet of fluid is ejected from the tip of the Taylor cone. The jet of the discharged polymer solution undergoes a drying process in the air where the solvent evaporates, leaving behind polymer fibers, which lay itself randomly (non-woven) on a grounded collecting metal screen. At the end of the spinning process, the discharged jet completely solidifies in two hours, and then collected on the grounded surface (possibly acoustic barriers). Adjusting the flow of the fluid, distance and the magnitude of the electric field mostly controls the spinning rates and morphology of the nanofiber [8-11].

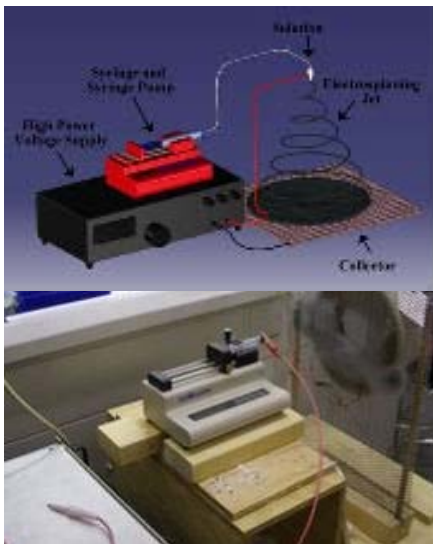


Figure 1: Schematic illustration of an electrospinning process (above) and an experimental setup (below).

There are many advantages of using electrospun nanofibers in noise control:

- Many flame resistant polymers can be electrospun
- Surface area of the nanofibers is 100-10,000 higher than the conventional fibers.
- Noise absorption rate is expected to be exponentially higher because of the interaction of air molecules of sound waves with the fiber surfaces.
- Overall weight of the materials used for the noise absorption will be lighter.
- Nanofibers can enhance physical properties of composites
- Nanofibers can be electrospun on both composite and metal surfaces
- Adhesives can be added into polymers to improve the adhesion between the fiber and surface
- Electrospinning is an economical and technologically mature method for bulk production.

EXPERIMENTAL MATERIALS

Unless otherwise specified, all chemicals used in the present study were purchased from Sigma-Aldrich and were all reagent grades. No further purification or chemical treatment was conducted on these chemicals. Melamine foam samples were also utilized to compare the results with the electrospun fibers.

ELECTROSPUN NANOFIBERS

The electrospun nanofibers were produced using PVC and polyvinylpyrrolidone (PVP) at various DC voltage, spinning distance and pump speed. PVC was dissolved in dimethylacetamide (DMAc) while PVP was dissolved in ethanol prior to the electrospinning process. Figures 2 and 3 show the SEM images of electrospun PVC-DMAc (80:20 ratio) and PVP-ethanol (85:15 ratio) fibers obtained using 20 kV, 25 cm separation distance and 3.5 ml/hrs pump speed. As is seen, the fiber diameters of all samples are below 1 μm, usually in the range of 150 nm to 600 nm.

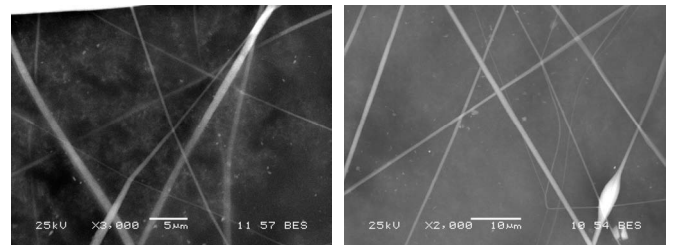


Figure 2: SEM images of PVC fibers obtained at 20 kV, 25 cm separation distance and 3.5 ml/hr pump speed.

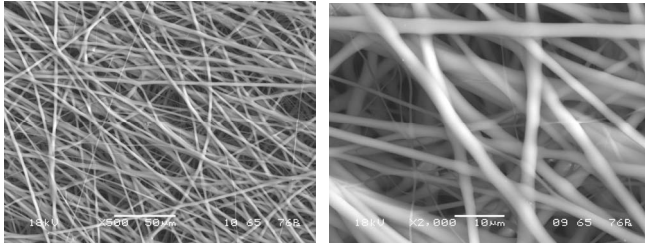


Figure 3: SEM images of PVP fibers obtained at 20 kV, 25 cm separation distance and 3.5 ml/hr pump speed.

IMPEDANCE MEASUREMENT

Thickness of the nanofiber samples used for the sound absorption tests was between 0.5 cm and 1.5 cm. The sample preparation as per ASTM 1050E guidelines usually stipulates using a water jet to cut the porous material. Since the nanofiber samples are exceptionally thin and limp, the use of water jet is impossible. Instead, the following procedure is used. A 29 mm diameter aluminum template is placed over the electrospun fiber samples. Using a sharp blade the samples were then cut around the edge of the template. A slightly larger sample size is deliberately cut. This allows them to be carefully glued around the edges by a tape. The sample is then carefully placed in the sample holder and care is taken to ensure flat sample surface with respect to the sound wave propagation direction [13-15]. The two-microphone Impedance Measurement Tube Type 4206 consists of a 100 mm diameter tube (large tube), a 29 mm diameter tube (small tube), sample holders, and extension tubes (29 and 100 mm), as shown in Figure 4 [14].



Figure 4: Impedance measurement tube for measuring sound absorption and reflection coefficients [14].

The impedance tube used in this experiment is supplied with two specially designed ¼-inch microphones viz. Type 4187 (capable of reducing errors due to pressure leakage at high frequencies), two ¼-inch Preamplifiers Type 2633, and three dummy microphones. The impedance tube is used to measure the acoustic absorption and reflection coefficients of any test samples in the frequency range of 50 Hz to 6.4 kHz. To measure over the complete frequency range from 50 Hz to 6.4 kHz, the

components can be assembled into two different setups: a large-tube (low frequency) setup to measure the parameters in the frequency range 50 Hz to 1.6 kHz, and a small-tube (high frequency) setup for frequency range from 500 Hz to 6.4 kHz. A loudspeaker (sound source) is mounted at one end of the impedance tube, and a test sample is installed at the other end of the tube. There are three types of frequency weighting for the loudspeaker: high pass for frequency measurements in the small tube, linear for measurements in the large tube, and low pass for extra measurement accuracy below 100 Hz. The loudspeaker generates broadband, stationary random sound waves which will then propagate as plane waves in the tube, as shown in Figure 5 [13-15].

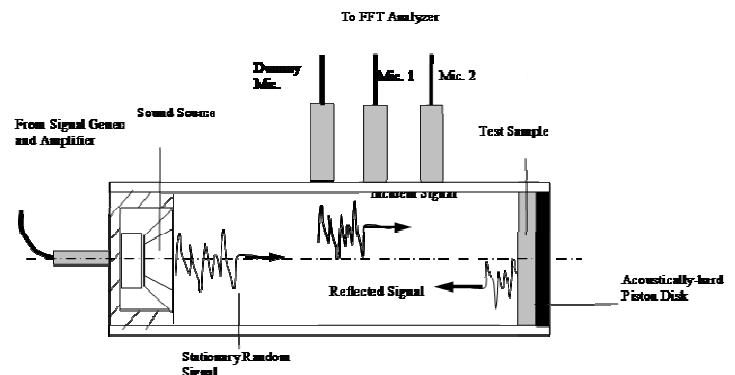


Figure 5: Cut-away diagram of the impedance tube for the two-microphone transfer-function method [14].

RESULTS AND DISCUSSION

The sound absorption tests conducted on 0.5 g, 1 g and 1.5 g of PVC nanofibers and 1 and 2 inches of Melamine foam samples are shown in Figure 6. The fiber diameter of PVC obtained using DMAc is between 200 nm and 500 nm. 1 and 2 inches of Melamine samples were 2 and 4 g, respectively. Surprisingly, lesser weight of the PVC nanofiber samples gave the higher absorption coefficient than the heavier Melamine foam samples. It was also determined that as the weight of the nanofibers increases, the absorption peak shifts toward the lower frequency, but with lower absorption coefficients.

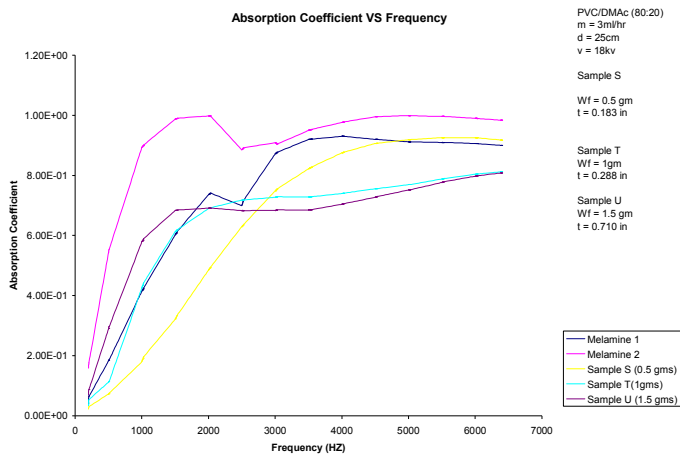


Figure 6: Absorption coefficients of electrospun PVC nanofiber samples compared with 1 and 2 inches thickness Melamine foam samples.

The second set of tests were conducted on PVC samples dissolved in 20% DMAc and electrospun at 15 kV, 20 cm distance and 3 ml/hrs pump speed. The fiber diameter ranges from 500 nm to 900 nm. As the size goes from nano level to micro level, the sound absorption characteristic varies drastically (Figure 7). In this test, unlike the previous test, the sound absorption coefficient increases as the weight of the samples increases. This may be related to the effects of flow resistivity, tortuosity, porosity, viscoelastic changes at nanoscale, thermal characteristic length, and/or viscous characteristic length. In the future, we will be focusing on this problem in detail [1].

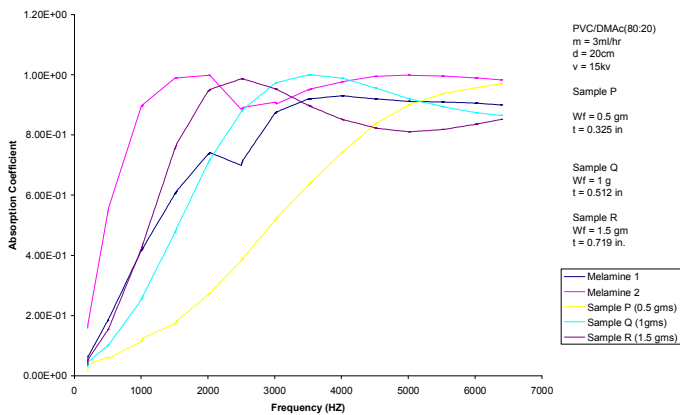


Figure 7: Absorption coefficients of electrospun PVC samples compared with 1 and 2 inches thickness Melamine foam samples.

The third set of tests were conducted on PVP samples dissolved in 20% ethanol and electrospun at 15 kV, 20 cm distance and 3 ml/hrs pump speed. The average fiber diameter of the samples is 4-5 μ m. Figure 8 shows the sound absorption test results of 0.5 g, 1 g and 1.5 g PVP samples compared with 1 and 2 inches of Melamine foam samples. As is seen, the 1.5 g

of the PVP fibers produced an absorption coefficient comparable to the 2 inch Melamine foam sample. This proves that electrospun PVP fibers can be used for sound absorption purposes.

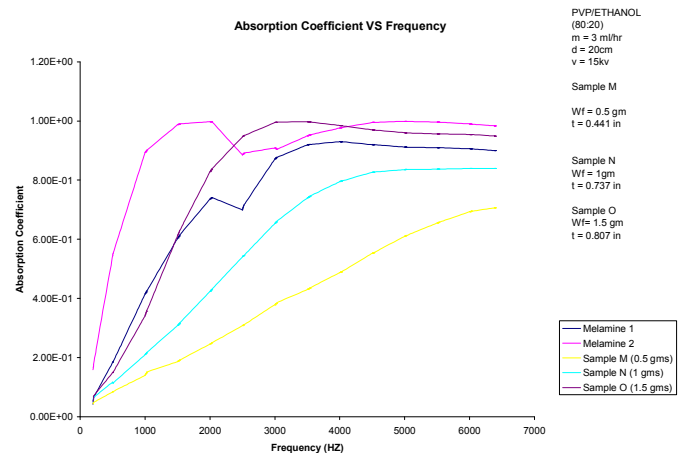


Figure 8: Absorption coefficients of electrospun PVP samples compared with 1 and 2 inches thickness Polyimide foam samples.

CONCLUSIONS

In the present study, we have produced various sizes of PVC and PVP fibers using the electrospinning method for the sound absorption purposes. SEM images show that the fiber diameters between 200 nm and 5 μ m. Impedance tube studies showed that high surface area flexible micron and nanofibers could absorb the sound better than conventionally used microscale sound absorbers. It is therefore concluded that these high surface area micro and nanofibers can be used as alternative materials to make lighter sound absorbers to reduce the interior noise of the aircrafts, as well as many other noise control applications.

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