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Acoustical Properties of Denim Shoddy based Recycled Material

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ABSTRACT

Glass wool has been a traditional noise control material which has excellent sound absorption properties but is accompanied by health hazards and high carbon footprint. This motivated the researchers to explore some alternatives, and the focus has shifted toward natural materials which have shown very promising results. An alternate step in this direction has been investigating the potential of recycled items based on natural materials, like bagasse fiber (a by-product of sugar cane industry), oil palm empty fruit bunch fiber, used cigarette butts, etc. One such material is denim shoddy which combines the properties of natural cotton and indigo and is used as a filling in furniture. Its sample has been fabricated, and the essential properties (density, airflow resistivity) are measured. These properties are used to predict the sound absorption coefficients through empirical models. The actual sound absorption behavior is measured on a two-microphone impedance tube as per ASTM-E-1050. The predicted and measured results are compared among themselves. The excellent sound absorption properties obtained even at low frequencies which makes this material suitable for industrial application.

Keywords: Sound absorber, Porous Material, Noise control
I-INCE Classification of Subject Number: 35

1. INTRODUCTION

The twentieth century has witnessed a lot of development in science and technology which resulted in the invention of many new types of machinery dedicated to easing of human life. Most of these machines has some kind of moving parts in them which generates noise and propagates in the surrounding, hurting human beings [1].

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This motivated the researchers and practitioners to devise some strategies for noise control. Noise control is achieved by using noise insulator and noise absorber. Noise insulation strategy is applied when the primary motive is that the noise generated from a source is restricted from entering the desired zone. Very dense materials like steel sheet, lead sheet, etc. are used for this purpose, which reflects the sound incident upon them. This can be easily observed in the form of generator set enclosures or barriers installed by the roadside [2]. Noise absorption strategy is applied when the primary motive is to minimise the sound incident onto a material. Porous materials like glass wool, rock wool, etc. are used for this purpose which dissipates the sound incident onto the material in their pores [3]. These materials perform fairly well but have a higher carbon footprint on the environment apart from being hazardous to the persons involved with its manufacturing or operation [4]. This motivated the acoustics community to come up with some alternate materials.

One step in this direction has been the development of noise absorptive materials from natural sources. A substantial amount of research has been done on natural materials across the globe which comprises fibers obtained from bamboo, tea leaf, coir, jute, etc. These fibers are porous which ensures the sound dissipation in their pores due to friction between the fibers, viscous effect, thermal effects etc, [5-8]. These materials have shown very promising results not just in the laboratory in the laboratory but some of them have been tested on actual machinery on which they performed quite well [8]. These fibers have many advantages like being light in weight, bio-degradable apart from being cost-effective. To further boost up these advantages, the researcher's focus has shifted towards recycled material, like oil palm empty fruit bunch fiber, cigarette butt, recycled rubber, etc. [9-11]. Cigarette butt mainly consists of cellulose acetate which is not easily biodegradable, and it turned out to be a great sound absorber. Old tyres are useless and serve a breeding ground for many insects. Rubber extracted from recycled tyres turned out to be a great sound absorber. One such material is denim shoddy which is obtained from used jeans, and it is discussed in this paper.

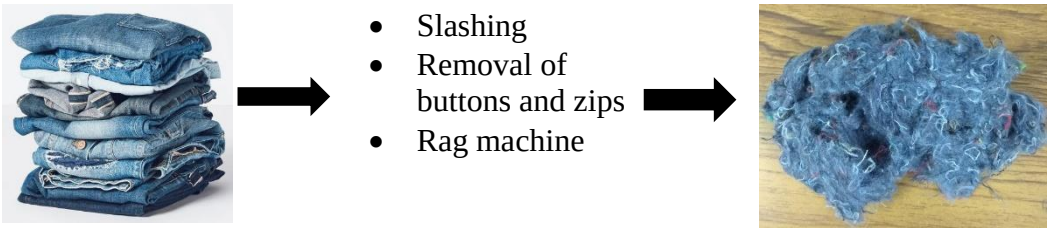
2. Materials and methods

This section explains the steps involved in the preparation of the material from the waste material. The first section describes how the denim shoddy fibers are prepared from the waste denim clothes. This section is followed by the methodologies involved in the measurement of the sound absorption coefficient, and finally, the third section explains how the sound absorption behavior of a material can be estimated by some empirical relations and bulk material properties.

2.1 Denim shoddy fiber preparation

Denim is a material which mainly consists of natural cotton and indigo. Its fabric in the form of jeans is used across the globe. After completing its life as cloth, it goes for recycling so that it can be utilized in some other form. Used clothes from many countries arrive at the shore of Kutchh in Gujarat, India. The first thing that happens is slashing of these clothes to ensure its unavailability as reusable cloth. It is then separated as per the type of fabric. These slashed clothes are then mainly packed to Panipat in Haryana which happens to be a hub of shoddy industry. The buttons and zip attached to these slashed clothes are removed manually. The slashed denim fabric without buttons and zip is

processed through a rag machine which shreds the fabric into the fiber. These processes are shown in figure 1.



a) Old Jeans to be recycled b) Mechanical operations c) Obtained denim shoddy

Figure 1: Procedure to obtain denim shoddy from old jeans

The fiber obtained in figure 1c was procured from ESKAY INTERNATIONAL, Kolkata in West Bengal for whom this happens to be a raw material for making blankets, door mats by processing these fibers on spinning, carding, and compacting machines.

The diameter of these fibers was measured to be around 10µm, and its density was around 1502 Kg/m^3. A sample of diameter 100 mm, having a thickness as 50 mm and density 42 Kg/m^3 was fabricated.

2.2 Measurement of the sound absorption coefficient

The prepared sample was tested on an indigenously developed impedance tube shown in figure 2.

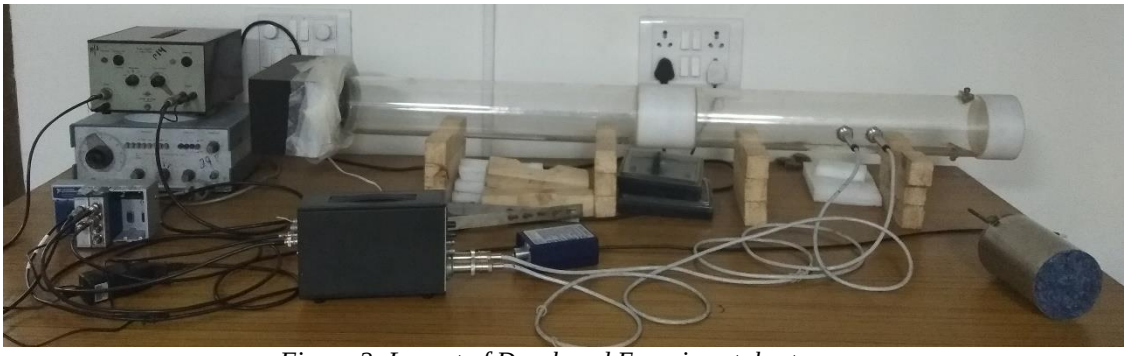


Figure 2: Layout of Developed Experimental set-up

The sample is mounted in the tube, and the speaker in this tube plays a uniform white noise through a speaker. Standing waves are formed in the tube, and the microphones mounted in it measure the sound pressure P_1 and P_2. This obtained sound pressure time signal is processed as per ASTM-E-1050 [12] to obtain the values of normal sound absorption coefficient.

The transfer function (H) between the two pressure time signal is obtained by the ratio of their cross-power spectrum (G_{12}) and auto-power spectrum (G_{11}).

$$H = G_{12}/G_{11} \quad (1)$$

The measured values of the transfer function are used to estimate the complex reflection coefficient (R) by using equation (2) and the distance between the microphone and specimen (s) and wave number (k).

$$R = \frac{H - e^{-jks}}{e^{jks} - H} e^{j2k(l+s)} \tag{2}$$

The normal sound absorption coefficient (α) is then estimated by equation (3)

$$\alpha = 1 - |R|^2 \tag{3}$$

2.3 Prediction of sound absorption coefficient by using empirical relations

The airflow resistivity of the same sample was measured as per ISO 9053 [13] and the value obtained was around 18000 N-s/m^4. This value was used as an input to the empirical model. One such model is the Delany-Bazley model which predicts the acoustic absorption by flow resistivity and thickness. It estimates the characteristics impedance, Z_c and propagation constant, k' [14].

$$Z_c = \rho c \left[1 + 0.586 \left(\frac{f}{\sigma} \right)^{-0.75} - j0.768 \left(\frac{f}{\sigma} \right)^{-0.73} \right] \tag{4}$$

$$k' = \frac{\omega}{c} \left[1 + 0.0857 \left(\frac{f}{\sigma} \right)^{-0.70} - j0.1749 \left(\frac{f}{\sigma} \right)^{-0.59} \right] \tag{5}$$

These two properties along with thickness (d) of the material are used to estimate surface impedance, Z_{in} and finally, we obtain the normal sound absorption coefficient of the material α

$$Z_{in} = -jZ_c \cot(k'd) \tag{6}$$

$$Z_{in} = \rho c \frac{1+R}{1-R} \tag{7}$$

$$\alpha = 1 - |R|^2 \tag{8}$$

3. Results and Discussions

The sound absorption coefficients measured on a 2-microphone impedance tube is plotted in figure 3. It is compared with the result obtained by empirical models of Delany-Bazley. They show a good match between them which means the measurement is true and reliable.

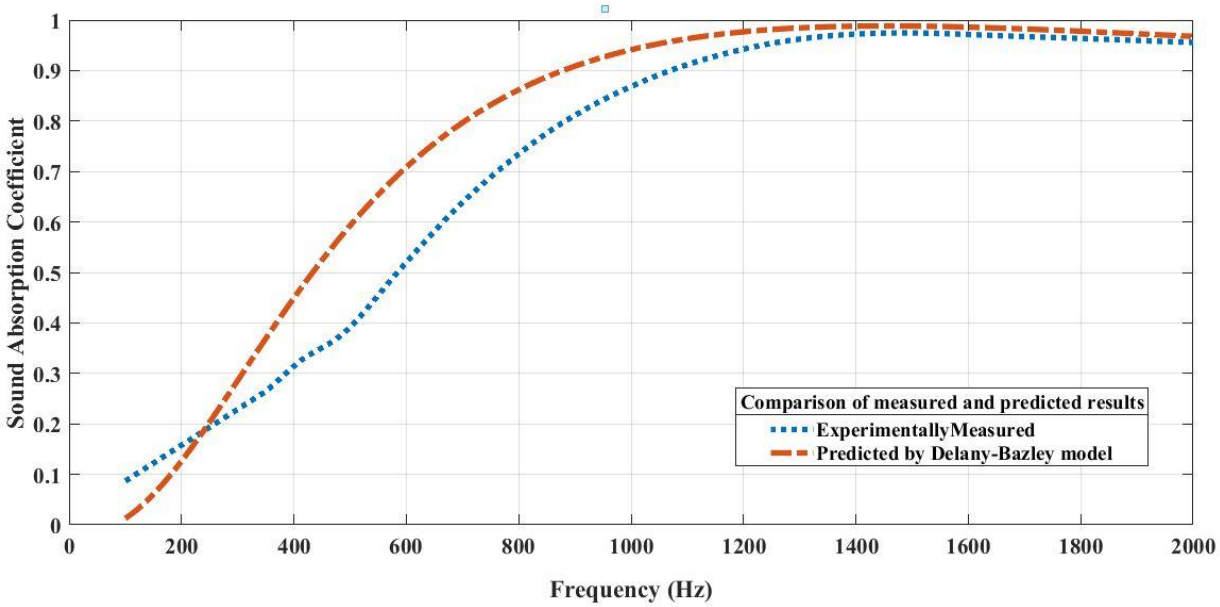


Figure 3: Comparison between measured and predicted results for denim shoddy

Further, the normal sound absorption coefficient measured at 500 Hz is around 0.35 while at 1000 Hz the value reaches up to 0.87. Above 1000 Hz, this value approaches around 1 which means this material is a good sound absorber.

4. Conclusions

This paper highlighted a waste material obtained from denim shoddy and investigated its potential to be used as an acoustic material. Noise reduction coefficient (NRC) measured at $1/10^{th}$ octave from experimental result comes out to be 0.5071. Further increase in NRC value can be achieved by appropriate modification in its thickness and density. The results obtained are very promising and a provides an alternative application of a waste material which can be a substitute to the synthetic acoustic materials used for sound absorption. This material in application as a sound absorber promises to leave lighter carbon footprint and will be a step towards environment conservation and sustainable development with minimum interference towards mother nature.

5. Acknowledgment

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