Experimental validation of analytical models for non-acoustic properties of loose fibers

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ABSTRACT

The characterization of materials is an important part of the process for the development of NVH packages in the automotive industry. In particular, fibrous materials for acoustical applications have been extensively studied over the past years and a considerable number of experimental tests have been carried out as a function of fiber geometrical characteristics (for example, bulk density, fiber diameter and density, open porosity, etc.) in order to determine analytical formulations for the prediction of physical parameters.

The type of components under investigation in this study are made from recycled fibers, both natural and man-made. Due to the random nature of the mix of individual fibers, which can include different densities and thicknesses, predictive models normally do not take into account the individual fibers but instead deal with the mixture as a whole.

This paper examines an ongoing study into the experimental characterization of individual fibers (in terms of airflow resistivity, open porosity, tortuosity, characteristic lengths and static thermal permeability) and the validation of new analytical models (as a function of open porosity and fiber radius) that will help in the determination of overall acoustic performance.

1. INTRODUCTION

In the definition of treatments for acoustic and thermal problems, molded fibrous solutions have become popular due to their high performance and high form factor mouldability. Numerous models exist in literature for the calculation of airflow resistivity, open porosity, tortuosity and viscous and thermal characteristic of lengths of fibrous materials, and thus their acoustical performances, and a comprehensive overview of such models can be found in [1]. The main difficulty consists in determining the radius of a certain fiber. In this paper an indirect approach is proposed based on the determination of fiber characteristics from airflow resistivity measurements on the same fiber at different compression rates and the use of an analytical model. Once the radius has been determined, physical and acoustic properties can be calculated for any arbitrary fiber radius and open porosity.

2. MATERIALS AND METHODS

2.1 Tested Materials

For the measurements discussed in this paper, a series of constituent fibers from a mixture were examined individually, these are summarized in terms of dtex and fiber density (taken from manufacturer specifications) in Table 1.

Fiber	Dtex [g/10km]	Fiber density [kg/m^3]
A_1	1.1	1370
A_2	28	1370
B_1	1.5	1380
B_2	24	1380
C_1	2	1500
D_1	2.2	1370

Table 1. Tested fibrous materials.

2.2 Experimental Survey

For each fiber type, standard airflow resistivity (ISO 9053-2003 method B) and normal incidence sound absorption (ISO 10534-2) have been measured for different compression rates and thus different densities. These measurements were repeated 10 times and the average result calculated; these are shown in Figure 1.

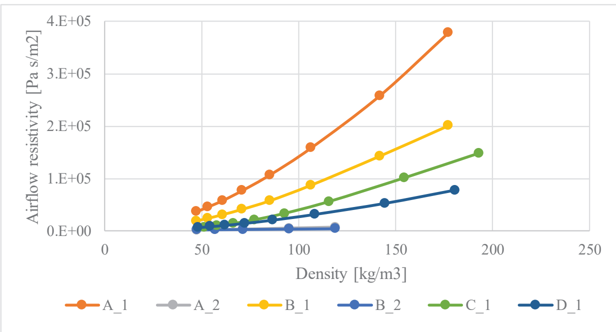

Figure 1. Airflow resistivity against density.

2.3 Theoretical Modelling

Pompoli and Bonfiglio have proposed in [1] analytical expressions for JCAL parameters (airflow resistivity, open porosity, tortuosity, characteristic lengths and thermal static permeability) using finite element models of 2D distributions of radii as a function of the porosity.

The aim of this step is to determine for each fiber the radius and standard deviation using analytical model of airflow resistivity as a function of density.

$$\sigma = \frac{\eta}{(2a)^2} \frac{\left(\sqrt{1-(1-\phi)}\right)}{0.21\left(\frac{0.71}{1-\phi} - 3\sqrt{\frac{0.71}{1-\phi}} + 3 - \sqrt{\frac{1-\phi}{0.71}}\right)} \quad (1)$$

From the radius a we can calculate all parameters using the Pompoli-Bonfiglio model [1] and then predict sound absorption to be compared with experimental results.

3. RESULTS

3.1 Fiber Radii

The fiber radius has been calculated using two methods, the first by using eq. 1 for all tested compression rates. Such analysis allows for all fiber the determination of average radius (a_{avg}) and an associated standard deviation σ_a. In addition, fiber radii have been calculated based on nominal dtex. The results from both stages can be found summarized in Table 2.

Fiber	a_{avg} [μm]	σ_a [μm]	a_{dtex} [μm]
A_1	6.9	0.3	5.1
A_2	33.1	1.3	25.5
B_1	9.3	0.5	5.9
B_2	34.8	5.5	23.5
C_1	13.1	2.5	6.5
D_1	15.8	1.1	7.1

Table 2. Minimized fiber radius for all tested fibers

It can be seen that the predicted values using nominal dtex are always systematically lower than the ones calculated using eq. (1).

3.2 Sound Absorption Predictions

Averaged radii and their standard deviations are summarized in Table 2. These were then used to predict the normal incidence sound absorption coefficient and compared with experimental measurements. Figure 2 compares predictions with experimental results for all fibres at varying densities and thickness. The experimental results are shown in red with predictions in grey. Grey shading is included to account for radius standard deviations. Figure 2 shows that apart from a specific frequency range around 1kHz, where elasticity effects are not negligible for fibers with small radius, the comparison can be considered satisfactory with deviations smaller than 10%.

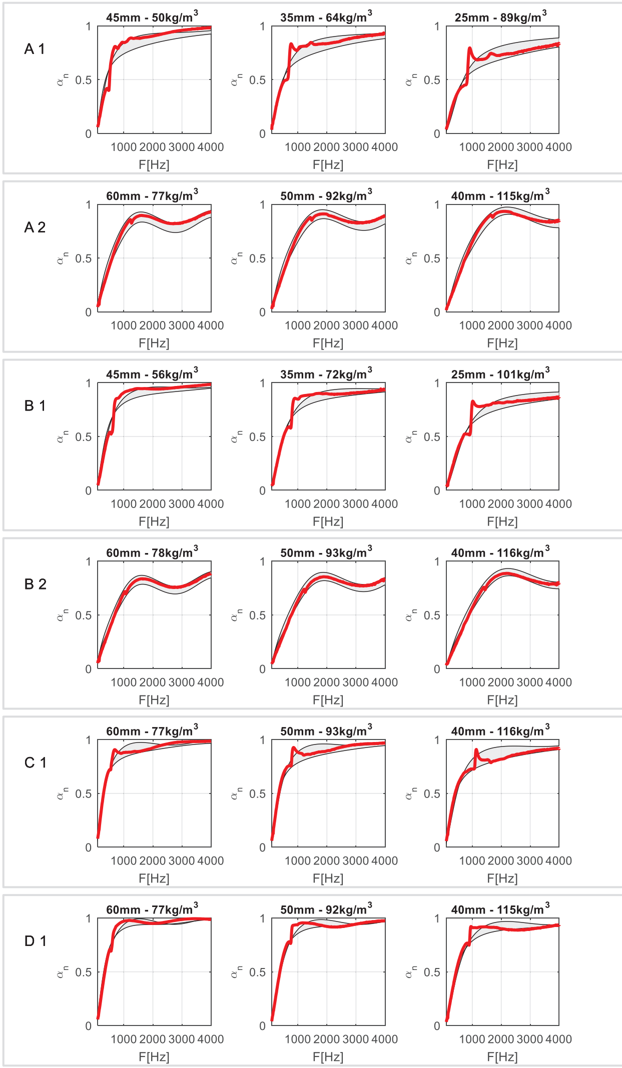

Figure 2. Sound absorption prediction and comparison with experimental tests for all tested fibers.

4. CONCLUSIONS

In the present paper experimental validation of analytical models for transport and acoustic properties of loose fibers has been proposed. The fiber radius is retrieved, via an indirect approach, based on experimental tests of airflow resistivity at different compression rates. Using this parameter, the acoustic performance was predicted with accuracy better than 90% for any arbitrary bulk density and thickness.

Future work will be devoted to the use of proposed approach for the prediction of acoustical properties of complex mixtures of loose fibers.

5. REFERENCES

[1] F. Pompoli, P. Bonfiglio: "Definition of analytical models of non-acoustical parameters for randomly-assembled symmetric and asymmetric radii distribution in parallel fiber structures.," *Journal of Applied Acoustics 2020;159:107091*.