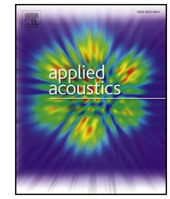
Applied Acoustics 140 (2018) 100–109

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust



Technical note

HVAC noise control using natural materials to improve vehicle interior sound quality

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ARTICLE INFO

Keywords:
Noise control
Sound quality
Jute felt
Natural materials
Sound absorption
HVAC

ABSTRACT

Heating, Ventilation and Air Conditioning (HVAC) unit is a major noise source in a vehicle's interior space. Reducing this noise will improve the sound quality of the vehicle's interior space and enhance passengers' experience. However, current noise control techniques are high-cost and hazardous to environment. Therefore, this paper studies the first ever usage of low-cost, biodegradable natural materials for vehicle's HVAC noise control. Jute felt and waste cotton were found to have higher sound absorption coefficients than other common sound absorbing natural materials, and were chosen as sound absorbers for noise control treatment of a prototype HVAC unit. Noise sources in the unit were identified and ranked, and the treatment was applied to these. The treatment significantly reduced the noise level (by 4 dBA) and loudness level (by 7 sones) due to the unit at the reference passenger's ear location, with negligible cost and weight. Sound quality evaluation by 24 participants showed that the treatment significantly reduced the annoyance of the vehicle interior soundscape comprising the HVAC noise. Thus, jute felt and waste cotton are low-cost, light-weight, biodegradable and recyclable natural materials with high potential for HVAC noise control.

1. Introduction

Sound quality of a vehicle interior space is an important aspect of a vehicle and demands special NVH (Noise, Vibration and Harshness) attention. Reducing noise inside a vehicle improves the sound quality of the vehicle interior space, which in turn leads to a higher passenger comfort, better driving experience, and lesser driver distraction. Moreover, reducing noise and improving vehicle interior sound quality enhances a customer's perception of the vehicle brand; thereby the vehicle attracts more customers and gets a competitive advantage in the market [1,2].

Research and development over the last two decades have led to quieter and better sounding engines. As a result, secondary sound sources located within a vehicle cabin such as heating, ventilation and air-conditioning (HVAC) system, entertainment systems, and audio driver assist systems have become more perceptible to passengers [3]. Among the secondary sources, the HVAC system is the most dominant noise source in a vehicle's interior space as it operates throughout as long as the vehicle is running. Additionally, the HVAC and blower fan noise reaches the interior space without any sound isolation and can strongly impact passengers' comfort. In the hot climate of a tropical country like India, a vehicle's HVAC system operates continuously at higher blower speeds and is one of the most important interior noise sources. Therefore, HVAC noise control is needed to improve the sound quality of the vehicle interior space, and it is gaining growing attention from researchers and manufacturers [3–8].

1.1. Conventional methods for HVAC noise control and sound quality enhancement

The major noise source in the HVAC unit is the aerodynamic blower noise [9–12]. Therefore, the conventional strategy for reducing HVAC noise includes design changes to the blower and its blades [9,10,13,14]. However, the unit examined in this paper was already designed and produced by the manufacturer for optimum performance; hence only noise control strategies at post-production stage are discussed in this paper. Existing post-production noise control techniques include active noise control [4,11,15], and passive noise control using synthetic sound absorbing materials such as micro-perforates [5,6], fiberglass, glass wool and polypropylene [16]. These approaches achieve up to 6–10 dB noise reduction. However, active noise control approaches involve costly equipment, work well only in low frequencies, and are effective only in specific zones of the vehicle interior space. Passive noise control approaches work best at frequencies above ≈500 Hz, and they apply noise reduction throughout the interior space. However, the synthetic sound proofing materials are costly as their manufacturing requires

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https://doi.org/10.1016/j.apacoust.2018.05.013
Received 13 February 2018; Received in revised form 7 May 2018; Accepted 9 May 2018

high-end equipment (for e.g., micro-perforated panels [5,6]) or high-temperature extrusion and synthetic chemical processes (for e.g., fiberglass, glass wool, polypropylene [16]). For the same reasons, these materials have higher carbon footprints, and are neither biodegradable nor recyclable.

1.2. Natural materials for noise control

Due to the discussed disadvantages of synthetic materials, the recent trend in automotive noise control is a shift towards natural materials, also known as natural-fiber materials. Some common sound absorbing natural materials are jute, cotton, flax, kenaf, hemp, coconut coir, bamboo curls, and banana [16–21]. These materials provide good sound absorption, are low-cost, light-weight and biodegradable. Therefore, they have begun to be applied for sound proofing automotive components such as floor carpeting [18] and car boot liners [20].

However, currently there is no research study on the usage and effectiveness of natural material(s) for noise control of a vehicle HVAC system. Testing the effectiveness of natural materials for vehicle HVAC noise control would help in developing low-cost and eco-friendly techniques to enhance vehicle interior sound quality. Furthermore, the existing HVAC noise control case studies ([4–6]) are usually limited in scope as they do not test the effectiveness of the noise control treatment on actual humans. Therefore, there is a need for a systematic case study of a vehicle HVAC noise control using natural materials that tests its effectiveness through human-subject sound quality experiments. Such case studies could guide future NVH engineers across various industries to adopt eco-friendly and human-centered noise control practices.

This paper presents the first ever case study of usage of natural materials, namely, jute felt [22] and waste cotton for noise reduction in a vehicle's HVAC unit. The other novelty of this paper is that it validates the effectiveness of this noise control treatment through human-subject sound quality evaluation of the HVAC noise and the vehicle interior soundscape comprising the HVAC noise. It also presents a first ever comparison of the sound absorption coefficient of jute felt with other contemporary sound absorbing natural materials. The remaining paper is organized such that Section 2 describes the materials used for noise control. Section 3 describes the test HVAC unit, and its noise evaluation is in Section 4. Section 5 describes the noise source ranking in the unit. Section 6 describes the treatment done on the unit and its noise evaluation. Section 7 describes the sound quality evaluation of the HVAC unit.

2. Details of the natural materials used

Jute is a naturally occurring plant that is readily grown at very low cost in the hot tropical and rainy regions of the eastern parts of India. Jute fiber is a lignin-cellulose fiber composed primarily of cellulose (major component of plant fiber) and lignin (major component of wood fiber). Raw jute fibers have high aspect ratio (length/diameter), high specific modulus, and high tensile strength (see details in [22]). Raw jute fibers are cleaned and spun into a jute yarn. Stacks of jute yarn laid in a definite sequence are pressed under pressure, and the resulting sheets are bonded using natural rubber. The resulting composite is called a "jute felt" (see details in [22]). Jute felt is biodegradable and recyclable, and thus environment-friendly. Jute felt has been extensively tested by Fatima and Mohanty ([22]) and 1% natural rubber treated jute felt is found to have lower flammability than fiberglass, wool and cotton. This jute felt has been shown to have very high normal specific sound absorption coefficient (see details in [22,23]). Recently, jute felts have been successfully applied to noise control in vacuum cleaners and domestic dryers, [19] and in building semi-anechoic chambers [24].

Experiments were done to compare sound absorption coefficient of a jute felt sample with some of the other existing low-cost sound absorbing natural materials, namely, coconut coir, flax, cotton, wood curls, and rice straw. The experiments were done in Acoustics and Condition Monitoring Laboratory at the Indian Institute of Technology Kharagpur using the two-microphone method in the B&K4206 impedance tube setup as per ISO 10534-2 [25]. The sound absorption coefficient will increase with increase in packing density of these materials. Therefore, for a more valid comparison the samples of these natural materials had similar packing densities within the range of ≈110–155 kg-m^{-3}. Table 1 shows the noise reduction coefficient (NRC) values and the densities of these natural materials. Fig. 1 shows the normal specific sound absorption coefficient of these materials. Jute felt was found to have the highest sound absorption coefficient and highest NRC, and was the lightest of the tested materials. Therefore, it was chosen as the primary material for noise control. Waste cotton is more flexible to fit into any shape and it also had good sound absorption, so it was also decided to apply waste cotton, but only in areas such as cavities where jute felt could not be easily applied.

Table 1
NRC and densities of 100 mm thick samples of some common natural materials.

Sample	NRC	Density (kg-m^{-3})
Jute felt	0.75	108
Flax	0.70	155
Waste cotton	0.65	137
Rice straw	0.65	154
Wood curls	0.55	110
Coconut Coir	0.45	108

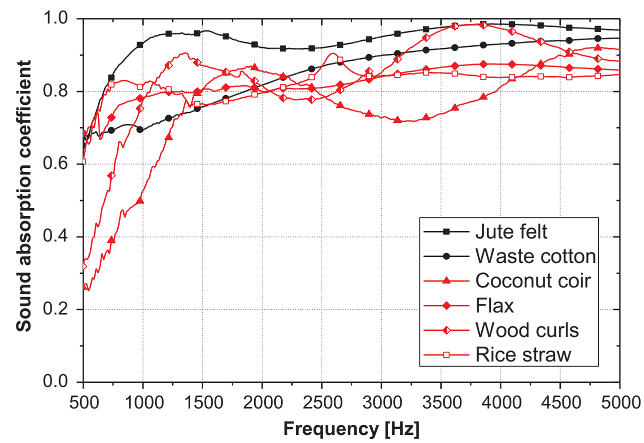

Fig. 1. Sound absorption coefficients of 100 mm thick samples of some common natural materials.

3. Description of the HVAC unit

The HVAC unit used for this case study is a prototype supplied by a manufacturer. It is made of ABS (Acrylonitrile butadiene styrene) plastic and has the following main components – fresh air inlet, recirculation inlet, evaporator, heater, and outlet vents (defrost vent, cabin vent and foot vent). Figs. 2 and 3 show the positioning of the HVAC unit in a car, and the detailed schematic of the HVAC unit respectively. A standard vehicle HVAC unit can operate in either "fresh air inlet mode" i.e. fresh air intake from outside the vehicle or "recirculation air inlet mode" i.e., air intake from inside the vehicle cabin" (see Fig. 2). For this case study, the fresh air inlet was blocked and the HVAC operated in the noisy recirculation mode. The recirculation inlet houses a 43-vane blower that sucks in the cabin air (Fig. 3). The air enters the unit through the recirculation inlet vent, passes through the blower, and then through the evaporator that consists of an evaporator coil for cooling the incoming air flow and a filter to purify the air. Some