NATURAL FIBRE COMPOSITES FOR ACOUSTIC APPLICATIONS

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The growing emphasis on green technology has resulted in an increased use of natural fibres in composites. Examples of these natural fibres include coir, flax, jute, and hemp. Natural fibres have advantages such as low cost, low density, good mechanical properties, biodegradable, and most importantly, environmentally-friendly. In the automotive industry, natural fibre composites have been traditionally used mainly for cabin noise control. Apart from that, there are also reported use of natural fibres to enhance the damping characteristics of carbon fibre or carbon nanotube reinforced composites in products such as tennis rackets and bicycle frames. Another potential use of natural fibre composites would be in hearing protection devices (HPDs), which commonly include earmuffs and earplugs. Earmuffs, in general, can provide superior noise mitigation as compared to typical earplugs. The aim of this work is to assess the feasibility of flax/carbon fibre composite earmuff for low-frequency noise mitigation. The composite ear cups were fabricated by compression moulding technique where flax/carbon fibre mats were incorporated in a typical thermoplastic matrix. The resulting composite ear cups were then assembled into an earmuff to evaluate its performance in different noise environments (continuous and transient). Results showed that the composite earmuff could enhance the low-frequency performance of typical earmuffs.

Keywords: Low-frequency noise, earmuffs, hearing protection devices, natural fibre, composite

1. Introduction

Over the past decades, the emphasis on green technology has been growing rapidly due to environmental pollution, which is a result of industrialisation. By understanding the importance of going green, it is highly believed that our living conditions in the future could be better. There are many ways to go green. For example, reported works on natural fibre composites have been increasing; spanning across different type of applications [1,2]. The advantages of natural fibre include low density, low cost, good mechanical properties, biodegradable. and most importantly, environmentally-friendly [3]. However, these benefits are accompanied with some limitations such as low durability (in comparison to synthetic fibre composites), high moisture absorption, and low processing temperatures. Although these drawbacks could be improved by specific treatments, one should still take note of the inherent limitations during the design phase.

Traditionally, natural fibre composites have been used in automobile design for noise mitigation [4,5]. Depending on the composition of the natural fibre composites, the noise level at problematic frequencies could be targeted and reduced. Considering their good acoustical properties, the use of natural fibre composites could also be extended to other applications for the same intention—noise mitigation. One of these applications could potentially be in hearing protection devices (HPDs), which commonly include earmuffs and earplugs. Generally, the former device can provide better noise attenuation than the latter device. Conversely, if the noise environment is predominantly low-frequency, off-the-shelf HPDs may not be as effective. Examples of such noise environments include automobile cabins, airports, and construction sites.

This paper examines the feasibility of flax/carbon fibre composite earmuff for low-frequency noise mitigation. This feasibility was evaluated by considering two different noise signals—pink noise and aircraft fly-by noise. To distinguish the improvement in performance of the composite earmuff, the experimental results were benchmarked against an off-the-shelf earmuff (3M™ Peltor™ Optime™ H510F). Also, for consistency, the geometrical design of the composite ear cups followed closely to that of the off-the-shelf earmuff (hereinafter referred to as reference earmuff). The fabrication is elaborated in Section 2 alongside the experiment method. Section 3 presents and discusses the performances of the composite earmuffs as compared to the reference earmuff in the considered noise environments. Section 4 concludes the work based on the experimental findings.

2. Fabrication and Experimental Method

This section first elaborates on the fabrication of the flax/carbon fibre composite earmuff. Subsequently, the experimental method is presented, which includes the test set-up and the post-processing of the test data.

2.1 Fabrication of the Composite Earmuff

The flax/carbon fibre composite earmuff was designed to replace the ear cups of the reference earmuff. As such, other components—headband, cushion, and inner foam lining—in the earmuff assembly remained the same. Using a compression moulding technique (Figure 1a), prescribed layers of flax fibre mats, carbon fibre mats, and polymer sheets were compressed into the shape of the ear cup. Subsequently, the formed ear cups were cooled to room temperature before the excessive materials were removed. The composite ear cups were then assembled with the remaining components to form the earmuff (Figure 1b).

(a) (b)

Figure 1: (a) A schematic representation of the set-up for the compression moulding technique; and (b) the assembled flax/carbon composite earmuff on the head and torso simulator

2.2 Experimental Method

The experiment was conducted in a reverberation chamber (227 m^3) with a temperature and humidity of 25°C and 70%, respectively. A head and torso simulator (B&K Type 4100) was placed in the centre of the chamber to measure the noise level in the chamber with and without the earmuff. Each noise signal (pink noise and aircraft take-off) was played via an audio system (Sony ZS-RS70BT). Connected to an amplifier (Larson Davis BAS002), the noise signal was transmitted into the chamber by an omnidirectional loudspeaker (Larson Davis BAS001). Figure 2 shows a schematic representation of the experimental set-up in the reverberation chamber.

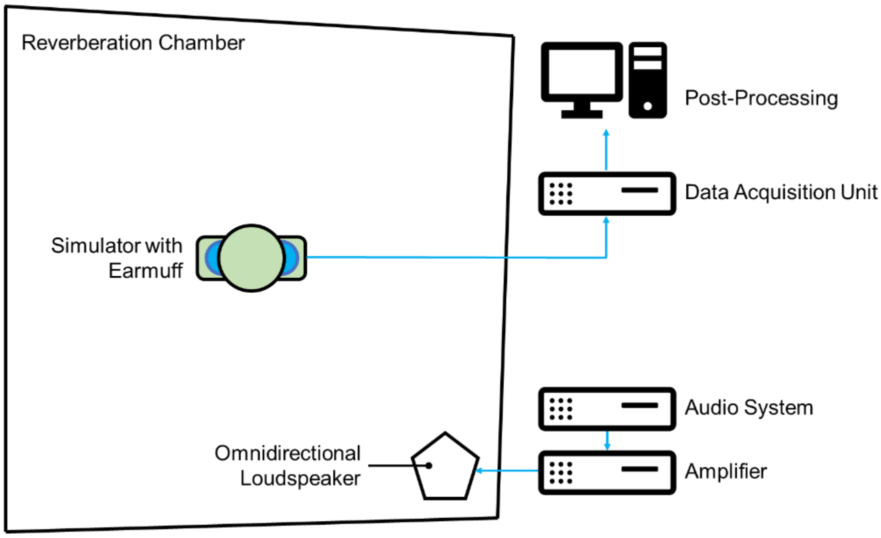

Figure 2: A schematic representation of the experimental set-up in the reverberation chamber

The noise level was first measured to ensure that it was at least 15 dB higher than the background noise level. Subsequently, the noise level was measured with the respective earmuffs donned on the simulator. These measurements were stored in a data acquisition unit (B&K Type 3663), which were later transferred to a workstation for post-processing.

One of the methods in evaluating the performance of HPDs is by determining the insertion loss (IL) of the respective devices. IL is defined by the difference in noise level with and without an earmuff. Mathematically, IL is expressed by [6]

$$\boldsymbol{IL_f\ (dB) = L_{O,f} - L_{C,f}} \tag{1}$$

where the subscript f denotes a frequency-dependent term; $L_{O,f}$ and $L_{C,f}$ is the noise level without and with the earmuff, respectively. It should be noted that the noise levels ($L_{O,f}$ and $L_{C,f}$) were calculated from the arithmetic average between both ears.

3. Results and Discussion

This section first presents the performance of the flax/carbon composite earmuff by comparing it with that of the reference earmuff. Next, the performances of the earmuffs in aircraft fly-by noise are presented.

3.1 Performance of Composite Earmuff in Pink Noise

Figure 3a shows the IL curves of the respective earmuffs in pink noise. From the results, the composite earmuff showed noticeable improvement in IL at two frequency regions—368–464 Hz and 2,848–6,160 Hz. In the higher frequencies, the performance of the composite earmuff was significantly improved (up to 15.9 dB at 5,120 Hz) in contrast to that of the reference earmuff. However, the frequency range is beyond the interest of this work in which the focus is placed on low-frequency performance.

In the lower frequencies, the improvement in performance of the composite earmuff was limited to a narrower frequency range between 368 Hz and 464 Hz. In this frequency range, the composite earmuff showed improved performance by up to 6.1 dB at 400 Hz in contrast to the reference earmuff. Between 480 Hz and 1,136 Hz, a compromise in the performance of the composite earmuff was observed. Nevertheless, traditional noise control solutions would be sufficiently effective at these frequencies [7]. In both earmuffs, an IL dip was observed at around 190 Hz, which could be due to the resonance of the air enclosed by the ear cups [6].

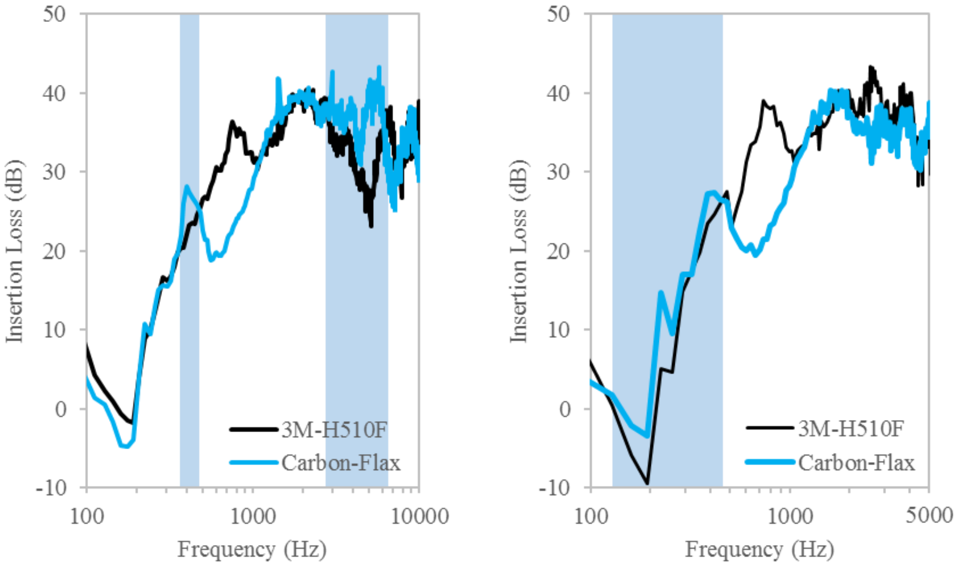

Figure 3: Plots showing the IL curves of the respective earmuffs in (a) pink noise; and (b) aircraft fly-by noise

3.2 Performance of Composite Earmuff in Aircraft Fly-By Noise

Having the performance of the composite earmuff determined in pink noise, it is of interest to evaluate their performance in actual noise environment—aircraft fly-by noise. The results were truncated at 5 kHz as the energy levels above this frequency were too low for meaningful observations to be made. Figure 3(b) shows the IL curves of the respective earmuffs in aircraft fly-by noise.

From the results, the reduced performance of the composite earmuff was observed at the same frequency range (480–1,136 Hz) as that in pink noise. Similarly, the improved performance of the composite earmuff was also observed at the same frequency range (368–464 Hz). Surprisingly, this improvement in IL extended from 368 Hz to 112 Hz where the reference earmuff was found to perform poorer in the highly-transient noise environment. The performance of the composite earmuff was shown to be improved by up to a maximum of 9.6 dB at 216 Hz, which corresponded to a noise reduction of about 90%.

Apparently, the performances of the respective earmuffs were found to be different when considered in a continuous or highly-transient noise environment. A possible explanation for this observation could be due to the inherent acoustical characteristic of carbon fibre in mitigating impulse noise as demonstrated recently by Augustine [8].

4. Conclusion

The recent emphasis on green technology has resulted in an increased use of natural fibre composites in many applications. Traditionally, natural fibres have been used for sound absorption in automobile cabins. In this work, a flax/carbon fibre composite earmuff is proposed to explore its feasibility for low-frequency noise mitigation. Its performance, in terms of IL, was evaluated by benchmarking against an off-the-shelf earmuff.

Results indicated that the performance of typical earmuffs in the lower frequency range (368–464 Hz) could be improved with the composite ear cups by up to 9.6 dB at 216 Hz. In a highly-transient noise environment, the performance of the composite earmuff in the low frequency range (112–368 Hz) was found to be even better as compared to that achieved in a continuous noise environment. In conclusion, if properly designed, the potential of composite earmuff for low-frequency noise control could be realised.

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