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INFLUENCE OF MOISTURE CONTENT ON THE ACOUSTIC PROPERTIES OF TEXTILE MATERIALS

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ABSTRACT

Moisture content in a material affects its ability to dissipate sound energy, particularly at mid to high frequencies. This effect has already been investigated for materials such as soil, perlite, or mineral wool, and trends appear to depend on the material. Therefore, acoustic models might not be accurate for hygroscopic materials in humid environments. Even though some explanations were suggested, underlying mechanisms remain unclear. Hence, in this study, fibrous absorbers (cotton and polyester) were analyzed in terms of their acoustic absorption behavior depending on the moisture content. Experimental methods were employed to measure the sound absorption coefficient with varied moisture contents reaching up to 20 wt-%. The results show an influence of the moisture content on the sound absorption, with an increased absorption coefficient for higher moisture contents. This means that changes in the relative humidity of the surroundings can affect the performance of fibrous sound absorbers. Further, when it comes to acoustic material characterization, conditioning of the test samples might be required to achieve reproducible and comparable results.

Keywords: *Absorption, Textile, Moisture, Humidity*

1. INTRODUCTION

Fibrous materials are effective sound absorbers due to their ability to dissipate acoustic energy within their pore structures. As sustainability is gaining importance, sound absorbers made from recycled and natural fibers are on the rise. However, most natural fibers are hygroscopic, which is why their physical properties are affected by humidity. Researchers have observed a strong correlation between relative humidity (RH) and moisture uptake for natural fibers such as cotton and wool. According to the review by [1], natural fibers exhibit increased swelling and weight gain under high RH conditions. As water molecules fill the voids, the pores are closed, and the airflow resistivity is increased, [2] thus potentially affecting the sound absorption. Here, [3] investigated wool-based materials and reported reduced sound absorption at high frequencies as moisture contents rose. On the other hand, most synthetic textile materials, such as polyester and polypropylene, show different behaviors under humid conditions due to their hydrophobic nature [2]. Therefore, the aim of this study is to determine how changes in moisture content impact the acoustic performance of fibrous sound absorbers, namely cotton and polyester nonwoven.

1.1 Effects of Moisture Content on Acoustic Performance of Materials

The effects of moisture content on the acoustic behavior have already been investigated for materials such as soil, perlite, or mineral wool, and trends appear to depend on the material. For soil, variations in moisture content were shown to affect the material's sound absorption, which can be related to changes in porosity ϕ and airflow resistivity σ. The moisture-dependent parameters are given by [4]:

$$\phi_{\text{wet}} = \phi_0 \cdot (1 - C_m M), \tag{1}$$

$$\sigma_{\text{wet}} = \sigma_0 \cdot (1 + C_r M), \tag{2}$$

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where ϕ_0 is the initial porosity, σ_0 is the dry resistivity, C_m describes the moisture-induced porosity factor and C_r describes the moisture-induced air resistivity factor. In Eqs. (1) and (2), some simplifying assumptions were made, such as linear relationships with moisture content and overlooks of material properties, along with a uniform moisture distribution.

1.2 Physical Effects of Moisture on Textile Materials

Many natural but also some synthetic fibers are hygroscopic to some extent, meaning they absorb moisture from air [5]. The amount of absorption depends on the fiber type and the environmental conditions, with natural fibers absorbing up to 30 % of their weight under high RH conditions, while most synthetic fibers usually take up less than 1 % [6–8]. For hygroscopic porous materials, water can be stored in the air voids either as vapor or in liquid form, or it may be bound inside the material itself [5]. Especially the latter can drastically affect fiber properties, including dimensional (mass, swelling), mechanical (tensile strength, extensibility), and electrical (resistance) properties [9]. The first study reporting structural changes in textiles from changes in moisture content can be found in [10]. Here, swelling of cotton fibers was found to affect a material's thickness and porosity [10]. Related to this, [2, 5] investigated the influence of moisture content on the air permeability of hygroscopic textiles and observed drastic changes at high RH caused by swelling, which reduced the free void space.

2. EXPERIMENT

As sound absorption is, among other factors, governed by porosity and airflow resistivity, this gives rise to the assumption that it might as well be affected by the moisture content in the fibrous material. Sustainable sound absorbers are often based on natural fibers (cotton). Cotton is hygroscopic and can bind moisture inside the fiber, whereas, for example, polyester can only store moisture in the voids formed by the fiber assembly. By testing these two types of fibrous absorber materials, namely a recycled cotton nonwoven and a recycled polyester nonwoven as reference material, we evaluate the influence of changes in moisture content on the acoustic properties of sustainable, fibrous sound absorbers.

2.1 Materials and Sample Characterization

The material under investigation is recycled nonwoven cotton, which is referred to as CO20. The material used as reference is a recycled polyester nonwoven (polyethylene terephthalate, PET), which is referred to as PET20. The sample properties are presented in Table 1. We estimated the porosity ϵ_0 of the samples based on the densities of the nonwoven structure ρ_n and the fiber densities ρ_f [11]:

$$\epsilon_0 = (1 - \frac{\rho_n}{\rho_f}) \times 100\ \% \tag{3}$$

The fiber densities from the literature are $\rho_f = 1.51 g/cm^3$ for cotton and $\rho_f = 1.38 g/cm^3$ for PET fibers. The air permeability κ was determined according to DIN EN ISO 9237:1995-12* at 200 Pa.

Name	ρ_n (kg/m³)	ϵ_0 (%)	t (mm)	κ (l/sm²)
CO20	45	97.0	20 ±0.2	538
PET20	40	97.1	20	1422

Table 1. Sample properties: ρ_n = density of structure; ϵ_0 = estimated porosity; t = sample thickness; κ = air permeability at 200 Pa

The recycled cotton samples did not only include loose fibers but also some smaller pieces of shredded fabric from the mechanical recycling process. On the other hand, the recycled polyester samples consisted of distinguishable fibers only. The microscopy and the SEM images of the samples are presented in Table 2.

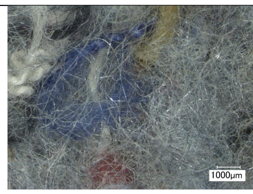
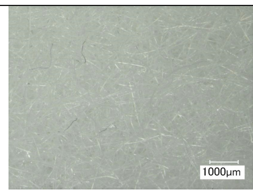
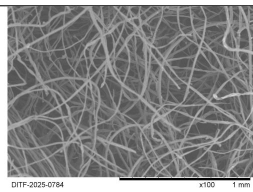
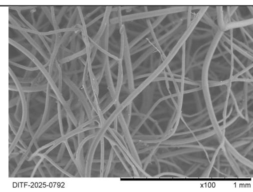
	CO20	PET20
top view		
SEM images		

Table 2. Microscopy images and SEM images of the samples

2.2 Sample Preparation

To imitate moisture contents in different RH surroundings, prior to measuring the acoustic properties, we steamed the specimens until reaching the desired amount of moisture, determined by the weight change. A moisture content of 0 % is not realistic for application scenarios. Therefore, the baseline for 0 % in this study is regarded as the moisture content in the specimen after being conditioned in a climate of T = 23 °C and RH = 40 % for at least 24 hours. The increase in moisture content M was calculated as a percentage increase in mass relative to the conditioned sample's mass m_{cond} and calculated as:

$$M = \frac{m_{\text{wet}} - m_{\text{cond}}}{m_{\text{cond}}} \times 100\,\%, \qquad (4)$$

where m_{wet} is the weight after moisture absorption. We increased the moisture content gradually in increments of 5 % until reaching 20 %, while measuring the acoustic absorption coefficient at each step. We tested three specimens of PET20 and five specimens of CO20 (due to higher expected variations for this material arising from its inhomogeneous structure).

2.3 Measurement of Acoustic Properties

We measured the sound absorption coefficient α over a frequency range of 50 Hz to 1,600 Hz using the two-microphone impedance tube method based on ISO 10534-2 with a tube diameter of 100 mm (impedance tube Brüel & Kjær Type 4206-T). We monitored the climate over the entire testing duration to exclude errors from changing climate conditions. We used linear regression analysis to determine the significance (p-value) of the influence of M on the absorption coefficient α for the different materials.

2.4 Results and Discussion

As shown in Figures 1 and 2, there is an increase in sound absorption coefficient α with higher moisture levels for both materials, particularly at the higher frequencies (M = 15 % not pictured for visibility purposes). Even though the change is small and for cotton the standard deviations are partly overlapping, the regression analysis still found the influence of M to be statistically significant for both materials with p-values of p = 0.001 for cotton and p = 0.000 for the polyester samples. Further, the biggest change in α can be found when going from M = 0 % to M = 5 % for both materials. Hence, small amounts of moisture can already have a noticeable impact on the sound absorption behavior.

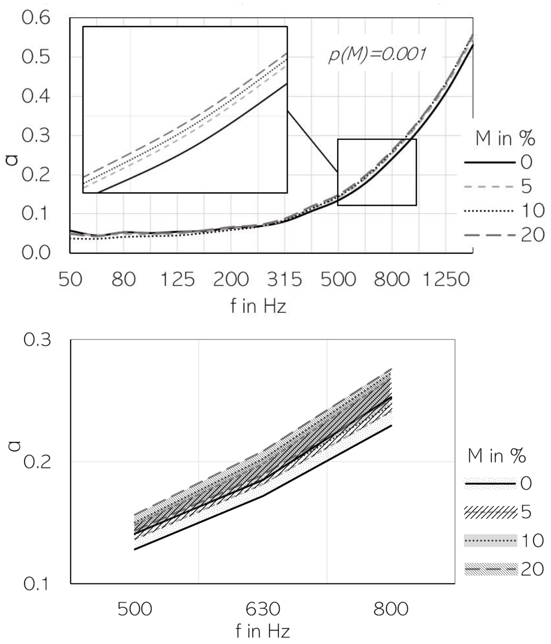


Figure 1. *TOP*: Average absorption coefficient α of CO20 for different moisture contents M; *BOTTOM*: Standard deviations for selected frequencies.

The increase in sound absorption can be attributed to several factors. One of the primary effects of moisture is the increase in airflow resistivity σ. As water fills the pores of the material, it creates additional resistance to airflow, which enhances the viscous damping of sound waves. The higher airflow resistivity in both CO20 and PET20 at elevated moisture levels likely increased sound absorption. Furthermore, thermal conductivity increases with water content, leading to enhanced dissipation of sound energy within the material.

The observed effect was more pronounced for PET than for cotton. This can be attributed to the (presumable) swelling of the cotton fibers in contrast to the PET fibers not swelling. While the water drops start filling the air voids, in the case of cotton, the fiber swelling further closes the pores. Hence, the porosity is reduced to a higher extent, thus counteracting the increase in sound absorption arising from the increase in air flow resistivity. In turn, the change in sound absorption is less dominant for cotton than for PET. Additionally, the inhomogeneous structure of the CO20 increased inter-sample variations, thus potentially overlaying some effects from moisture.

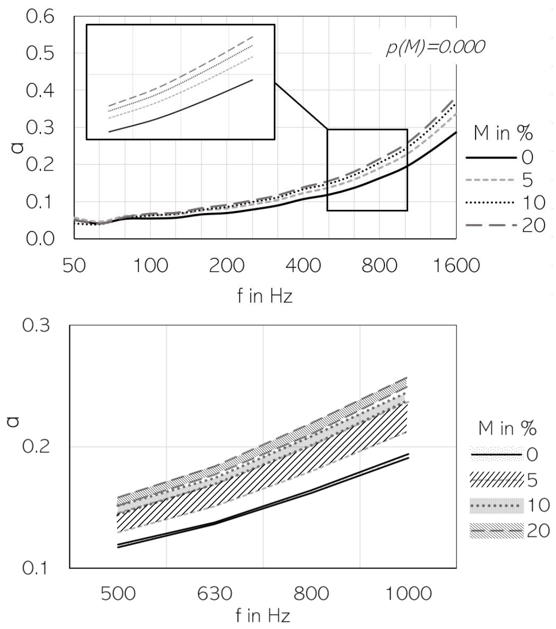


Figure 2. *TOP*: Averaged absorption coefficient α of PET20 for different moisture contents M; *BOTTOM*: Standard deviations for selected frequencies.

Nevertheless, it must be mentioned that the testing procedure not only increased the moisture content in the materials but also involved raised temperatures from the steaming process. Especially for PET this might be relevant as the glass transition temperature is in a similar region. We could not exclude this influence from the experiments, which is why this should be investigated in future work. Further, due to time constraints, we could only test a small number of samples. To increase statistical reliability, more repetitions should be performed.

Concluding we found that changes in the relative humidity of the surroundings can potentially affect the performance of fibrous sound absorbers. Further, when it comes to acoustic material characterization, conditioning of the test samples might be required to achieve reproducible and comparable results.

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