SOUND ATTENUATING PERFORMANCE OF NANOFIBRE MATERIALS USED IN UNMANNED AERIAL VEHICLES

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ABSTRACT

Filming from unmanned aerial vehicles (UAV's) for movies and live action footage has gained significant market acceptance within the cinematography industry, however meeting the film industry's noise expectations has proven to be an issue. Currently, it is a time consuming process to remove UAV noise from recorded audio and this is very difficult to achieve in real time. This paper shows the progress that has been made on the development of thin and lightweight sound attenuating nanofibre materials for use in propeller shrouds on quadcopter UAV's. It was found that the integration of thermoplastic nanofibres enables a dramatic increase in the sound absorption co-efficient of acoustic damping fabrics and foams. This technology, in conjunction with shroud and propeller design, has great potential to be used to create new generations of much quieter UAV's.

Keywords: nanofibre, electrsopinning, acoustic attenuation, sound absorption coefficient, impedance tube test.

1. INTRODUCTION

Filming from unmanned aerial vehicles (UAV's) has gained significant market acceptance within industry for commercial applications, including cinematography and live broadcasts, and is gaining momentum within the civil market [1]. The noise generated from UAV operations is a nuisance to personnel and wildlife, resulting in recorded audio that requires expensive and time-consuming post processing and restricts drone usage in noise-sensitive areas [2].

One approach to reduce the noise generated by UAVs is to enclose the noisy propellers in a rigid shroud which can direct the sound energy upwards where it would have the least negative impact on the surroundings (Figure 1). With the advent of 3D printing, rapid prototyping of UAV shrouds is now possible at reasonable cost. The sound absorbing characteristics of the UAV shrouds are further enhanced by incorporating a lining of thin and lightweight electrospun acoustic-attenuating nanofibre material. The nanofibre lining is able to capture a portion of the sound energy and attenuate it in varying degrees at different frequencies [3]. Nanofibres are generally produced using an electrospinning process, and are typically non-woven webs consisting of kilometre long nanofibres (Figure 2). It is possible to manipulate the electrospinning parameters to change the nanofibre characteristics (such as fibre diameter, packing density, pore size and thickness) to tailor the acoustic damping performance of the material.

Figure 1: Award-winning, lightweight propeller shrouds developed by Dotterel Technologies containing Revolution Fibre's Phonix™ sound-absorbing nanofibre material.

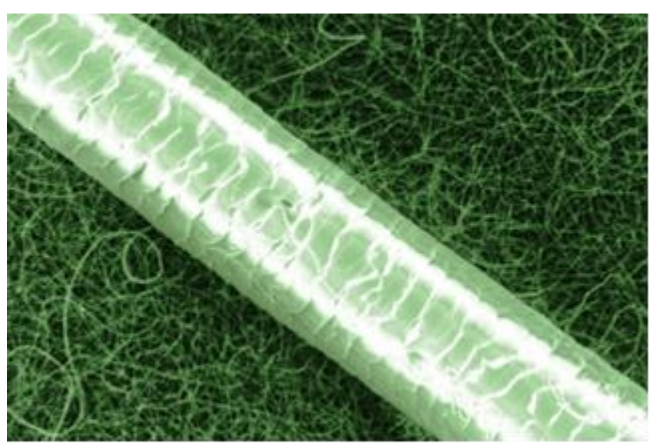

Figure 2: Scanning electron micrograph of PA66 nanofibres in relation to a human hair.

The ability to alter the acoustic attenuating characteristics of nanofibre materials enables them to be "tailored" for specific sound absorbing applications.

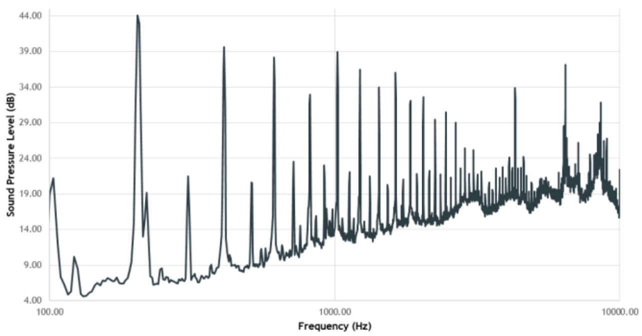

Figure 3: Noise frequency spectrum generated by a UAV with un-shrouded 6 inch propeller blades.

A UAV typically produces noise over a large frequency band, with peaks of over 30dB ranging from 200 Hz to 8,500 Hz (Figure 3). In order to produce a quieter UAV, the sound attenuating nanofibre material would be required to have sound absorption coefficients over a large frequency range and be able to "flatten" the peak frequencies that are responsible for the most noise.

Currently available acoustic damping materials such as foams, microfibres, membranes, perforated panels, etc. are typically heavy and bulky and are not well suited for use in weight-critical UAV's. They have good noise reducing properties in the high frequency range but insufficient absorption performance in the low-medium frequency range (250-2000 Hz) in which human sensitivity to noise is high. For noise control applications, it is desirable to have materials with excellent noise reduction properties in this low-medium frequency range. Nanofibres are thin and lightweight and have been shown to have good sound damping properties, but generally only in frequencies above 1000 Hz. It is therefore necessary to understand how the nanofibres can be manipulated to absorb sound at different frequency ranges so that they can best be utilised to produce quieter UAV's.

2. MATERIALS AND METHODS

Thermoplastic nanofibres were electrospun onto various substrates using Revolution Fibres' proprietary "Sonic Electrospinning" process. The nanofibres were produced from the following polymers: Poly(methyl methacrylate) (PMMA), Polyamide 66 (PA66) and Polyvinyl butyral (PVB). The substrate materials that were used are as follows: 16gsm (66µm thick) spunbonded polypropylene (PP), 30gsm (160µm thick) spunbonded polypropylene (PP) and a 95gsm (2mm thick) polyester foam. Samples were fabricated such that the nanofibre layers were sandwiched in between two layers of substrate. Samples were ultrasonically welded to adhere the layers together.

In this investigation, the following variables were manipulated to determine their effects on the sound absorbing properties of acoustic nanofibre materials: nanofibre polymer type, average nanofibre diameter, nanofibre areal weight (thickness), substrate material, nanofibre orientation, back cavity depth, and packing density of the nanofibre. Sound absorption coefficients were determined for each sample using an impedance tube in accordance with the ASTM E1050-12 test method.

The performance of a nanofibre lining in drone shrouds was assessed using a Microflown PU-based near-field acoustic camera system. This tool enabled the direct measurement of both sound pressure and particle velocity to produce sound maps to visualize the sound intensity within a specified frequency range.

3. RESULTS AND DISCUSSION

The constituents and characteristics of each of the nanofibre/substrate sandwich samples can be seen in Table 1, and the impedance tube test results can be seen in Figures 4 – 10.

As can be seen in Figure 4, the nanofibre polymer type can influence acoustic performance. PMMA nanofibre appears to perform better at frequencies below 2000 Hz and above 4000 Hz. PVB, however, performs better at frequencies between 2000 Hz and 4000 Hz. Both of these nanofibre types had similar fibre diameters and were considered to be "lofty" in nature due to their low packing densities.

Table 1: Summary of test samples

Sample	Nanofibre Polymer	Ave Nanofibre Diameter	Nanofibre Characteristics	Nanofibre Areal Weight	Sample Structure	Nanofibre Orientation
#1	PMMA	370nm	lofty	2.7gsm	16gsm PP/nanofibre sandwich	Random
#2	PMMA	370nm	lofty	2.7gsm	16gsm PP/nanofibre sandwich with foam core	Random
#3	PMMA	349nm	lofty	2.9gsm	30gsm PP/nanofibre sandwich	Random
#4	PMMA	385nm	lofty	5.2gsm	16gsm PP/nanofibre sandwich	Random
#5	PMMA	379nm	lofty	5.1gsm	30gsm PP/nanofibre sandwich	Random
#6	PMMA	376nm	lofty	43gsm	16gsm PP/nanofibre sandwich	Random
#7	PMMA	719nm	lofty	5.6gsm	16gsm PP/nanofibre sandwich	Random
#8	PA66	518nm	cohesive	4.7gsm	16gsm PP/nanofibre sandwich	Random
#9	PA66	415nm	cohesive	5.2gsm	16gsm PP/nanofibre sandwich	Random
#10	PA66	181nm	cohesive	5.1gsm	16gsm PP/nanofibre sandwich	Random
#11	PVB	369nm	lofty	5.4gsm	16gsm PP/nanofibre sandwich	Random
#12	PA66	224nm	cohesive	4.5gsm	16gsm PP/nanofibre sandwich	Oriented
#13	Control 1	-	-	0gsm	2x layers 16gsm PP	None
#14	Control 2	-	-	0gsm	2x layers 16gsm PP	None

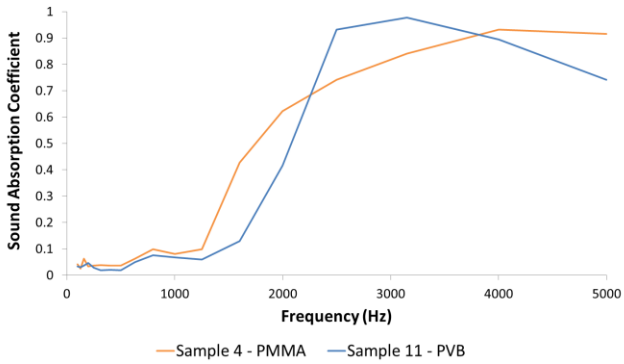

Figure 4: Effects of nanofibre polymer type on sound absorption coefficient.

The effects of nanofibre diameter on sound absorption coefficient can be seen in Figure 5(a) and (b). For “lofty” nanofibres like PMMA, smaller nanofibre diameters perform better than larger diameters. For cohesive nanofibres like PA66, the nanofibre diameter has no effect on sound absorption.

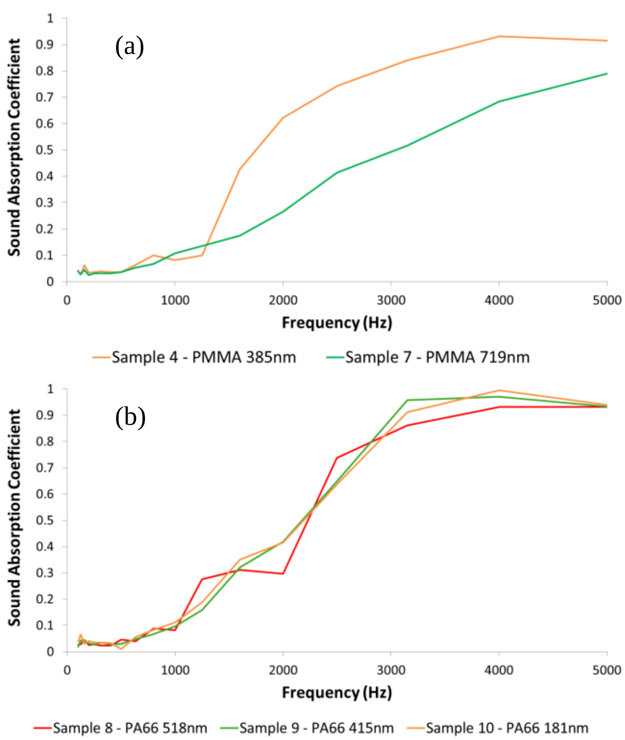

Figure 5(a) and (b): Effects of average nanofibre diameter on sound absorption coefficient.

Figure 6(a) and (b) show how nanofibre areal weight can influence sound absorption. It can be seen that heavier nanofibre depositions outperform lighter nanofibre depositions up to a point. Low Nanofibre areal weights (2.7gsm and 2.9gsm) appear to be less effective in sound absorption than 5gsm nanofibre, and it is interesting to observe that 43gsm PMMA nanofibre was not significantly different to 5.2gsm PMMA.

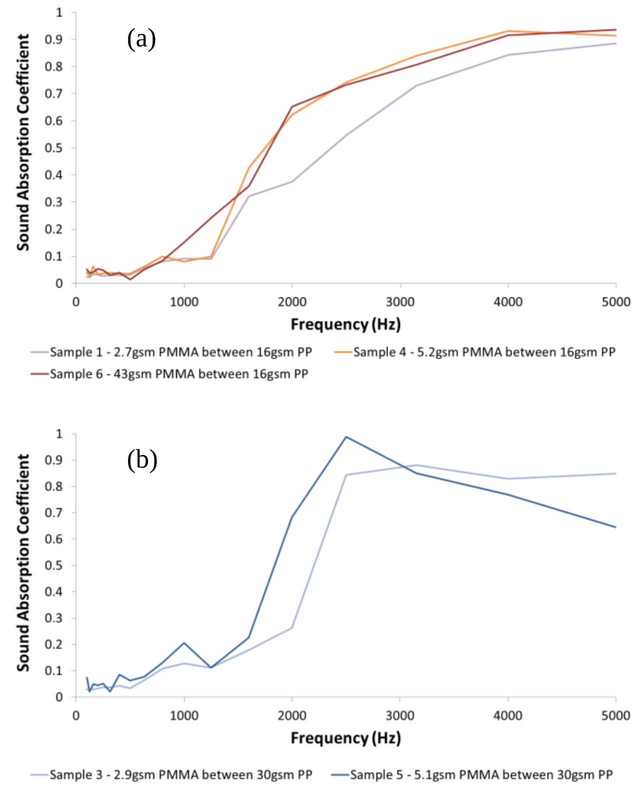

Figure 6(a) and (b): Effects of nanofibre areal weight on sound absorption coefficient.

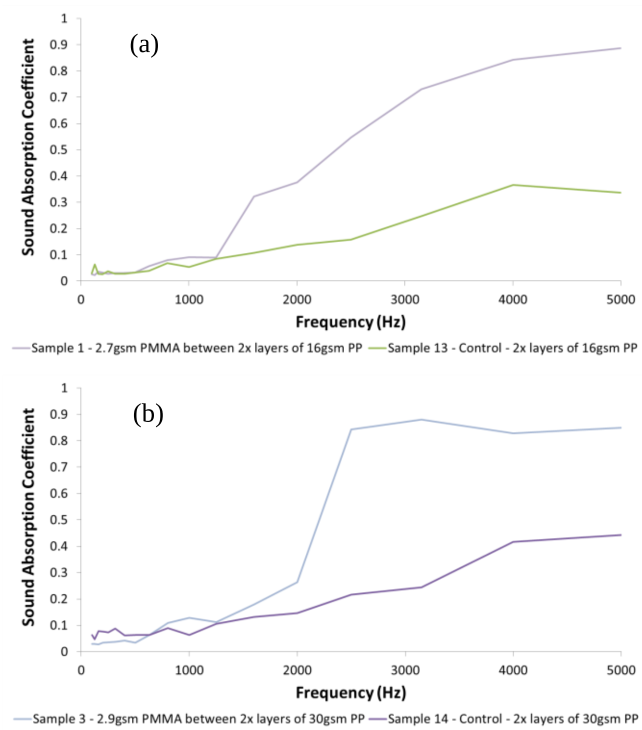

Figure 7(a) and (b): Effects of substrate material on sound absorption coefficient.

As can be seen in Figure 7(a) and (b), both the 16gsm and 30gsm PP substrates perform poorly by themselves, and are practically acoustically transparent. Nanofibre significantly increases the sound absorption performance of the materials. It can also be seen that the nanofibre performs marginally better when sandwiched between two layers of 30gsm PP as opposed to 16gsm PP.

The effects of nanofibre orientation on sound absorption coefficient can be seen in Figure 8. There does not appear to be a significant difference between nanofibres that are aligned and those that are randomly oriented, and it can be concluded that nanofibre orientation has a negligible effect on acoustic attenuation performance.

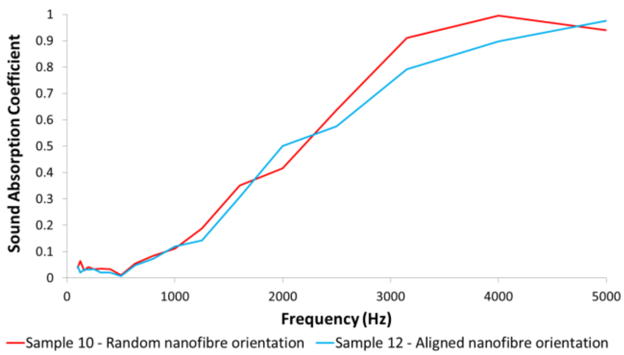

Figure 8: Effects of nanofibre orientation on sound absorption coefficient.

Figure 9 shows the effects of back cavity depth on sound absorption coefficient. Increasing the size of the back cavity shifts the sound absorption to the lower frequencies. This observation has also been reported in the literature [4]. In practical applications, placing the nanofibre on a thicker acoustic backing foam can create the same effect as increasing the back cavity depth in an impedance tube test.

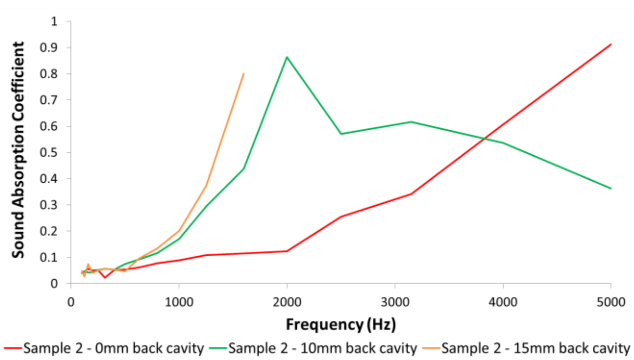

Figure 9: Effects of back cavity depth on sound absorption coefficient.

As can be seen in Figure 10, the nanofibre packing density can have an effect on sound absorption coefficient. Lofty nanofibres such as PMMA have a better acoustic damping performance at lower frequencies (below 2800 Hz), whilst cohesive nanofibres such as PA66 have a better performance at higher frequencies (above 2800 Hz).

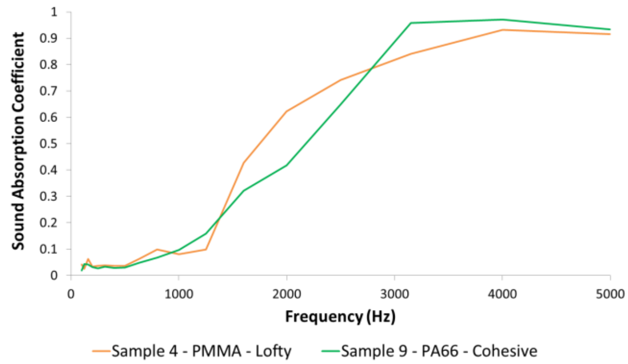

Figure 10: Effects of nanofibre packing density on sound absorption coefficient.

The tests on the drone shrouds, with results shown in Figure 11, were carried out at low speeds and show comparisons between an unshrouded propeller and shrouded propellers with and without acoustic nanofiber linings. The no-shroud test shows that the majority of the sound energy is radiated beneath the propeller. This was used as a comparative baseline for shrouded designs. An unlined shroud shows how the noise can be directed upwards. Finally, an acoustic nanofiber lining was incorporated into the shroud assembly, which greatly improved the sound attenuation properties of the shroud and resulted in a much quieter drone.

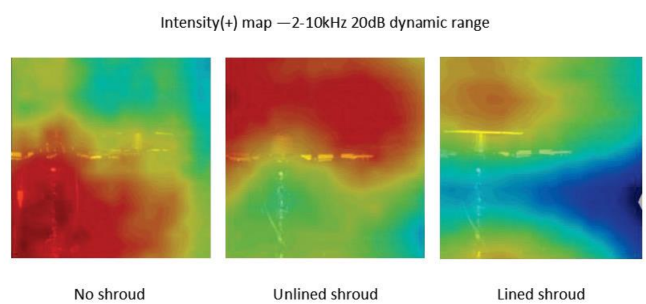

Figure 11: Sound intensity maps showing comparisons between an unshrouded propeller and shrouded propellers with and without acoustic nanofiber linings

4. ACKNOWLEDGEMENTS

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5. REFERENCES

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